On the transmission of anthrax disease in the Arctic region

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Introduction

Recent cases of anthrax disease have severely affected reindeer herds in Siberia (**Figure 1**). These outbreaks have been caused by infected carcasses emerged from the thawing permafrost due to climate change.

In this respect, we propose and analyze a novel epidemiological model for anthrax transmission in the Arctic region and compare the deterministic approach versus the stochastic one.

Anthrax 2016 outbreak (EMPRES-I, source: OIE):

- ~2000 reindeer carcasses
- 110000 susceptible animals
- 1 reported human death

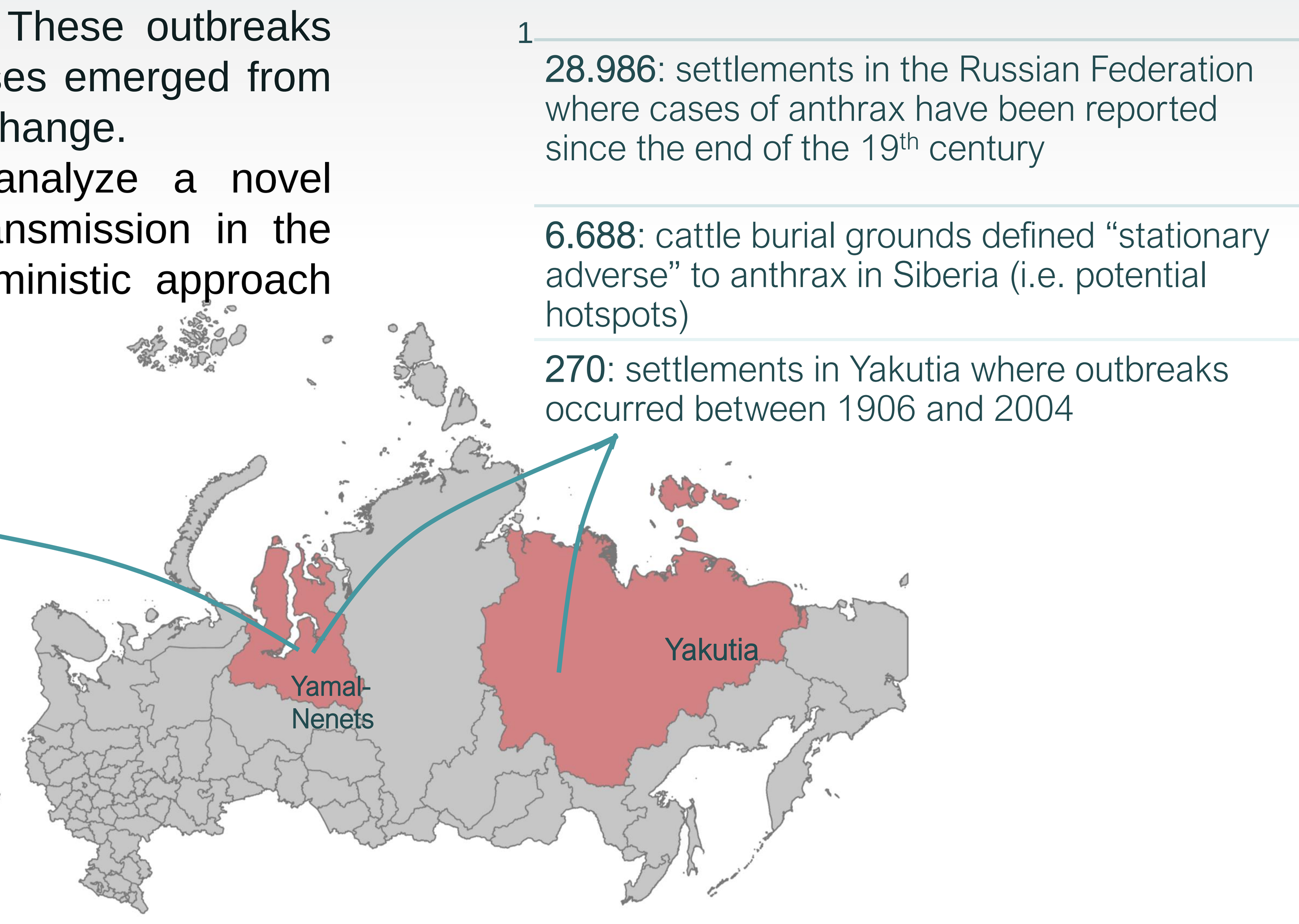


Figure 1 Reported anthrax cases and hazards in Siberia (Boris et al., 2011)[1]

About Anthrax

Anthrax occurs in nature as a global zoonotic and epizootic disease caused by the sporulating bacterium *Bacillus anthracis*. It principally affects herbivores and causes high animal mortality among livestocks and it may also be transmitted, directly or indirectly, to wildlife and humans (rare cases).

