Modeling potential effects of climate change on potato late blight

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Overview

- **Introduction and rationale**
  - Climate change worldwide
  - Collaborative grant with CIP
  - Climate change and potato systems in the Andes
  - Climate change and plant disease
  - Late blight
- **Research objectives**
- **Experimental work**
- **A Late Blight Simulation model**
- **Further Modeling Plans**
- **Conclusions**

Introduction: Predicted climate change

- **Average** expected changes in 21st century
  - Increase in global temperature at least 1.5-2°C
  - Overall **diurnal amplitudes** are expected to decrease
  - Increase in frequency and magnitude of hot weather extremes
  - Occasional cold winter extremes

Introduction: Climate change in the Andes

- Glacier retreat common in Andes, due to increased temp. and El Nino
  - 0.1°C increase per decade since 1939
  - 4-5°C increase predicted
- Reduced cloud cover -> **increase in daily temperature range**
- Precipitation has slightly increased
  - 0.5-2.5% increase in RH (1950-95)
- Objective: predict the effects of climate change on potato production systems and potato late blight

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Introduction: climate change and plant disease

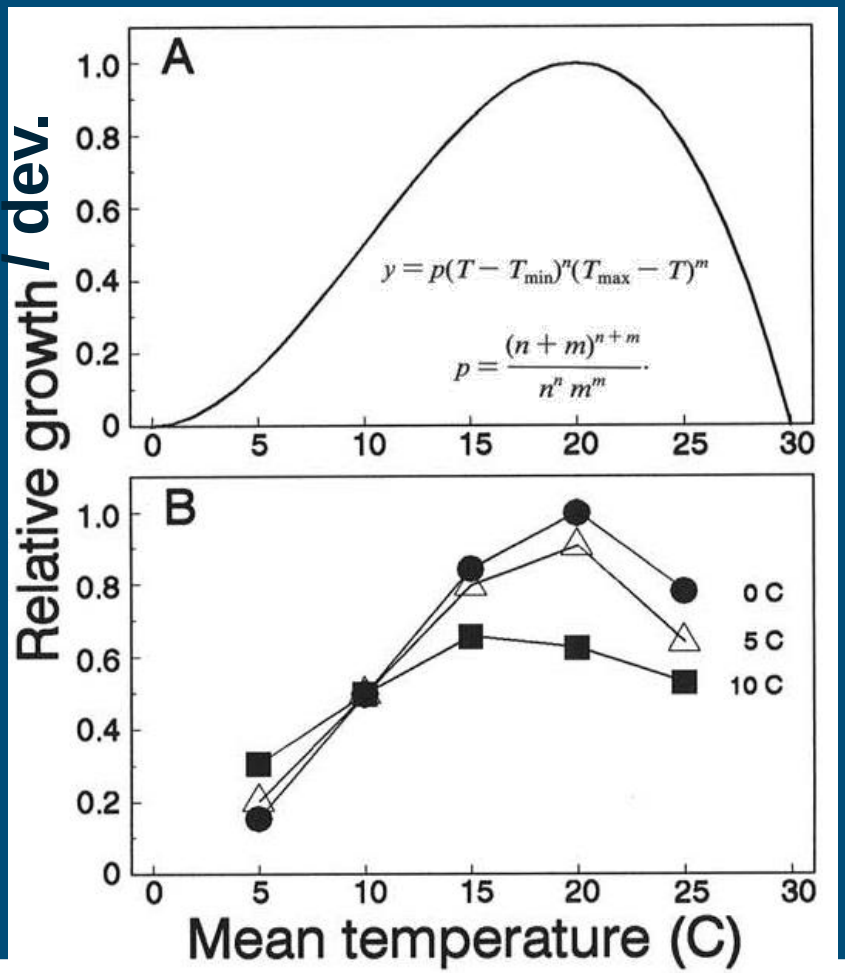
- Potential effects of climate change on plant disease epidemics
  - Modification of host physiology and resistance
  - Shift in geographical distribution of host and pathogen
  - Changes in the rate of development and survival
  - Increased sporulation and infection
  - Evolution of new races of pathogens

Introduction: microclimate and plant disease

Stages in infection cycle	Dura-tion	Tempe-rature	Leaf wetness	Relative humid.	Wind speed, dir.	Solar rad.
Spore germination	2-24 hrs	Optim. curve	Duration, positive	Positive	No effect	Negative
Colonization (latent period)	Several days	Inverse optimum curve	No effect	No effect	No effect	No or indirect effect
Sporulation	At night, days	Optim. curve	Positive effect	Positive effect	Negative at high wind	Negative
Spore release	Morning hours	No effect	Negative	at drop in RH	Positive	Positive, trigger
Spore dispersal	Morning days	Negative at high T	Rain positive	Positive survival	Wind, positive	Negative (UV)
Spore deposition	Seconds	No effect	Rain +/ -	Neutral	Wind, pos./neg.	No effect

Introduction: theoretical relations between disease development rate and temperature

- A: constant temp growth curve
- B: simulations with oscillating temps with 0, 5 and 10°C ampl.
- Conclusions:
  - substantial differences between development at constant and fluctuating temperatures with the same means
  - mean temperatures without information about amplitudes may not be sufficient to predict growth or development

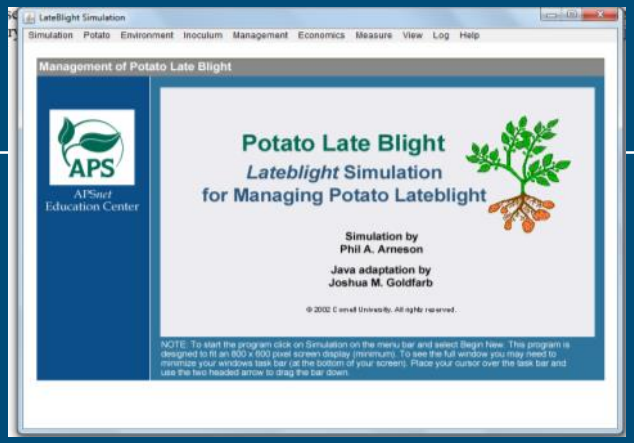


Scherm and van Bruggen, 1994

Introduction: Late blight

- Pathogen: *Phytophthora infestans*
- Emergence of new aggressive isolates
- Emergence of fungicide resistant isolates
- Life cycle dependent on weather variables
  - Infection: low temperature and leaf moisture
  - Germination: 10-20°C, leaf wetness
  - Symptom development: 20-22°C
  - Spore production: 12-14°C and high humidity
  - Dispersal: 1-2 m/s wind speed
  - Survival: few hours (temperature, moisture and solar radiation)

