Statistical climate modelling of droughts for Austria and the period 2011-2040

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Introduction

- One of the most important agricultural production regions in Austria is located in the Eastern Lowlands: Marchfeld region
- Climate chatacteristics
  - E.g. Low annual precipitation sums (~ 500 mm)
- If we extrapolate the observed temperature trend to 2040, this region will face higher evapotranspiration rates and therefore, less water will be available for the plants
- Risk assessment of drought disaster for
  - past observations (1981-2010)
  - future scenarios (2011-2040)

Introduction

- How to model droughts?
  - Sensitivity analysis: Bootstrapping
    - E.g. droughts every 15 years, every 10 years, every 5 years, every second year
    - Impacts on risk assessment
  - Apply different possible models for developping climate change scenarios including droughts

Daily stochastic precipitation models (based on Wilks, 1999)

- Investigation for locations primarily in the US, and spanning a wide variety of precipitation climates
- We tested the same models for the Marchfeld region in Austria
- Future work will be in expanding these models to Austria with its complex terrain
  - Occurrence of precipitation
    - Precipitation in a sequence of days
  - Intensity of precipitation
    - Precipitation amounts on wet days
  - Models are often found to be deficient with respect to
    - Interannual variability
    - Extreme precipitation events, particularly extended droughts

Occurrence of precipitation

- First-order Markov dependence
  - 2 parameter model
  - Can be defined in terms of 2 transition probabilities (P01, P11)
  - Wet spells reasonably portrayed
  - Long dry spells may be produced too infrequently
- Mixed Geometric distribution
  - Length of the next spell is simulated
  - E.g. for dry spells: 6 parameters are needed
- Simple Geometric distribution
  - 2 parameter model, equivalent to the first-order Markov dependence

Occurrence of precipitation

- Negative Binomial distribution
  - Geometric distribution is a special case of this distribution
  - When used for lengths of both wet and dry spells, it is a 4 parameter model
- Higher order Markov Models (2nd and 3rd order dependencies)
  - Number of parameters increases exponentially, e.g. $2^2=4$, $2^3=8$, …
- Markov Chain of hybrid order: probability that day t is wet depends on whether precipitation did or did not occur on the previous l days
  - These models retain first-order Markov dependence for wet spells, but allow higher-order dependence for dry sequences
  - Number of parameters required is only k+1 rather than 2^k

Intensity of precipitation

- Two-parameter Gamma distribution
  - Most common choice for representing distributions of nonzero precipitation amounts in stochastic weather models
  - Daily nonzero precipitation amounts modeled as being independent and identically distributed -> day-to-day correlation of daily precipitation amounts (excluding dry days) = 0
- Three distinct Gamma distributions may be appropriate for
  - Single wet days
  - Leading day of a multi-day wet spell
  - Subsequent days of multi-day wet spells
  - 4 parameters for these three distinct Gamma distributions needed

Intensity of precipitation

- Mixed Exponential distribution

  - Probability mixture of two one-parameter Exponential distributions
  - 3 parameter distribution
  - Provides superior fits to daily precipitation data

Occurrence & Intensity

- All models are fitted using maximum likelihood
  - Goodness-of-fit to the data
  - Assessed here with AIC (Akaike‘s Information Criterion; Akaike 1973)
  - Smallest value gives the model with the best fit

$$AIC = -2\ln(L) + 2k$$

L … maximized value of the likelihood function for the estimated model

k … number of parameters

AIC: model comparison first results

Precipitation occurence models:	AIC
First-order Markov dependence	14813.70
2nd-order Hybrid Markov model	14810.30 (p11, p101, p001)
Second-order Markov dependence	14823.82
3rd-order Hybrid Markov model	14823.69 (p11, p101, p1001, p0001)
Precipitation intensity models:	**AIC**
Gamma distribution	19559.75
Mixed Exponential distribution	19301.96

Overdispersion

- Underrepresentation of the lower-frequency variations
- Overdispersion in wet-day variance is found to be smallest produced by the Mixed Exponential distribution, although not zero
- Improvement in the simulation of interannual variability
- Best combination of occurrence and intensity models reduces the overdispersion
  - Dependent on region and topography

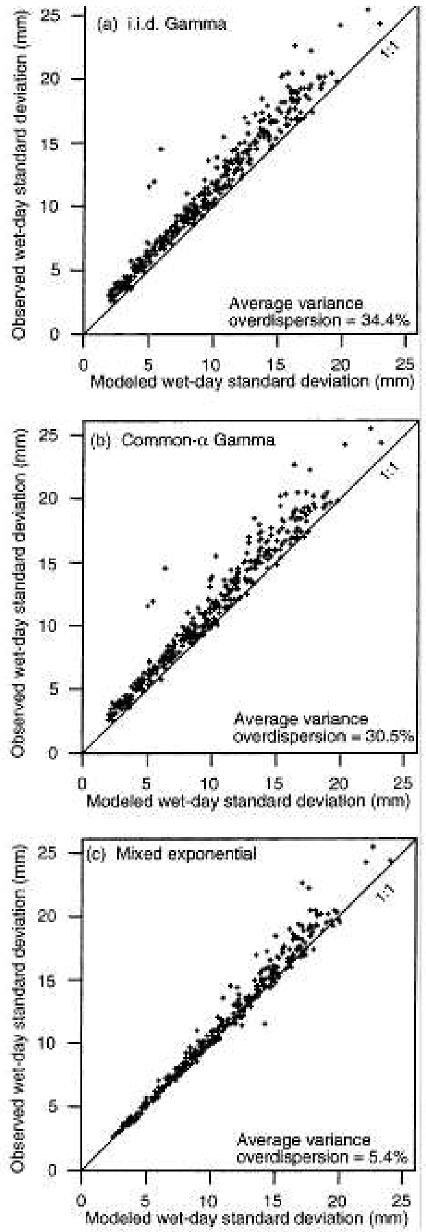

Fig. 1. Relationships between the (square-root) of the wet-day variance σ^2 in the observations (vertical) and the model-derived standard deviations for (a) iid Gamma distributions, (b) Common-α Gamma distributions, and (c) Mixed Exponential distributions.

Wilks (1999)

Extremes

- Capacity to reproduce the observed extremes of spell lenghts and precipitation amounts
  - Underrepresentation by precipitation amounts estimated with conventional two-parameter Gamma distribution
  - Improvement by allowing three distinct Gamma distributions, but still a clear negative bias
  - Mixed Exponential intensities match the observed extremes quite well!
  - For the longest observed dry spells: second-order hybrid Markov model provides a noticeable improvement!
  - All models represent the extreme wet-spell lengths reasonably well

Outlook

- Droughts in the Marchfeld region (and later in Austria) will be modeled using
  - Hybrid-order Markov model (occurrence of precipitation)
    - first-order Markov dependence for wet spells, and higher-order dependence for dry sequences
  - Mixed Exponential distribution (intensity of precipitation)
    - Overdispersion is small
- Advice / suggestions?

References

- Akaike (1973): Information theory and an extension of the maximum likelihood principle. Second International Symposium on Information Theory, 267-281.
- Wilks D.S. (1999): Interannual variability and extreme-value characteristics of several stochastic daily precipitation models, Agricultural and Forest Meteorology 93 (1999) 153-169.