Control and surveillance

(Dragon and Rennie, 1995, WHO, 2008)

→ BREAKING the cycle of the disease (**Figure I.1**)
(Correct disposal of the carcasses, decontamination, vaccination,etc.)

→ to prevent or reduce losses
(Education, correct diagnosis, implementation of control measures, reporting).

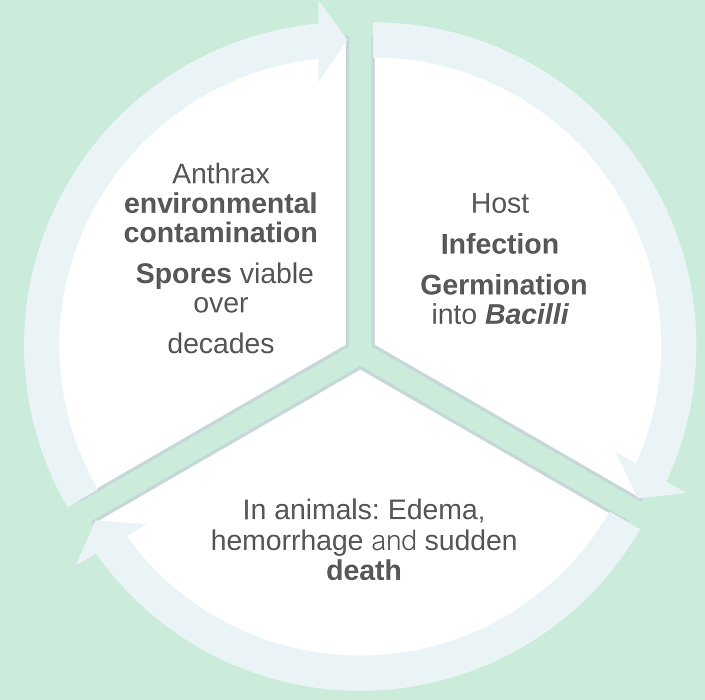


Figure I.1 Cycle of infection

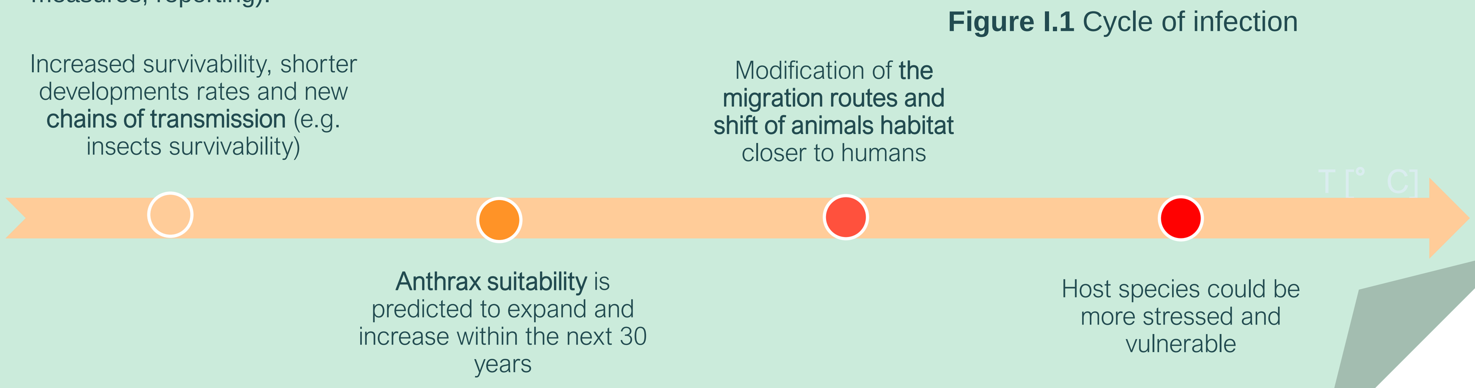


Figure I.2 Effects of climate change on Anthrax disease (Walsh et al., 2018)