Introduction: late blight models



- Current late blight models
  - Forecast model Blitecast, accumulated severity values (Krause, 1975)
  - Simulation model LATEBLIGHT (Bruhn and Fry, 1981) disease severity, daily average weather, fungicide use, host resistance, economic relations
- Current models predicting effects of climate change
  - Based on Blitecast: accumulation of daily heat units
  - Based on LATEBLIGHT: daily average temperature during periods with high relative humidity
- Effects of changing daily amplitudes not possible
- New model with hourly time step needed

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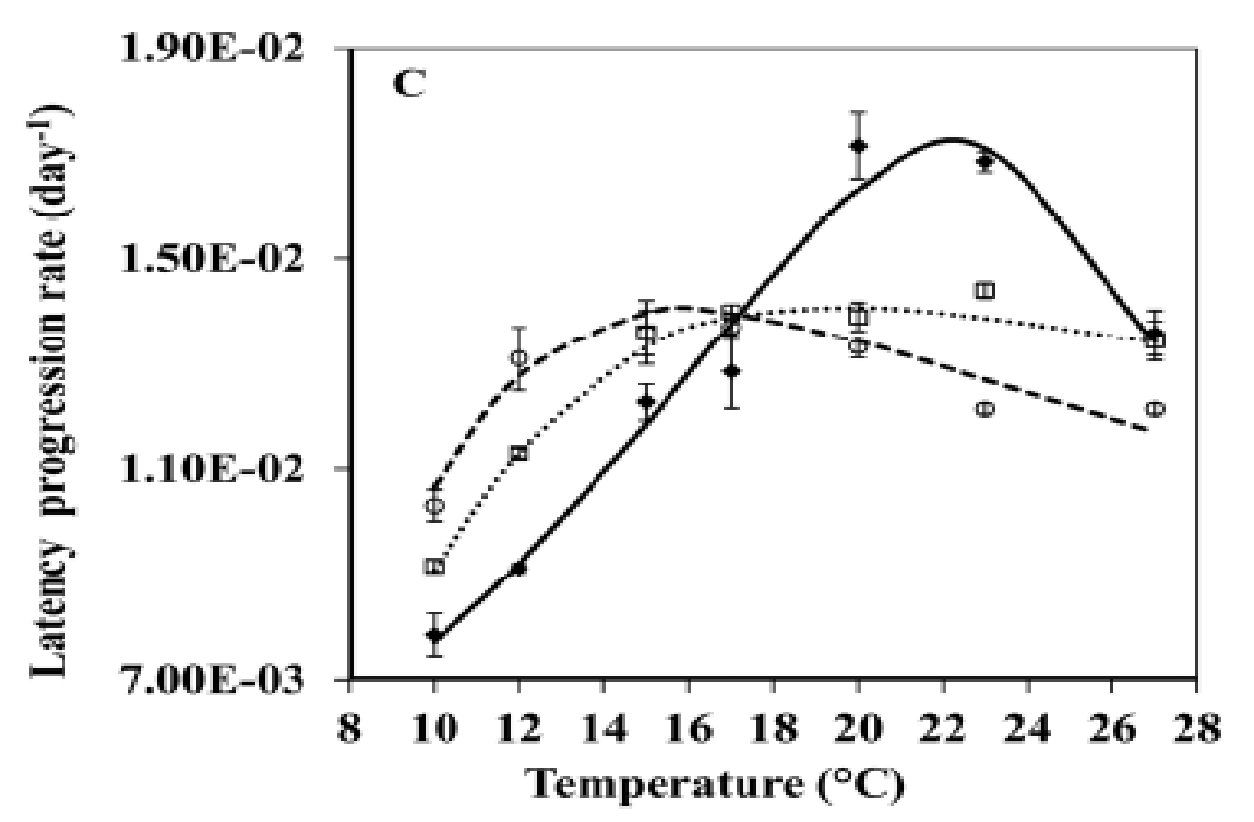
Research assumptions and objectives

- Assumptions
  - Global climate change associated with changes in diurnal oscillations.
  - Response of pathogen to change in temperature is instantaneous
  - Current models based on accumulation of heat units do not predict late blight development accurately under climate change
- Objectives
  - Study the effect of oscillating temperatures on late blight epidemic components
  - Develop a simulation model that takes daily temperature oscillations into account.

Growth Chamber Experiment - Methods

- Effects of temperature oscillation on epidemic components
  - Two clonal lineages of *Phytophthora infestans*
  - Susceptible potato cultivar
  - Drop inoculation (20,000 spores/ml)
  - Pre-incubation: 14 hours
  - Treatments: 7 mean temperatures, constant and oscillating with two daily amplitudes
- Components assessed
  - Incubation and latent periods
  - Number of lesions – infection efficiency
  - Lesion growth rate
  - Sporulation intensity

Growth Chamber Experiment - Results



- Effect of constant and oscillating temperatures on latency progression rate, (h^{-1}) of late blight. Curves were obtained by fitting the data to a 4-parameter thermodynamic model.

