Phenology model for the Jacaranda Blossoms

MISG2020 SA Graduate Modelling Camp Problem

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Jacaranda Blossoms

- Jacaranda refers to the tree species *Jacaranda Mimosifolia*
- Introduced to South Africa from Brazil in the late 1800s as ornamentals to the pavements of the CBD of Pretoria, and later expanded through Pretoria, Johannesburg, and later to smaller cities of Pietermaritzburg, Pongola, Paarl, etc.
- Pretoria referred to as the 'Jacaranda City'
- Classified as a category 3 invasive species, replanting and sale of these trees is prohibited, but existing trees do not need to be removed
- Given the aesthetic and identity importance, These trees therefore represent a relatively unique *flagship invasive species*, and there is considerable public interest in protecting the existing trees.

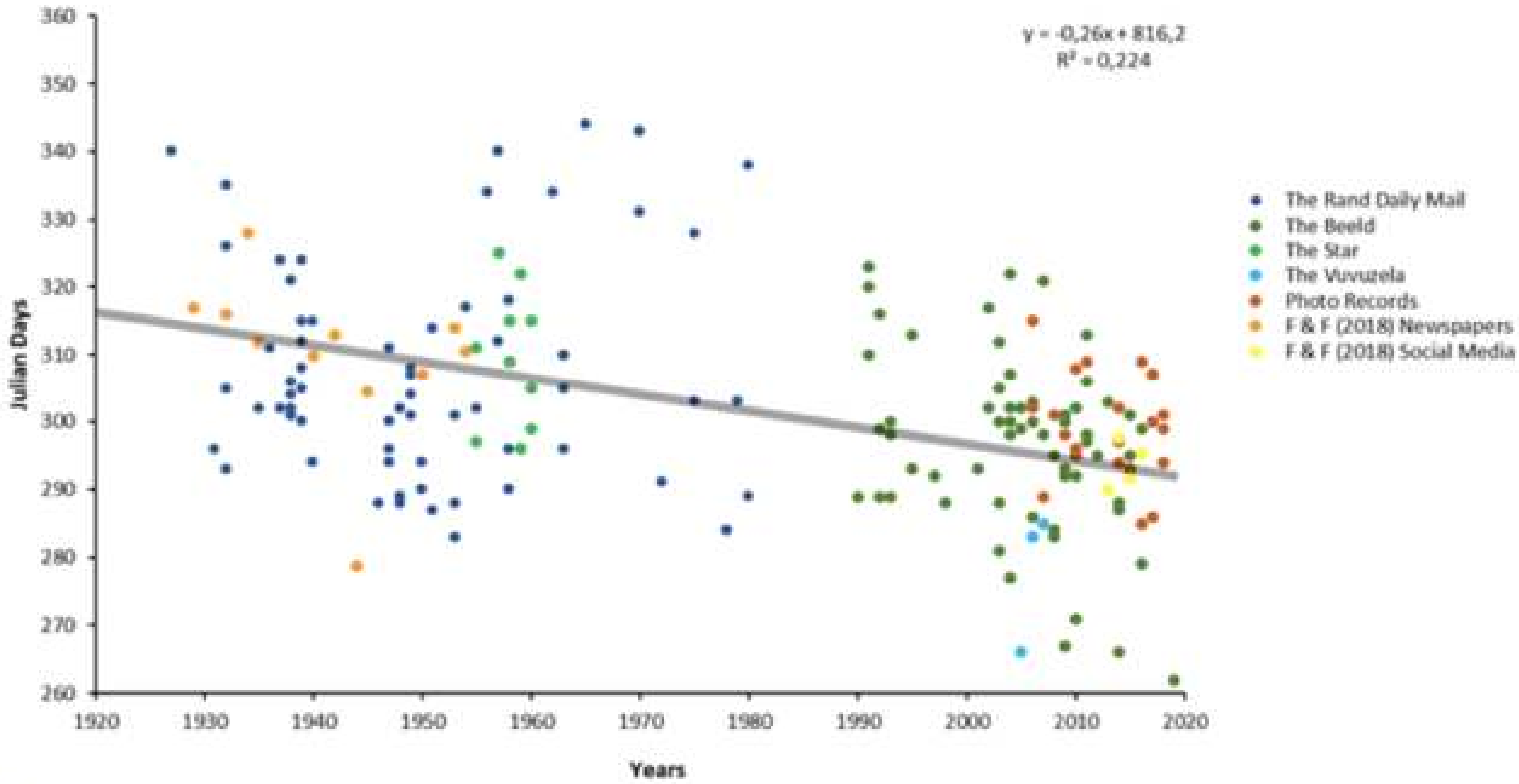
Jacaranda Blossoms

- Jacarandas flower in early summer with clustered purple blossoms
- Urban legend held that if the Jacarandas were blossoming and you had not started to study it would be too late to pass; if a Jacaranda flower landed on your head it would bring good luck for exams

Jacaranda Blossoms

- In the 1920s, Jacarandas were blossoming in mid- to late-November
- In 2019, the blossoms in Gauteng appeared in mid-September; the same was true in 2018 and 2017. In 2015 and 2016 they appeared in the last week of September
- This shift in the timing of flowering has been observed across almost all plants. You might notice that spring blossoms are appearing in mid-winter, or that the orange leaves that indicate autumn are occurring later into the months of May, June and even July.
- Looking at newspaper records we can see that this has been a progressive advance over the past century
- This is termed a **phenological shift**, and is occurring as a result of climate change

