Characterization of flood and precipitation events in Southwestern Germany and stochastic simulation of extreme precipitation (Project FLORIS-SV)

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overview & motivation

Flood hazard originates from a combination of different meteorological, hydrological and hydraulic processes. Currently there is no defined methodology available for evaluating and quantifying the flood hazard and related risk for an entire river catchment.

Historic flood events:

- Several major flood events along the rivers Elbe and Danube (e.g. 2002, 2013) with huge losses (about 2 billion Euros each)
- Last major flood events in Baden-Württemberg (BW) in 1978, 1993/1994 (losses around 150 million Euros each) along the rivers Rhine and Neckar
- Probable maximum loss of a 200 year flood event (PML200) in BW widely unknown

- Project **FLORIS-SV** (**FLO**od **RIS**k – **S**parkassen **V**ersicherung)
- Statistical analysis of historic flood events for estimating probability density functions (pdf) of relevant atmospheric variables
- Development of a high resolution stochastic precipitation model (SPM) as the beginning of a complete chain of modelling flood risk in Baden-Württemberg

data sets

- **REGNIE** (**REG**ionalisierte **NIE**derschläge)
  - gridded precipitation data set of the German Weather Service (DWD) for German state territory
  - interpolation of observational data weighted with orography to high resolution of approx. 1 km²
  - daily precipitation amount since 1951 to date
- **Observational** data (rain gauges of the DWD)
- **Sounding** data **Stuttgart**-Schnarrenberg
- **RADOLAN** (**RAD**ar **O**n**L**ine **AN**eichung)
  - radar data of the DWD standardized with observation data
  - hourly precipitation amount since 2005
- high resolution **orography** data

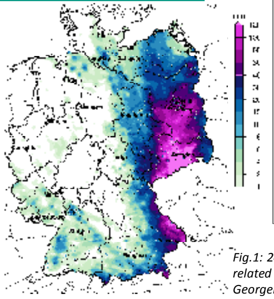


Fig.1: 24-hour precipitation totals on August 12, 2002 (REGNIE data); major rainfall event related to the 2002 flood and all time record in Germany (312 mm at Zinnwald-Georgenfeld)

historic event analysis

- **considered variables**
  - event duration and spatial mean precipitation
  - Antecedent Precipitation Index (API)
  - atmospheric conditions: stability, humidity, wind, temperature
- **bottom-up** →
  - link heavy rainfall with corresponding flood events **if possible!**
- **top-down** ←
  - link flood events with corresponding precipitation totals

REGNIE data FILS catchment

rank	year_month_day	spatial mean [mm]
1	1978_08_07	65,1
2	1982_10_06	62,4
3	1998_10_28	58,5
4	1994_04_12	55,5
5	1979_11_06	52
6	1951_01_19	51,9
7	1956_03_02	51,7
8	1978_05_22	49,3
9	1971_06_07	48,9
10	1984_06_05	48,9
11	1963_07_23	48,2
12	1971_06_06	47,2
13	2004_01_13	47
14	2013_05_31	46,6
15	1978_05_23	46,3

gauge data of Plochingen (FILS)

rank	day.month.year	local time	runoff [m³]
1	7. 5.1931	13.00	[illegible]
2	13. 1.2004	[illegible]	[illegible]
3	[illegible]	[illegible]	[illegible]
4	[illegible]	[illegible]	[illegible]
5	1. 6.2013	[illegible]	[illegible]
6	[illegible]	[illegible]	[illegible]
7	10.11.1927	[illegible]	[illegible]
8	21. 3.2002	[illegible]	[illegible]
9	2. 7.1987	2.40	[illegible]
10	[illegible]	[illegible]	[illegible]
11	[illegible]	[illegible]	[illegible]
12	[illegible]	[illegible]	[illegible]
13	[illegible]	[illegible]	[illegible]
14	[illegible]	11.00	[illegible]
15	20. 9.1927	7.00	[illegible]
16	[illegible]	[illegible]	[illegible]
17	[illegible]	11.00	[illegible]
18	[illegible]	[illegible]	[illegible]
19	[illegible]	[illegible]	[illegible]
20	[illegible]	[illegible]	[illegible]
21	21. 1.1951	[illegible]	[illegible]
22	2. 7.1932	17.00	[illegible]
23	[illegible]	7.00	[illegible]
24	[illegible]	[illegible]	[illegible]
25	[illegible]	[illegible]	[illegible]