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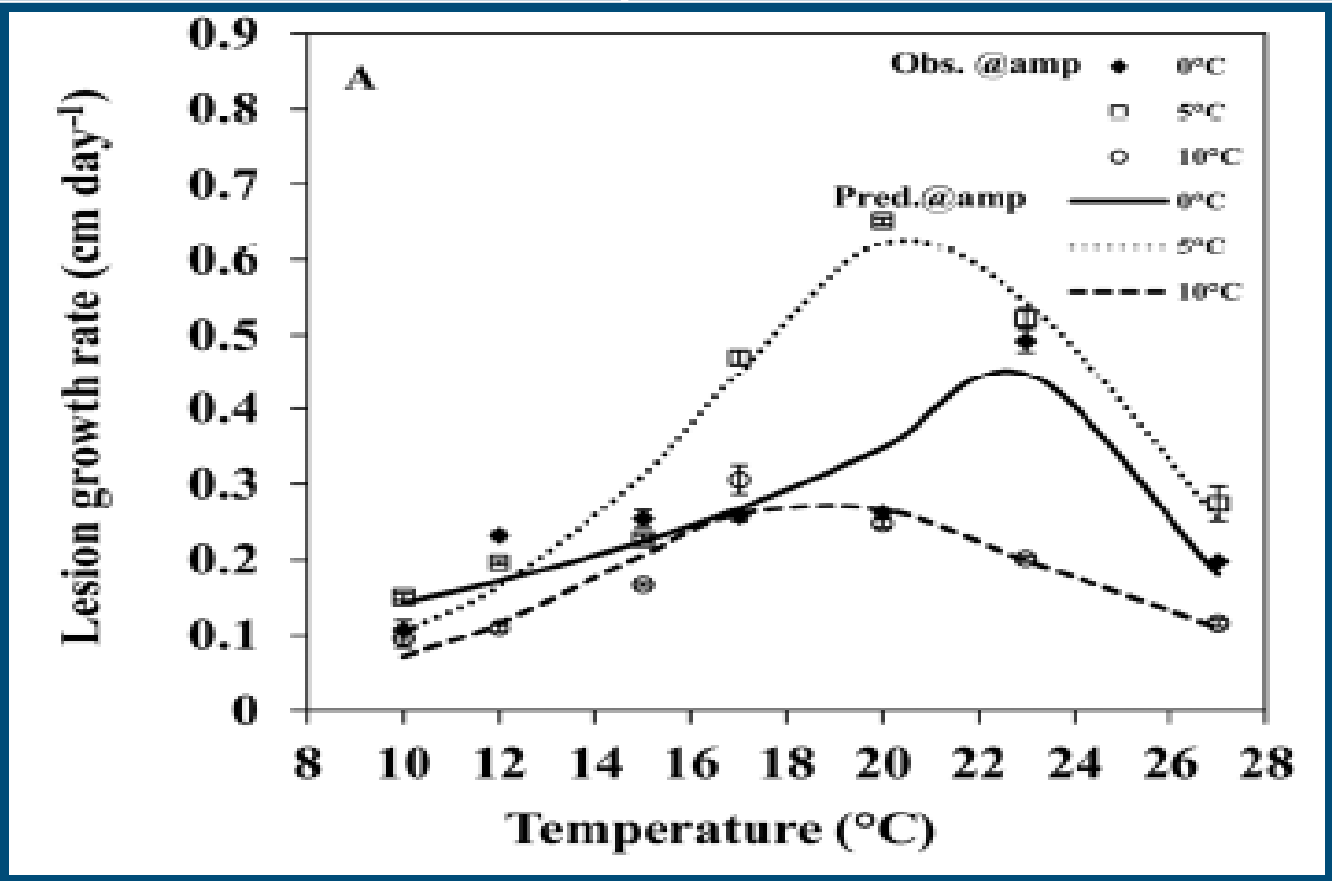
Shakya et al., 2015

Growth Chamber Experiment - Results



- Effect of constant and oscillating temperatures on the late blight lesion growth rate in cm day^{-1}. Curves were obtained by fitting the data to a 4-parameter thermodynamic model.

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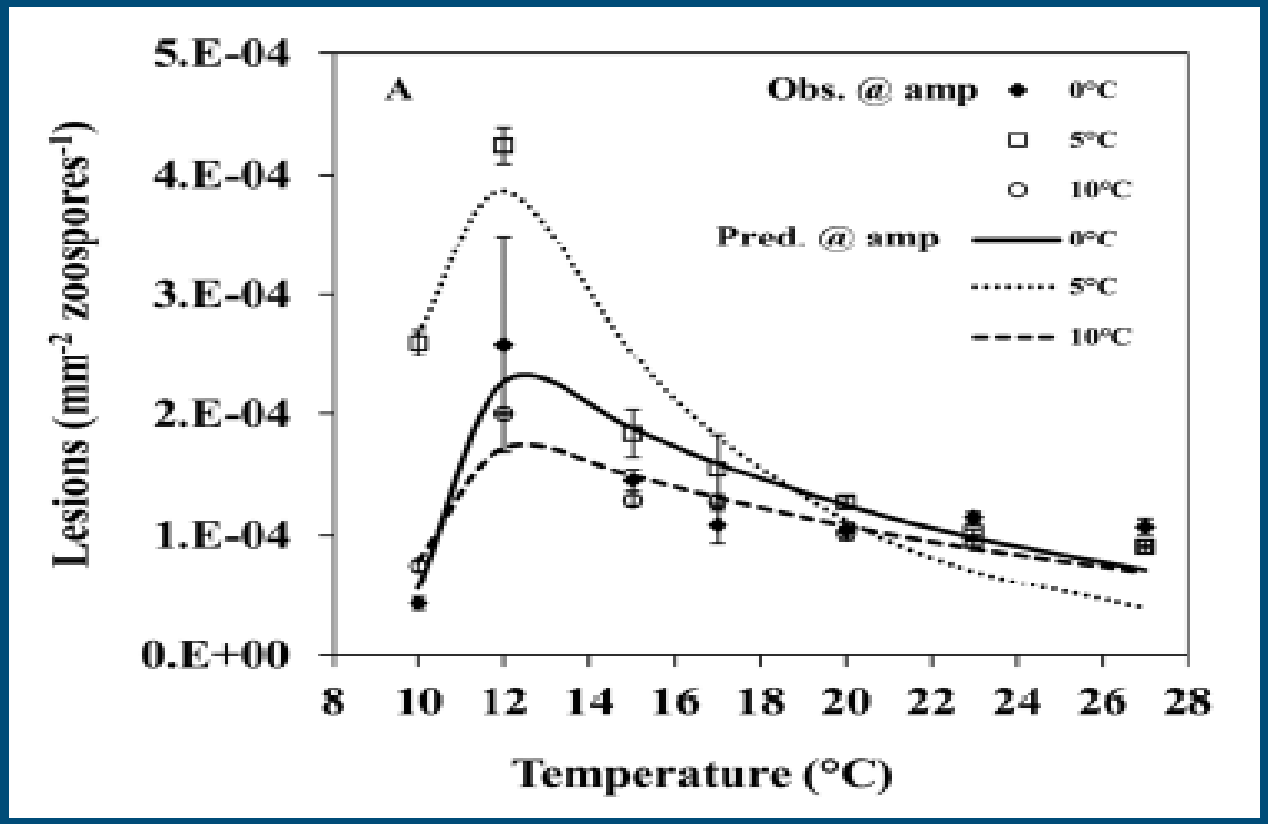
Shakya et al., 2015

Growth Chamber Experiment - Results



- Effect of constant and oscillating temperatures on number of late blight lesions mm^{-2} $zoospore^{-1}$. Curves were obtained by fitting the data to a 4-parameter thermodynamic model.