Model formulation

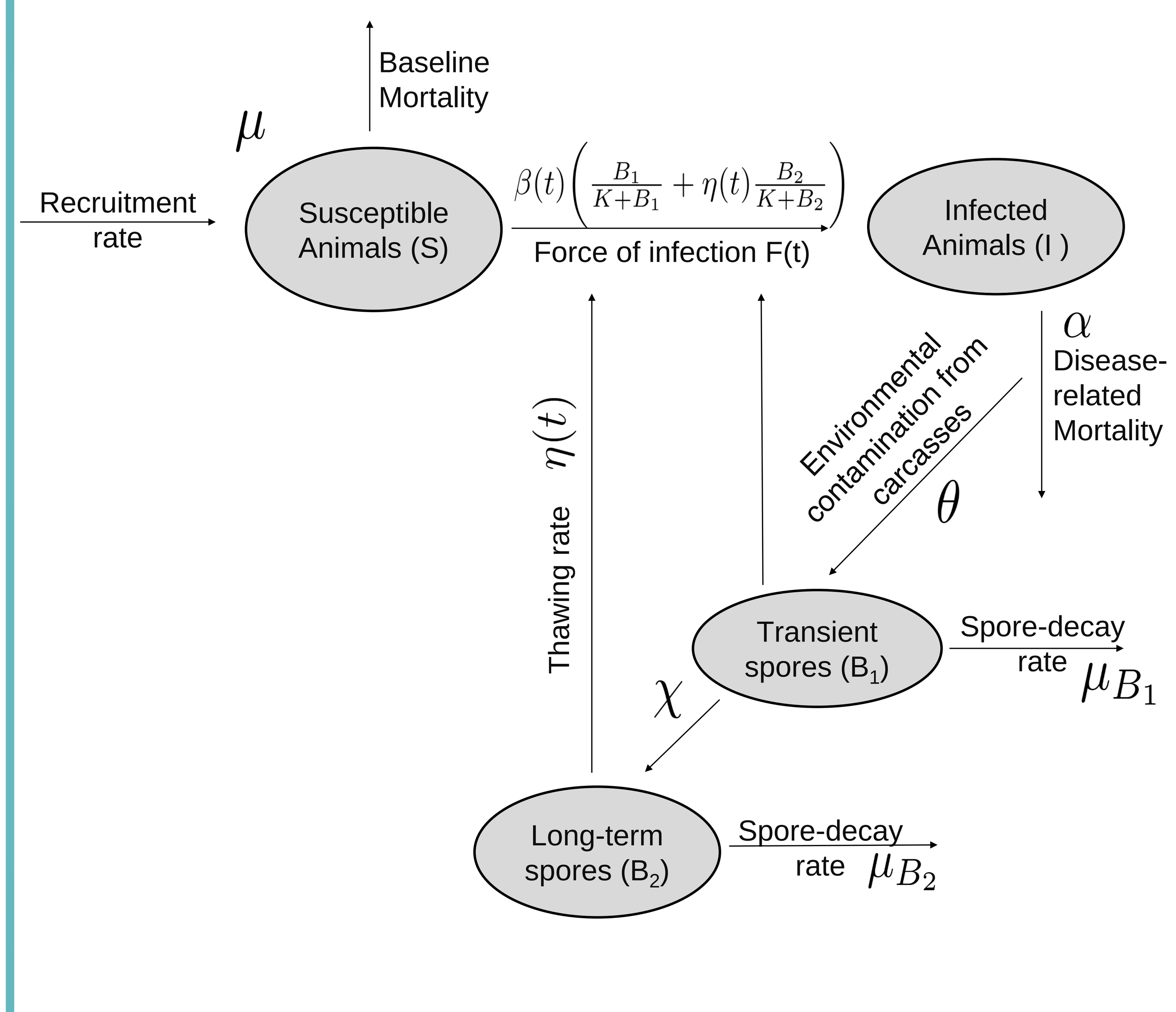


Figure 2 Conceptual map of the anthrax model

Deterministic formulation

- **Real continuous** variables
- **B_1 transient spores:** immediately released
- **B_2 long-term spores**: stored after B_1 have been removed from the soil surface

$$\frac{dS}{dt} = \mu(H-S) - F(t)S$$

$$\frac{dI}{dt} = F(t)S - (\mu+\alpha)I$$

$$\frac{dB_1}{dt} = \theta\alpha I - (\mu_{B_1} + \chi)B_1$$

$$\frac{dB_2}{dt} = \chi B_1 - \mu_{B_2} B_2$$

Stochastic formulation

- **S** and **I discrete** variables
- **B_1** and **B_2 real continuous**
- **Occurrence of stochastic events** (**Table 1**)

Stochastic Simulator Algorithm SSA (Gillespie, 1977)

Table 1 State transitions and rates of all possible events involving susceptible and infected animals.

