Analyzing the phase statistics of phenological records: fluctuations and correlations with temperature

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Motivation

Phenology: Introduction

- describes the timing of certain periodical development stages of species throughout the year (I.L. Hudsen, Climatic Change 100, 2010)
- e.g. flowering, fruit ripening, leaf coloring, foliation
- well-known concept in ecology
Figure: courtesy Anne Holsten
Motivation

Phenology: some previous work

- Phenological phases are sensitive to temperature.
- Shifts of phases indicate change of climate.
- Earlier onset of plant phases of 3.8 days per 1°C (Europe) (N. Estrella et al., Clim. Res. 39, 2009)
  - Negative shifts for spring phases
  - Positive shifts for fall phases
Motivation

Phenology: our approach

- previous studies concentrate on response of specific phases or groups
- no integrated approach assessing changes
- **we describe the system from a statistical physics viewpoint**
- propose a phenological index
- simultaneously characterizes shifts of spring and fall phases
Data

Phenological records

North Rhine-Westphalia (NRW)

- collected by the German Weather Services (DWD)
- observations by volunteers (2-3 times per week)
- 1951-2006
- 75 phases (159)
- 17 sites in NRW (660)

also: records of annual mean temperature
First, we want to study how strongly phenological phases fluctuate. Therefore, we apply the Rayleigh measure:

\[ \sigma_{\phi} = \sqrt{\langle \cos \phi \rangle^2 + \langle \sin \phi \rangle^2}, \]

where \( \langle \cdot \rangle \) is the average over time, separately for each phenological plant.
For the phase $\phi_{p,t}$, i.e. the day of the year when the phenological event $p$ occurs in year $t$, we consider the phase anomaly

$$\varphi_{p,t} = \phi_{p,t} - \langle \phi \rangle_p,$$

where $\langle \cdot \rangle$ denotes the average over time and $\langle \phi \rangle$ is defined by

$$\tan \langle \phi \rangle := \frac{\langle \sin \phi \rangle}{\langle \cos \phi \rangle}.$$

Linear regression to $\varphi_{p,t}$ against $\langle \phi \rangle_p$:

$$\varphi^*_{p,t} = \alpha_t \langle \phi \rangle_p + \beta_t.$$

Eliminating $\varphi$ one obtains

$$\phi = \langle \phi \rangle (\alpha + 1) + \beta,$$

i.e. $\alpha$ corresponds to a temporary change of frequency.
example: $\varphi = \phi - \langle \phi \rangle$ vs. $\langle \phi \rangle$
Figure: Idealized cycle of advantageous and disadvantageous phenological years as well as premature and delayed years.
Figure: Dülmen 1951-2006. (a) slope $\alpha$ (pheno-index), (b) intercept $\beta$, (c) root mean square deviations from the fit $\sigma_\varphi$, and (d) number of phenological phases used for each year.
Figure: Dülmen 1951-2006: phenological index and annual mean temperature.
Correlations with mean temperature

Legend
- Climate station
- Phen. station
- Correlation:
  - < 0.3
  - 0.3-0.4
  - 0.4-0.5
  - 0.5-0.6
  - >0.6

Height [m]
- 0
- 50
- 100
- 150
- 200
- 250
- 300
- 350
- 400
- 450
- 500
- 550
- 600
- 650
Discussion and conclusions

**Pheno-index & phenological cycle**

Assuming $C(\phi) = A \sin(\phi + \lambda) + B$ and

$$\int_{-\pi}^{\pi} [A \sin(\langle \phi \rangle + \langle \lambda \rangle)] \, d\langle \phi \rangle = 0$$

we find:

$$\int_{-\pi}^{\pi} [A \sin(\langle \phi \rangle(\alpha + 1) + \beta + \lambda)] \, d\langle \phi \rangle \approx 2\pi A \alpha \sim \alpha.$$

**Phenological records**

- regression to $\phi - \langle \phi \rangle$ versus $\langle \phi \rangle$ can be used to characterize anomalies of the phenological cycle.
- slope $\alpha$ represents a temporary change of frequency and intercept $\beta$ a temporary phase shift.
- spring and late summer phases exhibit the largest fluctuations while the early summer and fall phases exhibit the smallest fluctuations.
Thank you for your attention!


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