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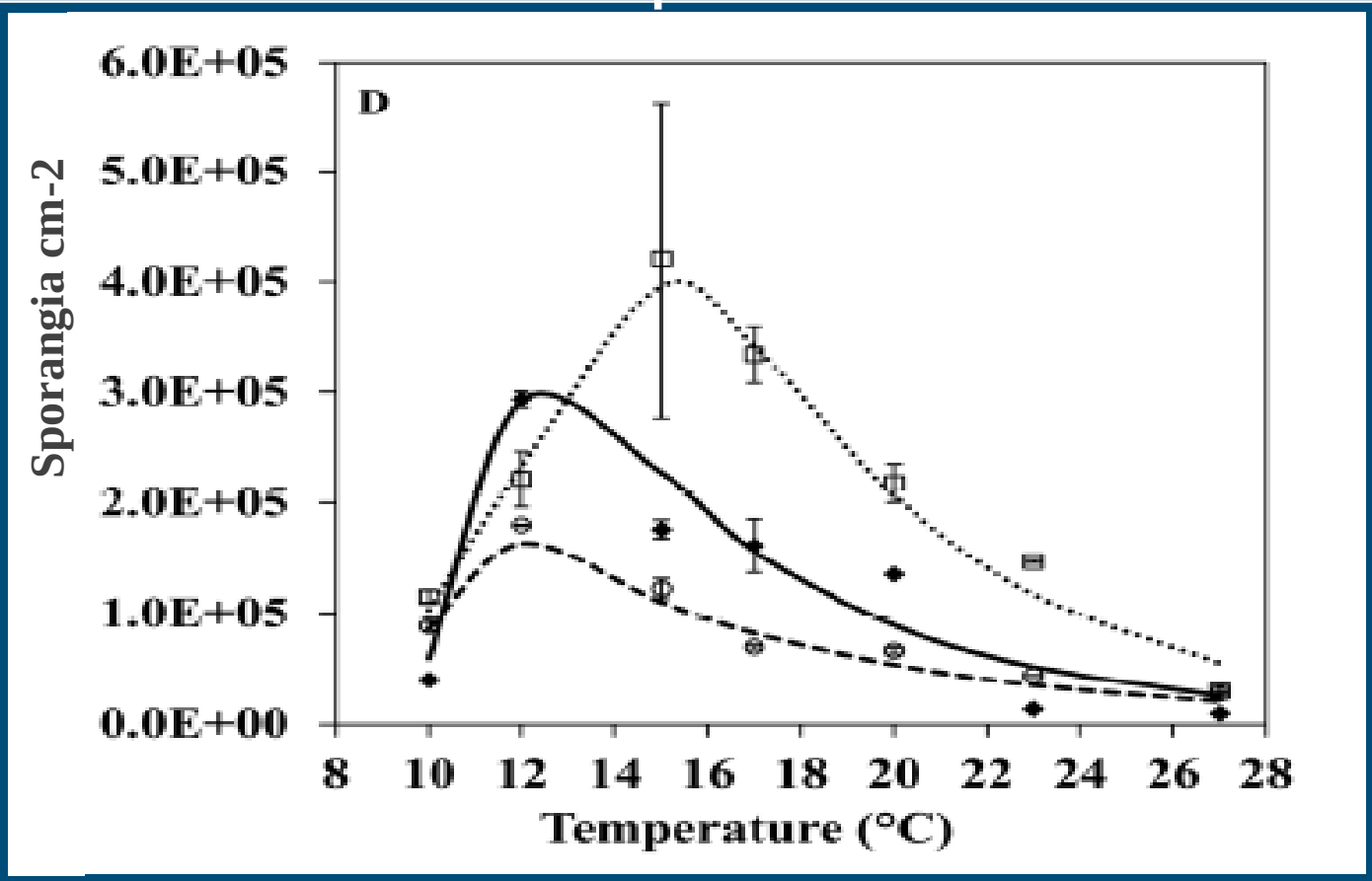
Shakya et al., 2015

Growth Chamber Experiment - Results



- Effect of constant and oscillating temperatures on the *P. infestans* sporulation intensity as sporangia cm^{-2}. Curves were obtained by fitting the data to a 4-parameter thermodynamic model.

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Shakya et al., 2015

Conclusions from growth chamber experiment

- Growth and development of *P. infestans* differed significantly under oscillating temperatures compared to constant temperatures
- Faster incubation and latency development under oscillating temps at relatively low average temperatures
- Small oscillation in temperature (±5°C) increased infection efficiency, lesion growth rate and sporulation intensity
- Lesions continue to grow even at high mean temperature with ±10°C amplitude
- **Need to incorporate temperature oscillations when simulating plant disease development under climate change**

