# 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

# Motivation

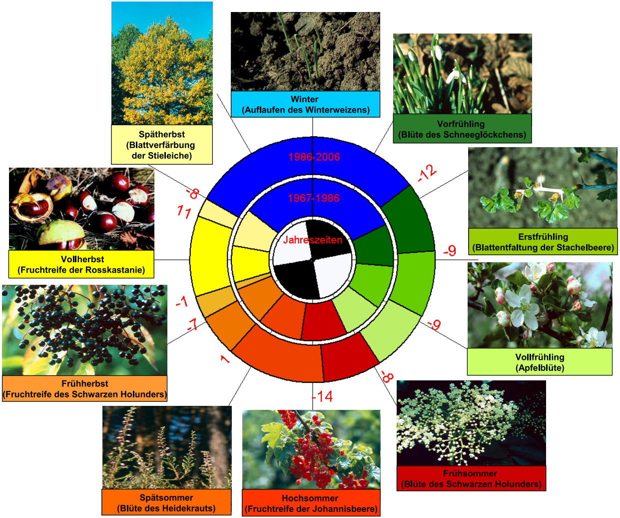



Figure: courtesy Anne Holsten

# 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
- cherry blossom in Kyoto advanced by 7 days (1971-2000) (Y. Aono, K. Kazui, Int. J. Climatology 28, 2008)

## 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 view point**
- **propose a phenological index**
- **simultaneously characterizes shifts of spring and fall phases**

# Data

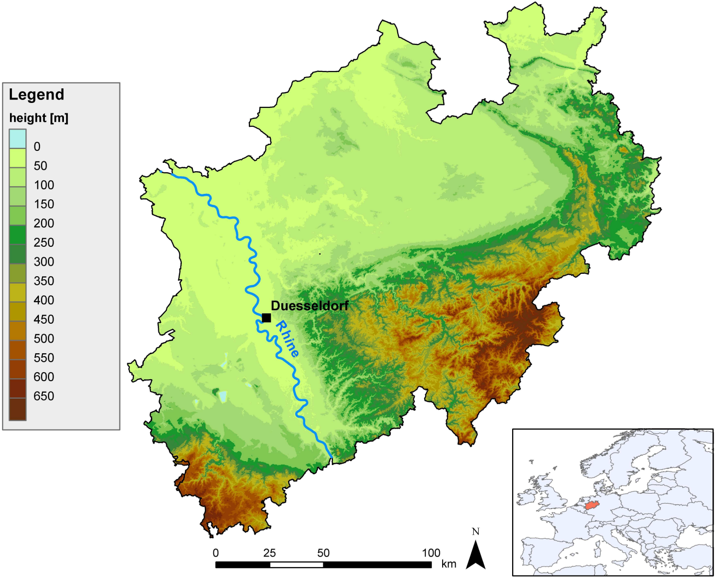
## Phenological records

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

# North Rhine-Westphalia



# Fluctuations

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.

# Fluctuations

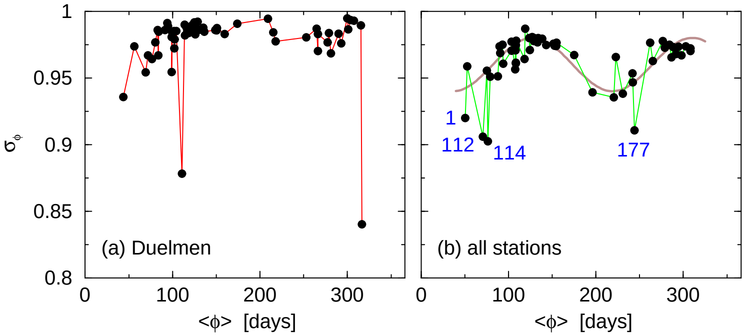



Figure: 1: Hazel, *Corylus Avellana*: flowering; 112: European Alder, *Alnus Glutinosa*: flowering; 114: Cornel Cherry, *Cornus Mas*: flowering; and 177: Wild Brier, *Rosa Canina*: fruit ripening.