Event	State transition	Event rate
Birth	$(\mathcal{S},\mathcal{I}) \to (\mathcal{S}+1,\mathcal{I})$	$r_1 = \mu H$
$\mathcal{S}$ Death	$(\mathcal{S},\mathcal{I}) \to (\mathcal{S}-1,\mathcal{I})$	$r_2 = \mu \mathcal{S}$
$\mathcal{I}$ Death	$(\mathcal{S},\mathcal{I}) \to (\mathcal{S},\mathcal{I}-1)$	$r_3 = (\mu+\alpha)\mathcal{I}$
Infection	$(\mathcal{S},\mathcal{I}) \to (\mathcal{S}-1,\mathcal{I}+1)$	$r_4 = \mathcal{F}(t)\mathcal{S}$

Parameters set-up

Fixed parameters (WHO, 2008)

μ	Recruitment rate Baseline Mortality	**1/5 [years^{-1}]**
α	Disease-related mortality	**1/14 [days^{-1}]**
μ_{B_1} μ_{B_2}	Spore-decay rate	**1/10 [years^{-1}]**
χ	B_1 storage rate	**1/10 [days^{-1}]**

Varying parameters

$$F(t) = \beta(t)\left(\frac{B_1}{K+B_1} + \eta(t)\frac{B_2}{K+B_2}\right)$$

$\beta(t)$: Exposure rate (seasonal grazing)

$$\beta(t) = \beta_0\left(1 + \epsilon sin\left(\frac{2\pi}{365}t\right)\right)$$

$\eta(t)$: Exposure probability to long-term spores — Permafrost thaws!

θ: Environmental contamination from carcasses [day^{-1} carcass^{-1}]

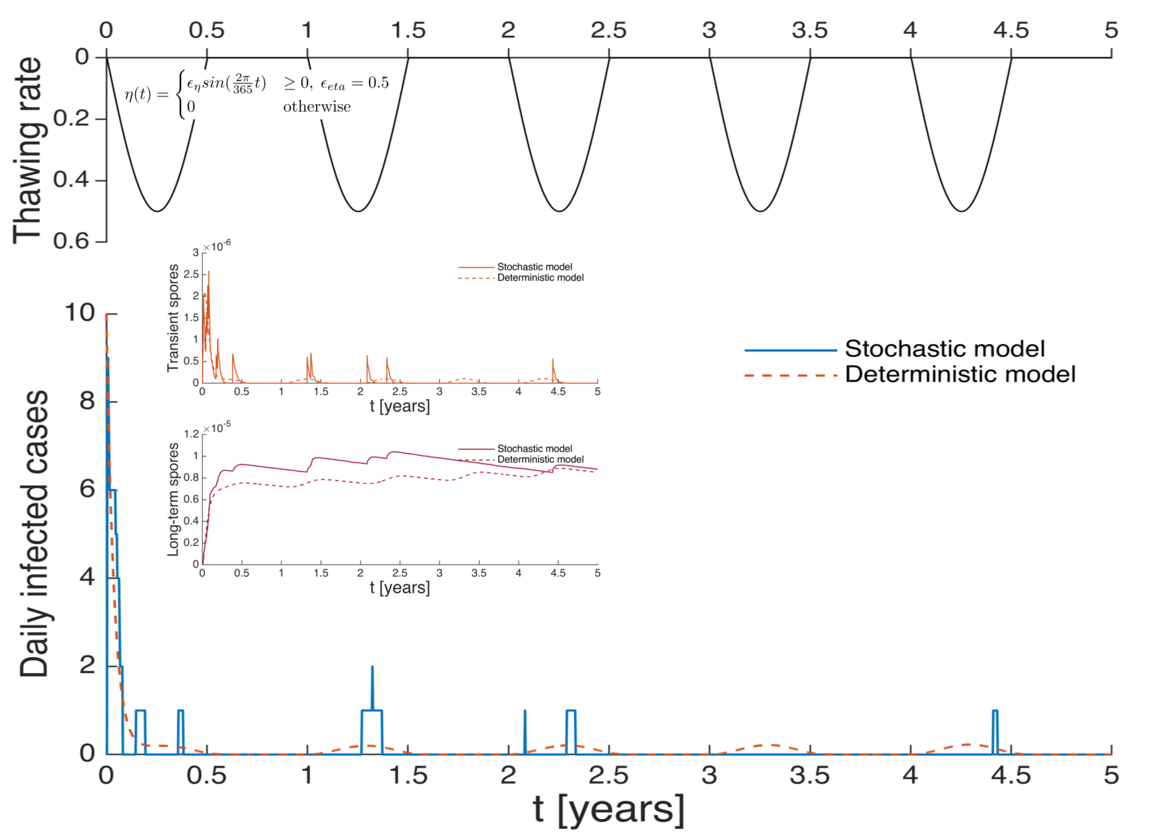
Reproduction number
(i.e. number of secondary cases from one single case, analyzed at disease-free equilibrium, DFE)