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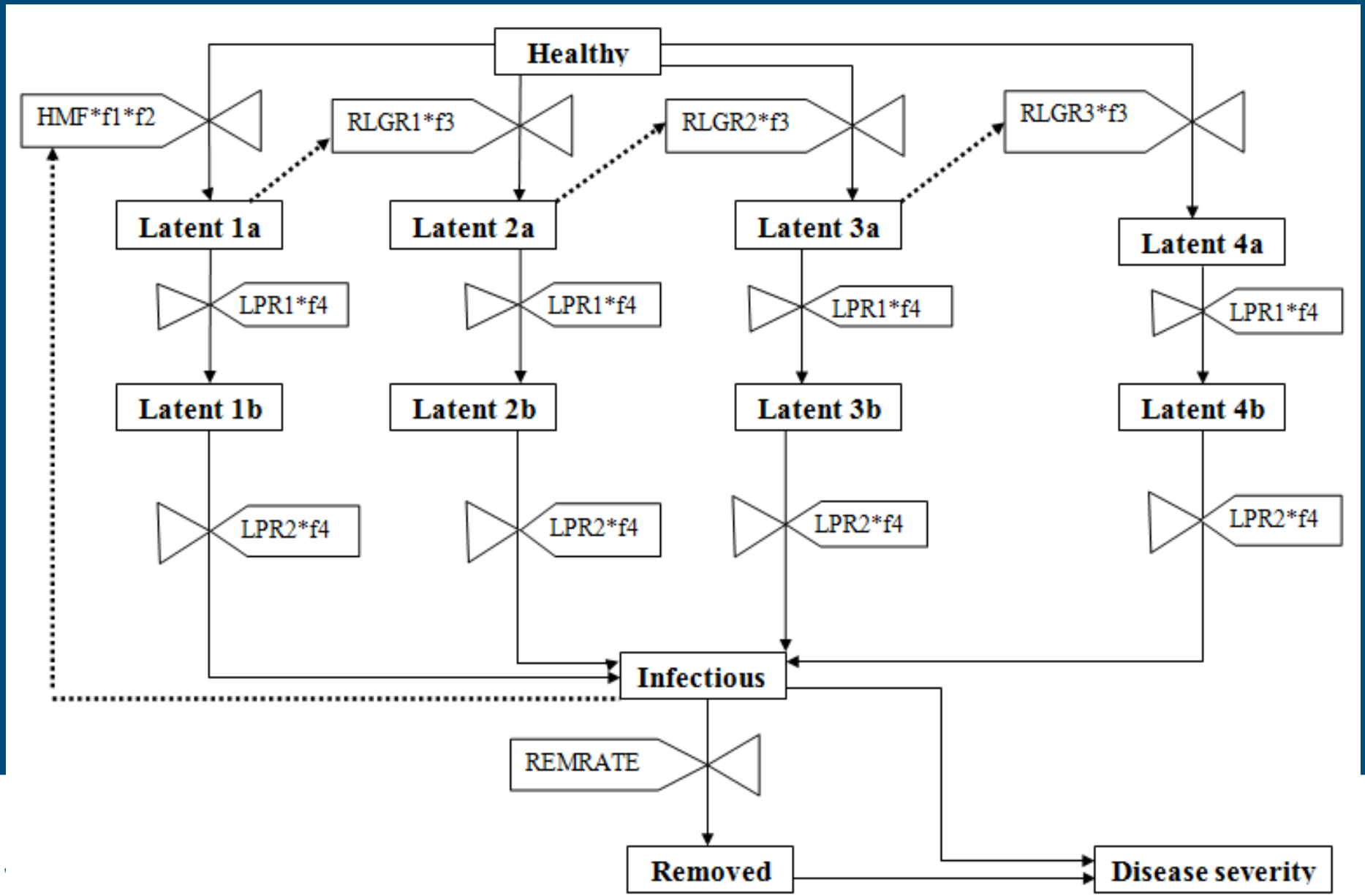
Shakya et al. 2015

BLIGHTSIM model development

- **Model structure and assumptions**
  - BLIGHTSIM is a mechanistic simulation model
  - Total potentially susceptible sites are distributed over healthy, latently infected, infectious and removed sites.
  - A site is $1mm^2$
  - Max. number of sites per leaflet= 2000
  - Minimum latent period= 57 hours
  - Lesion grows for 3-5 days at decreasing relative rates
  - Infectious period= 24 hours
- **Input variables:** Hourly temperature and relative humidity
- **Programming language:** R

BLIGHTSIM model structure



Methodology: Model description

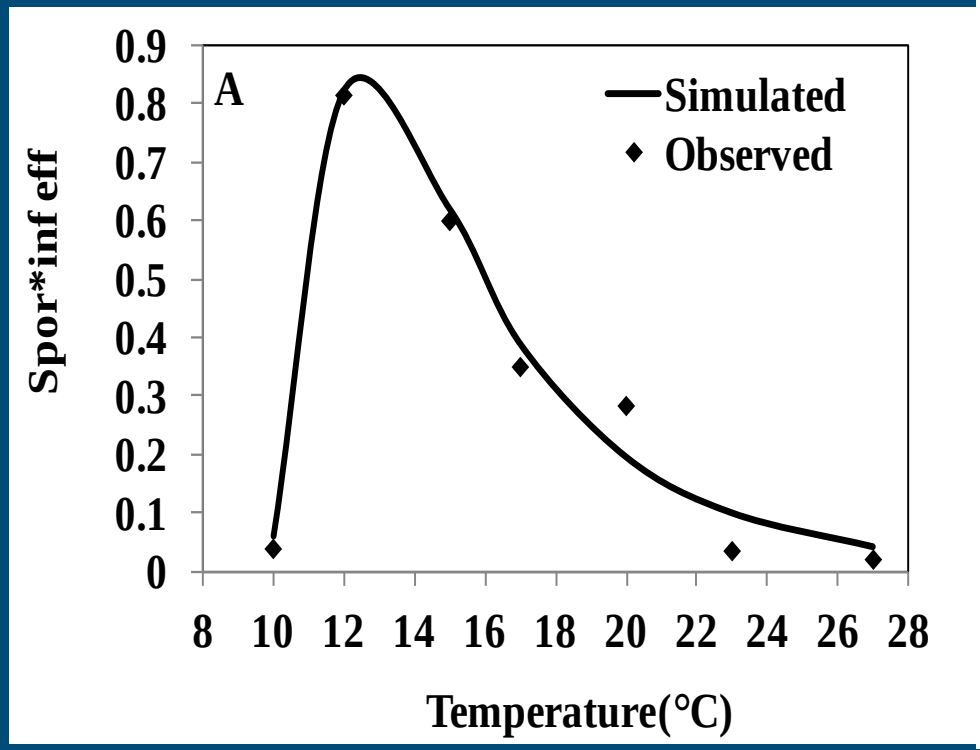
- Latent sites originate from two sources: infectious sites and day-old latent sites
- Model starts with fixed number of initial latent sites
- f1-f4 are reducing functions for temps (and RH) below and above the optimum, derived from growth chamber experiments
- Relative lesion growth rate was estimated by dividing the area increase by the observed area that day.