# Method

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. $\langle\phi\rangle$

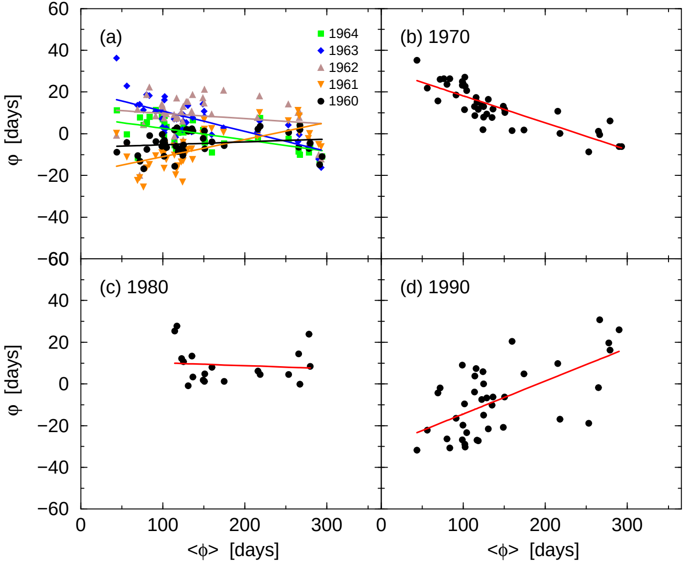



Figure: Dülmen near Münster

# Schematic illustration

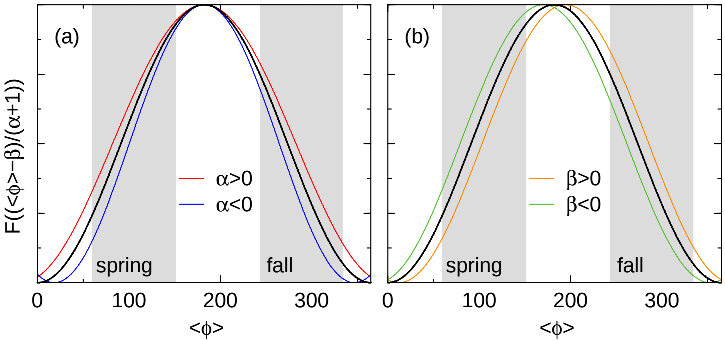



Figure: Idealized cycle of advantageous and disadvantageous phenological years as well as premature and delayed years.

# Phenological Index

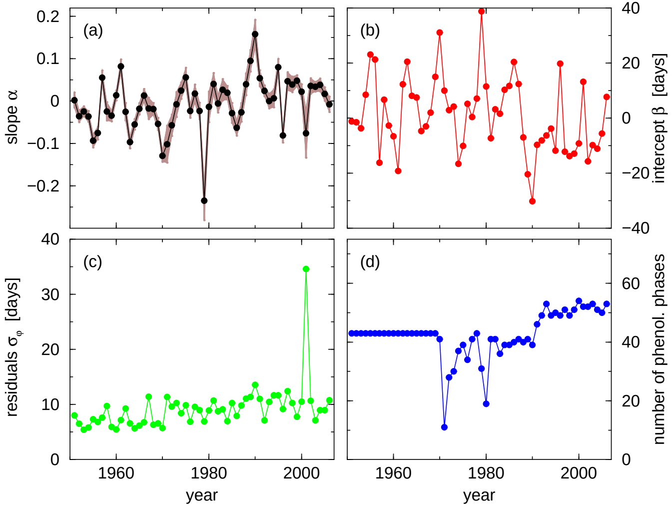



Figure: Dülmen 1951-2006. (a) slope $\alpha$ (pheno-index), (b) intercept $\beta$, (c) root mean square deviations from the fit $\sigma_\varphi$, and (d) number of phenological phases used for each year.

# Comparison with temperature

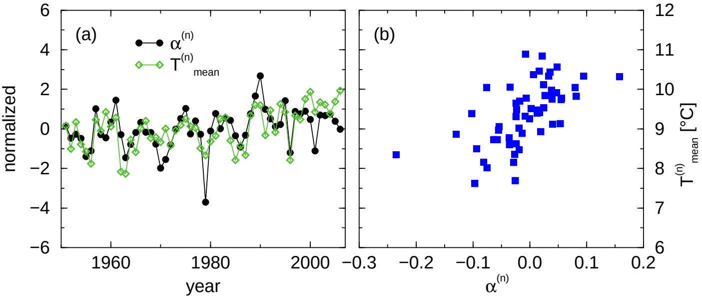
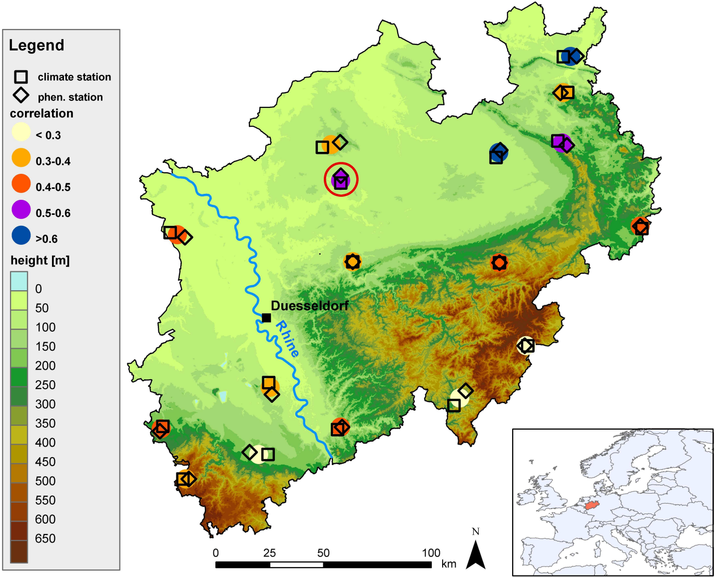



Figure: Dülmen 1951-2006: phenological index and annual mean temperature.

# Correlations with mean temperature



# Discussion and conclusions

## Pheno-index & phenological cycle

Assuming $C(\phi) = A\sin(\phi + \lambda) + B$ and $\int_{-\pi}^{\pi} [A\sin(\langle\phi\rangle + \langle\lambda\rangle)]\,\mathrm{d}\langle\phi\rangle = 0$ we find:

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

## 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!

D. Rybski et al., Physica A 390, 2011, 680-688.

http://www.rybski.de/diego/