Fig.2: ranked spatial mean precipitation for the Fils catchment from REGNIE data (left) compared with ranked runoff data of gauge Plochingen (right); colored boxes link precipitation event with flood event; arrows show bottom-up/top-down direction of analysis

stochastic model (SPM)

- **model characteristics**
  - event-based simulations (N=100.000)
  - seasonal differentiation of all variables
  - linear theory for precipitation
  - Computation in Fourier space
- **precipitation composition (additive)**
  - background precipitation R_∞
  - orographic precipitation R_{oro}
  - frontal precipitation R_{front}
  - convective precipitation R_{conv}
- **tuning parameter**
  - uplift sensitivity
  - time delays
  - "rain shadow" strength
  - Calibration to historic events
- **best pdf estimation**
  - Combination of bias, rmse and χ²

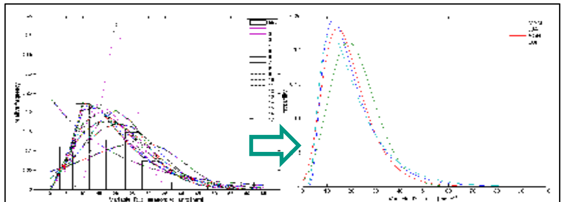


Fig.3: Test of different pdfs for each variable and season; shown: histogram and pdf pool for background precipitation in winter (left) and estimation of the best-fitting pdf (right)

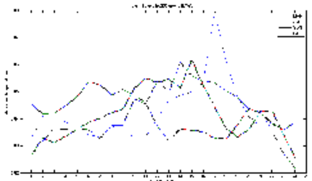


Fig.4: Seasonal differing diurnal precipitation cycle (spatial means for BW) in terms of relative precipitation amounts calculated from RADOLAN data; used for disaggregation of daily model output

Flow chart of model components

- statistical data (pdfs)
- orographic data set

- model parameters (size, resolution, ...)
- tuning parameters

↓

stochastic simulation of all parameters

↓

stochastic event set (loop of N events)

↓

event characteristics: season, duration, pre-conditions (API)

2 times per day: $R_\infty + R_{oro}$ → ones per day: $R_{front} + R_{conv}$

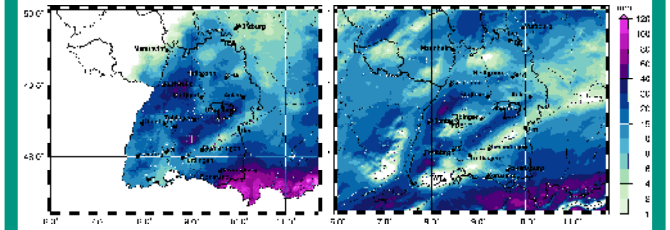
total 24 hour precipitation $R_{tot} = R_\infty + R_{oro} + R_{front} + R_{conv}$

↓

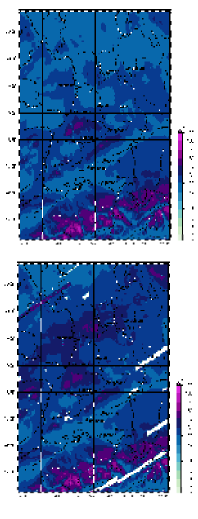
Disaggregation into hourly values → save variables, characteristics, precipitation fields

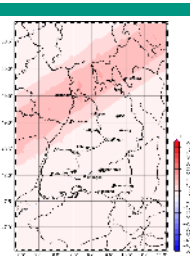
SPM - calibration

Fig.5: Comparison of REGNIE data (left) and model output (right) for June 1st, 2013; model calibration (tuning parameters) for best compliance



SPM - simulations





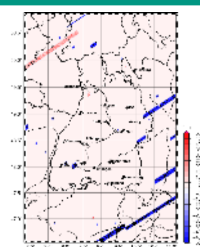


Fig.6: Composition of 24-hour precipitation totals for a stochastically generated precipitation event: background and orographic precipitation (top left), frontal precipitation (top middle), convective precipitation (top right) and new 24-hour total (bottom). Frontal and convective parts can be both, positive and negative, whilst background and orographic parts always have positive values. (Model Version 0.9, 31.03.2016)

- **conclusions**
  - linear theory works quiet well for orographic precipitation
  - fast computation due to FFT application
  - Link between precipitation and flood events (bottom up) not always possible
  - SPM with frontal and convective parts yields realistic precipitation totals

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