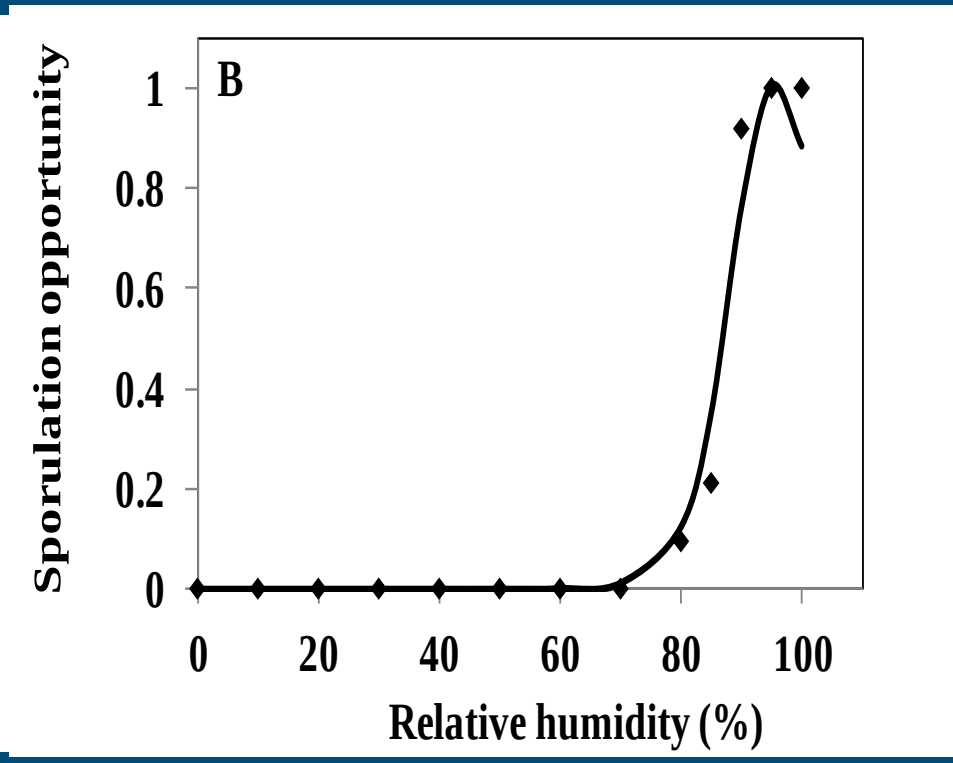
Methodology: Model fitting for calibration of growth chamber data

- Disease progress curves (US-23 isolate) for all temperature*amplitude combinations
- Initial number of infectious sites=0
- Variable number of initial latent sites (optimization, taking infection efficiency into account)
- Hourly multiplication factor HMF=0 (one cycle in growth chamber experiment); for field validation HMF=0.15 -0.45
- Model was run for 154 hours; for field validation 6000 hrs

Methodology: adjustment functions

- Temperature functions as obtained from growth chamber data
- **Spor.*InfEff vs. temp**. and **Spor. vs. RH** for HMF adjustments





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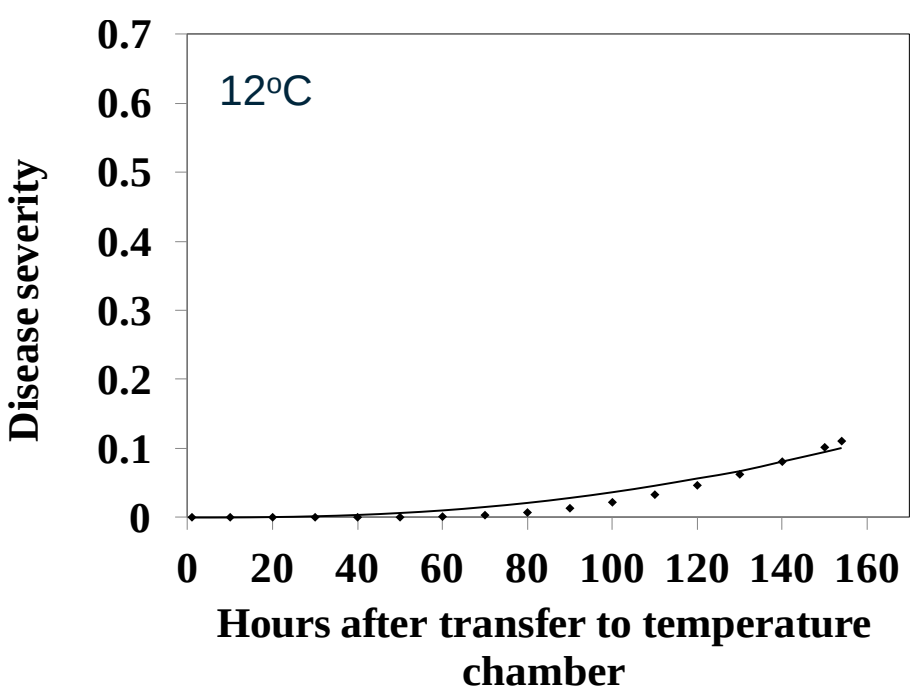
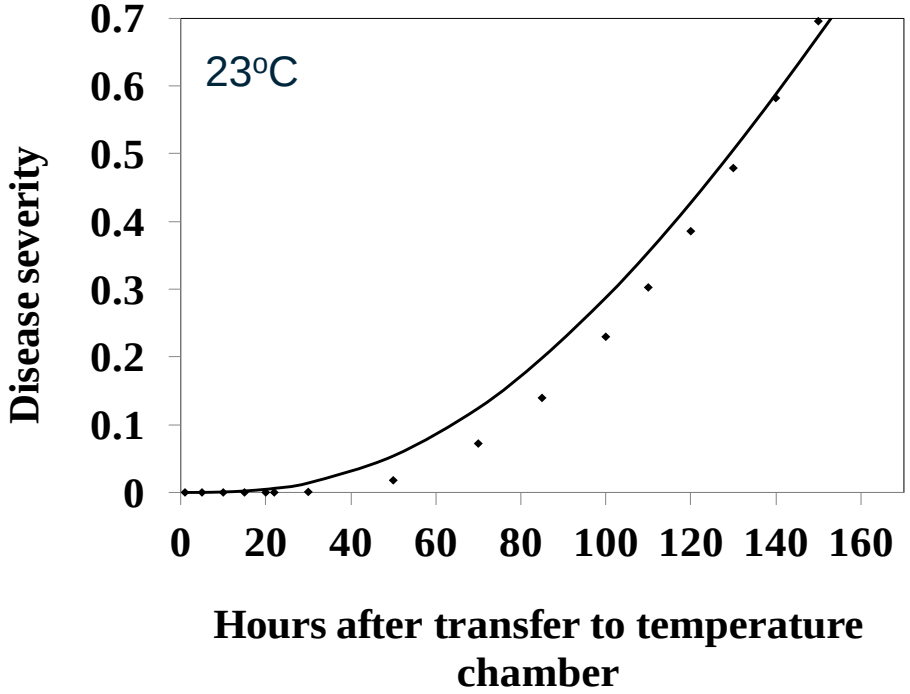
Shakya, unpubl.