$$R_0 = \frac{\beta_{max}\theta H\alpha(\mu_{B_2}+\eta\chi)}{\mu_{B_2}(\mu+\alpha)(\mu_{B_1}+\chi)}$$

$$\beta(t) = \beta_{max} = cost$$
$$\eta(t) = \eta_{avg} = cost$$

Results

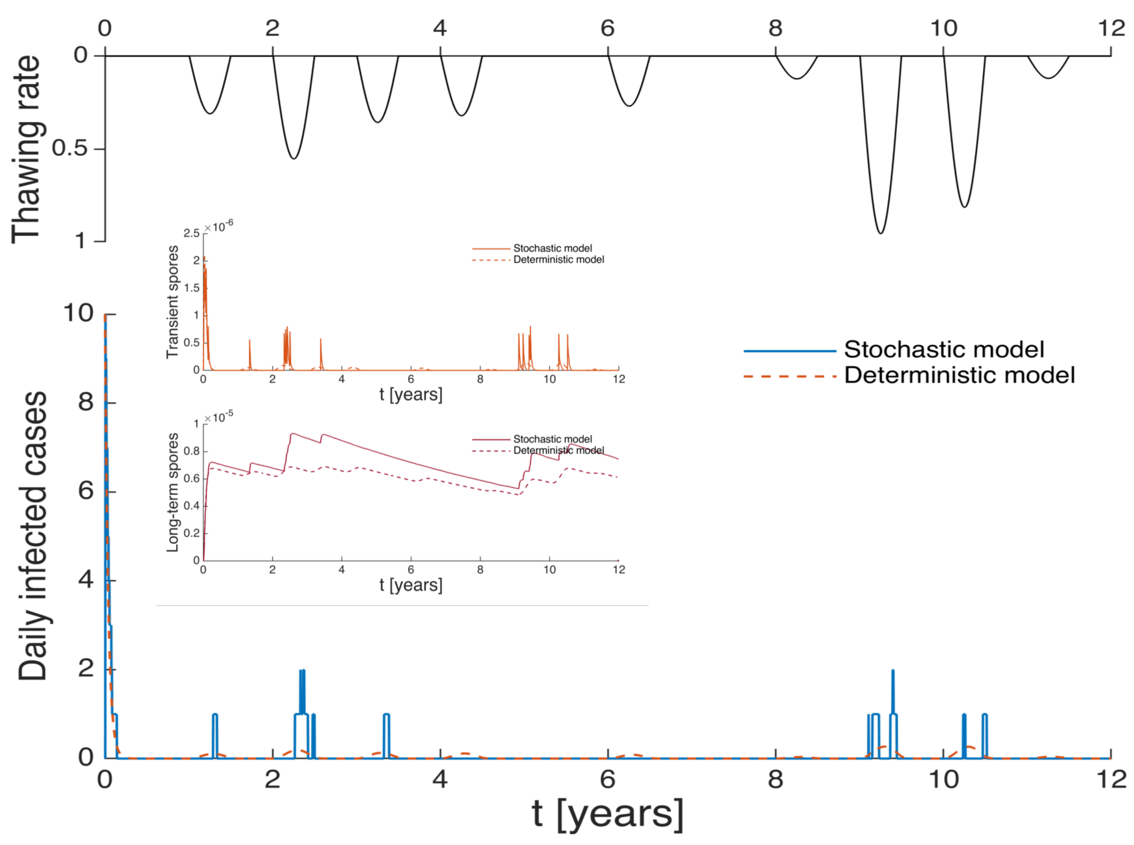
Case a) Regular seasonal thawing



- R=5
- β=2
- Total animals (H) = 1000
- Initial infected animals= 10

- **Simple basic case**
- **Moderate disease diffusion**

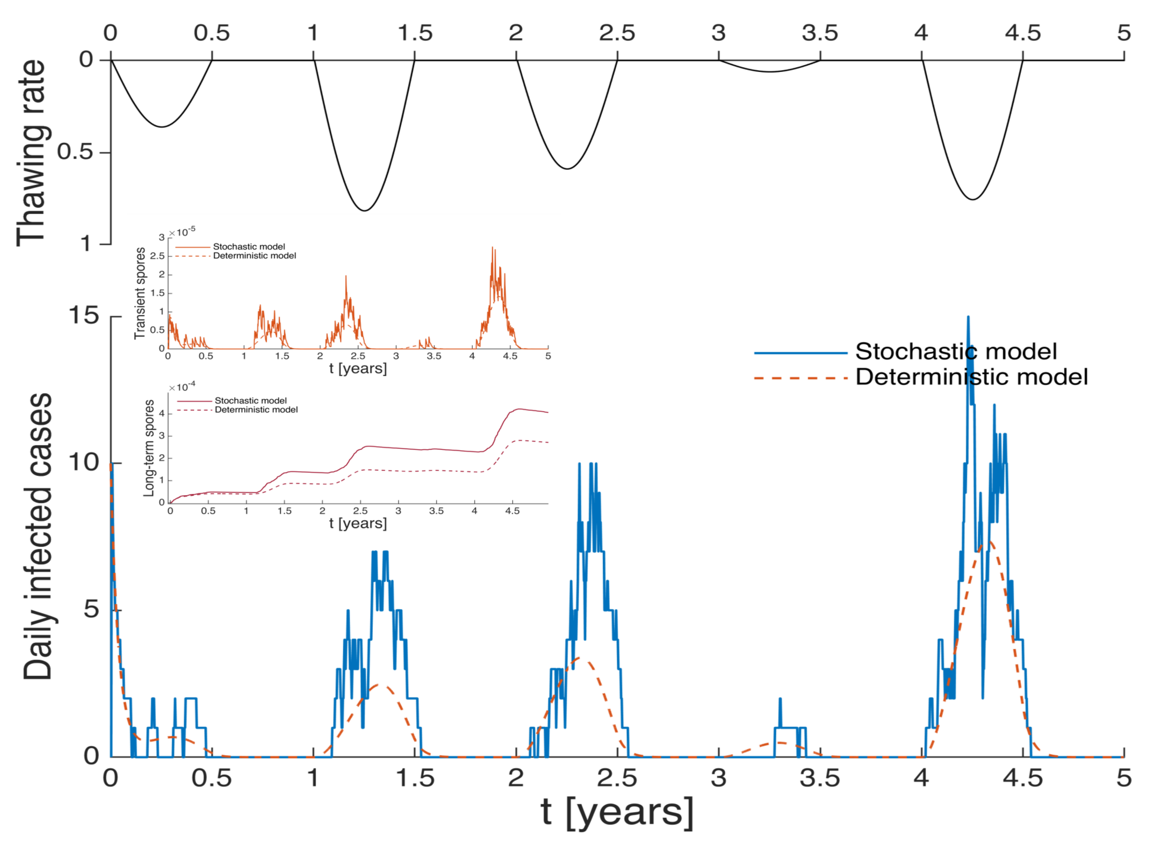
Case b.1) Stochastic seasonal thawing



- R=5
- β=2
- Total animals (H) = 1000
- Initial infected animals=10

- **More realistic simulation**
- **Moderate disease diffusion**

Case b.2) Stochastic seasonal thawing



- R=20
- β=2
- Total animals (H) = 1000
- Initial infected animals = 10

- **More realistic pattern**
- **High disease diffusion**

Discussion and conclusions

We present three cases in which the deterministic and the stochastic formulations are compared. In general the stochastic model reproduces better the intrinsic probabilistic nature of disease transmission, in particular in conditions of moderate anthrax diffusion (cases **a)** and **b.1)**), as in some years disease transmission may not happen (which is not captured by the deterministic model). The proposed formulation may support pastoralist communities in the **management of anthrax risk** related to **thawing permafrost**. In particular, **vaccination strategies** and **spatial diffusion** can be included in the model to account for **disease control** and **herds mobility.** Further analysis will account for available records of permafrost thawing level.

References

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