Jacaranda Blossoms



Source: Fitchett & Raik, *in prep*

Jacaranda Blossoms

- This phenological shift poses a threat to the future of these trees
- Phenological shifts are a response of a plant to better adapt to their environment, as unlike animals they are unable to move during their lifetime
- However, these shifts cannot occur indefinitely, at which point the plant is at risk:
  - Interception of flowering and frost
  - Flowering outside of the rainfall season
  - Flowering after insufficient dormancy
  - Flowering before the species required for cross pollination
- For Jacarandas which cannot be re-planted, this could mean the end of the purple cities!

Phenology

- Phenology refers to the timing of annually recurrent biological events
- In plants, these include leaf unfolding, blossoming, fruit development, leaf colouration and fall
- In animals these events are more diverse and relate to the species in question, but can include the timing of hibernation, migration, breeding, molting, animal calls, growth of antlers, etc.
- The study of phenology tracks the timing of these recurrent biological events, and considers their biotic and abiotic forces
- This scientific field emerged in the 1960s, and forms one of the subdisciplines of *Biometeorology*

Phenology

- The greatest abiotic force affecting the timing of phenological events is the climate
- Depending on the species, location and event in question, these can be triggered by factors including:
  - Onset of rainfall
  - Threshold number of sunshine hours
  - Temperatures above a certain threshold
  - Accumulation of heat through the dormant period (growing degree days)
  - Accumulation of cold through the dormant period (chilling days)
- As the climate changes, the timing of these trigger events is changing. To the plant, 'spring' is now occurring in late winter, and 'autumn' in early winter

Phenology

- Scientists track the timing of phenological events via:
  - Ground-based observations
  - Documentary records
  - Digital repeat photography
  - Remote sensing
- Extensive records have been captured for the global North, and the phenological responses are understood at high resolution
- These are then related to climate datasets, which allow for the triggers to be well-understood, and for future models to be developed
- For the global South, the phenological and climate records are far more sparse
- This is where phenological models become valuable

Phenological models

- Allow for the timing of phenological events, and shifts thereof, to be determined for locations and time periods for which phenological records are not available.
- Use climate variables – which are the abiotic forces of these phenological events – to mathematically model the phenology of a particular species
- South Africa has 200 registered weather stations – so this allows for far greater coverage than the existing phenological studies
- By understanding the covariance in phenological shifts between species elsewhere, this also allows for a range of species phenophase shifts to be modelled in South Africa
- Can be integrated into climate models to allow for changes in carbon storage to be more accurately projected and the impacts on climate forecasted

Phenological models

- Statistical studies of phenology and climate usually rely on aggregated mean monthly temperature and rainfall, with reasonably successful results
- More complex studies additionally explore factors such as first and last frost date, number of frost days rainfall date, first dates above specific threshold temperatures, and a larger range of climatic variables including sunshine hours, humidity, wind, drought and synoptic events such as mid-latitude cyclone passage.
- None of these, however, are the direct triggers for a phenological events
- Phenology models usually work with these direct forcings – accumulation of moisture, heat or chilling units

Phenological models

"Forcing" describes, very vaguely, the accumulation of heat stimuli for a plant following the period of dormancy. When sufficient heat portions are accumulated the plant will start flowering. A very well-known and widely used forcing model for the beginning of blossom of many plant species is the Spring-Warming model. It has the form

$$F^* = \sum_{i=t_1}^{t_2} R_f(T_i)\Delta t \qquad (1)$$

$R_f(T_i)$ is a function of the daily mean temperature T_i on day i and is called the forcing rate function. Δt is the time step, usually 1 day (1 d). The smallest summation index t_2, for which the sum on the right side approaches or exceeds the prescribed plant-specific forcing requirement F^* is the date (day of year = DOY) of the beginning of blossom in the year under consideration. The starting day t_1 of the summation is prescribed as a fixed value (e.g., 1 January) or has to be determined by optimization. In a forcing model which is supposed to be a mechanistic model and not a pure fitting model, t_1 should lie before the first forcing days but after the "release of dormancy". If one applies Eq. (1) to spring temperatures T_i of several, subsequent years, one obtains a prediction for the beginning of blossom $t_2(pred, j)$ for each year j.

Blümel & Chmielewski, 2012

The Problem

Developing a phenological model for the timing of Jacaranda Blossom in the Gauteng City-Region, South Africa that accurately represents documentary evidence

- You have at your disposal:

1. The documentary evidence – newspaper reports and photographic evidence of Jacarandas in bloom in Gauteng City-Region spanning 1927-2018
2. Daily Temperature data for Pretoria and Johannesburg
3. Daily Rainfall data for Pretoria
4. Key texts on phenological models

The Problem

Your model needs to be able to:

- Consider the climatic variables that may force Jacaranda flowering and model their interaction
- Produce output values within the range of the documentary sources
- Track the advance in the mean blossom date over the period 1927-2018

A very good model would be able to:

- Model first flowering
- Model the duration of the flowering period
- Assess long- and short-flowering seasons
- Project a critical advance threshold using climate model output data