Harrison and Lowe, 1989

Results: calibration at constant temperatures in the growth chamber





- Observed (. . .) and simulated (___) disease progress in the growth chamber under constant temperatures

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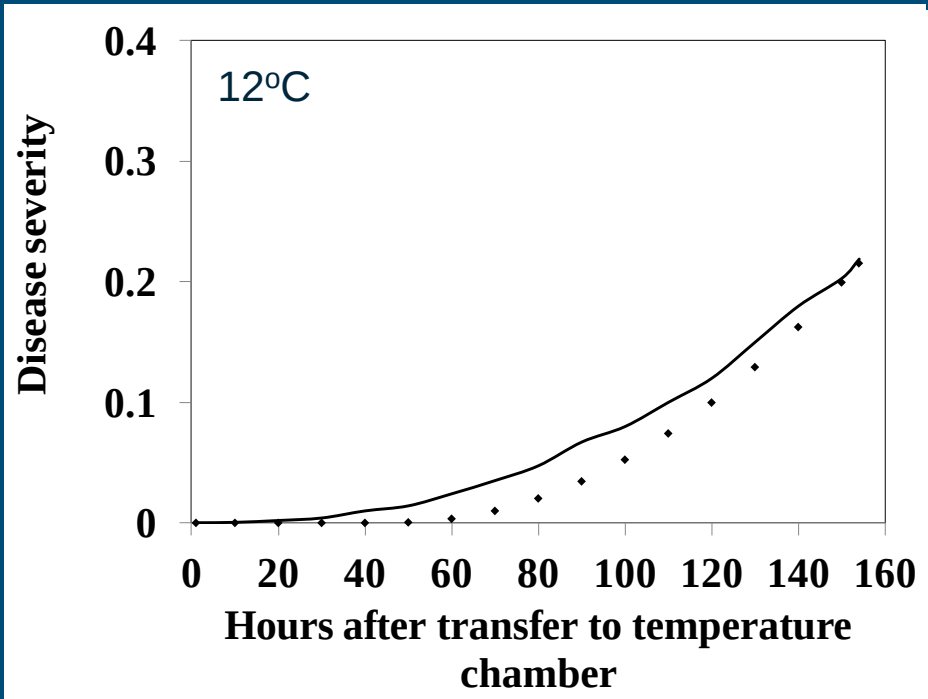
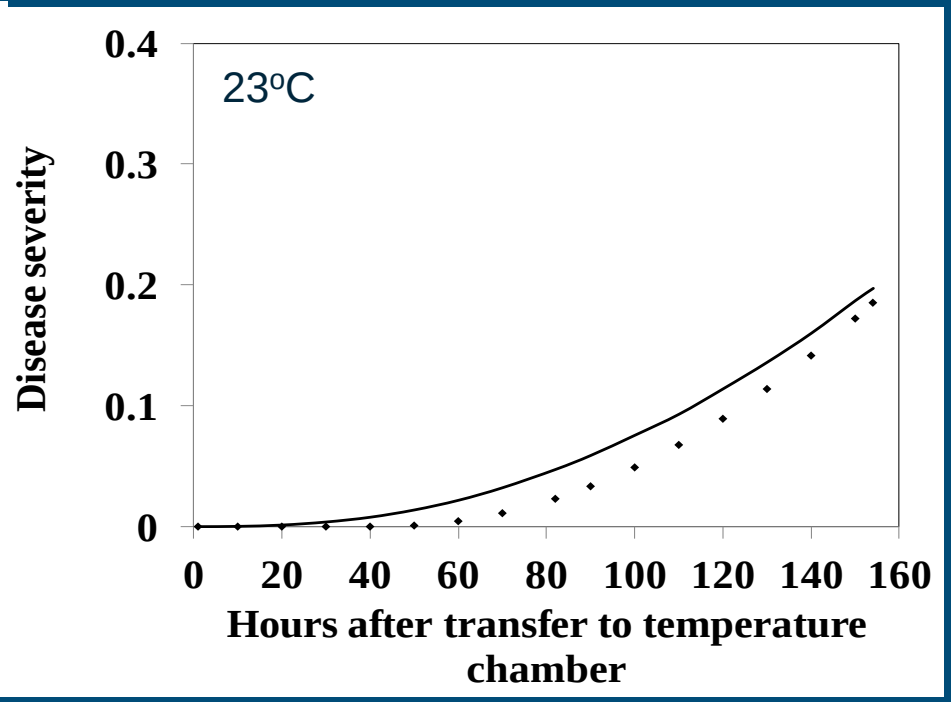
Results: calibration at oscillating temperatures in the growth chamber





- Observed (. . .) and simulated (___) disease progress in the growth chamber under oscillating temperatures (± 5ºC)

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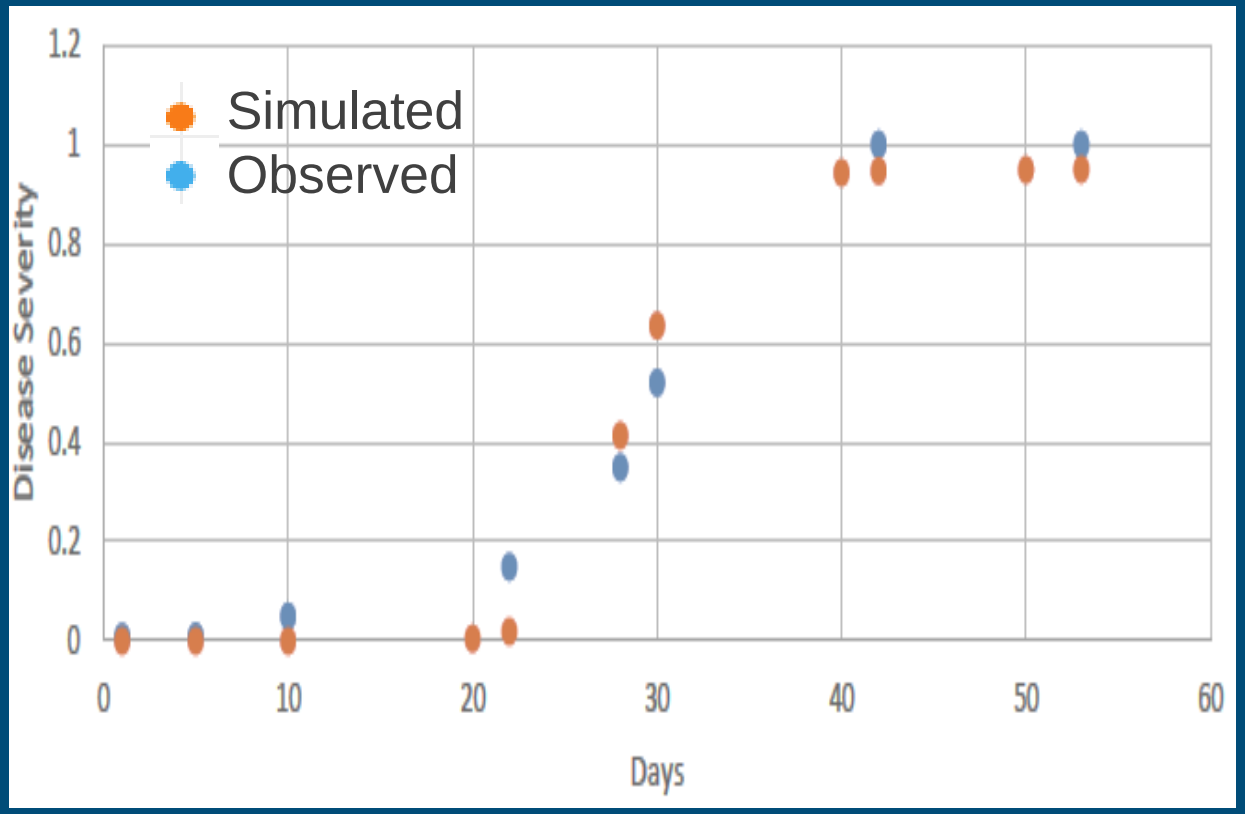
Methodology: Model fitting for calibration and validation of field data

- Hourly temperature and relative humidity data from Ecuador
- Approx. weekly late blight severity data (Jorge Andrade)
- Initial number of infectious sites=0
- Initial number of latent sites=0.00000001 (50 sites/ha)
- Hourly multiplication factor optimization: 0.15 - 0.45
- Model was run for 1680 hours (10 weeks)

Calibration of field data of potato late blight

- Latola, Ecuador, 1997
- Initialization:
  - $I_{1a} = 10^{-8}$ sites
  - H =0.99999999
- Parameter:
  - HMF=0.21



Narouei Khandan et al., unpubl.

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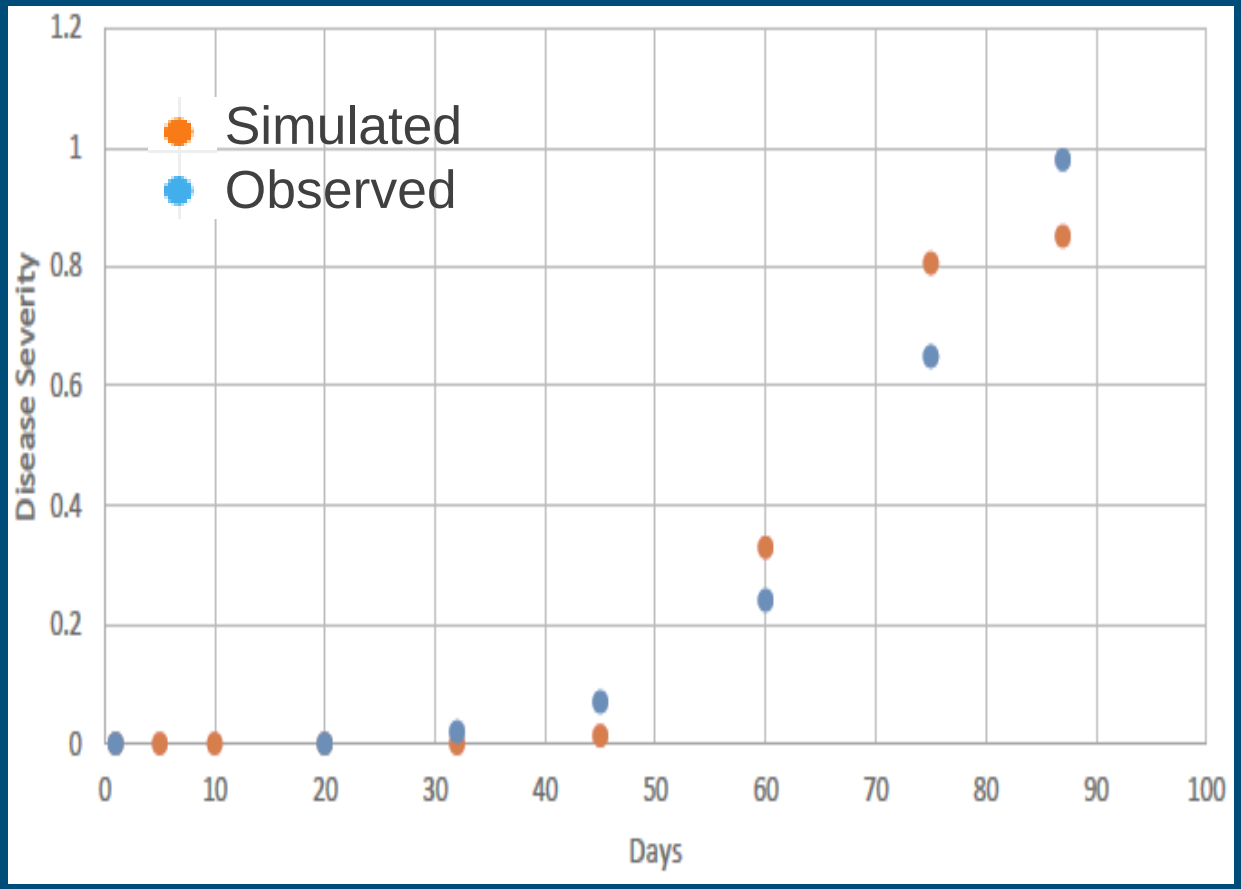

Narouei Khandan et al., unpubl.

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Further modeling plans

- Comparison of BLIGHTSIM and LATEBLIGHT
- Sensitivity analysis of all parameters in BLIGHTSIM
- Scenario analysis: changes in average daily temperatures versus changes in daily temperature ranges
- Link BLIGHTSIM to a potato growth and yield model
- Predict effects of climate change on yield and economics in Andes

Conclusions

- BLIGHTSIM is a simple model (< 1 page of code in R)
- BLIGHTSIM simulates late blight development accurately in the growth chamber and in the field
- The model provides a good fit to the disease progress data: Plots of predicted versus observed values: R^2= 0.77-0.98 and slope close to 1.
- Additional sensitivity analysis and field validation of BLIGHTSIM are still required.
- Integration of BLIGHTSIM with a potato growth model will help in understanding the effect of climate change in the Andes region where the DTR is expected to increase.

Acknowledgements

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