Modeling weather-within-climate for index insurance contract design

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Outline

• modeling and simulation of daily rainfall records over Ethiopia with a hidden Makov model (HMM)

• comparison of various rainfall simulators for index insurance contract design for teff at Adiha village, for which only 7 years of historical data are available

Introduction

• financial instruments based on climate index insurance are becoming viewed as potentially important tools for climate risk management in agriculture. Insurance contract design requires estimates of value-at-risk based on long local meteorological time series that are generally not available;
• here we explore the ability of a hidden Markov model to construct long simulations of local daily rainfall, conditioned on large-scale historical climate information;
• we use simulated stochastic daily rainfall sequences from the HMM and a single-station Bayesian stochastic weather generator for developing an index insurance contract for teff at Adiha in the Ethiopian highlands;
• this village only has 7 years of historical rainfall measurements, suggesting the use of simulators

Conclusions

• the hidden Markov model provides a means to model daily rainfall based on multiple daily station records, and to "assimilate" the impacts of various large-scale influences (e.g. seasonal predictions);
• such models can provide valuable insight into daily rainfall records, and which aspects may be robust and predictable; they also have the potential to generate much longer synthetic rainfall records for insurance-risk estimates;
• examples of HMM simulations at Adiha illustrate the potential pitfalls of uncritical application;
• use of multiple methodologies for generating rainfall simulations is highlighted for index-insurance contract design, especially in regions of short historical time series.

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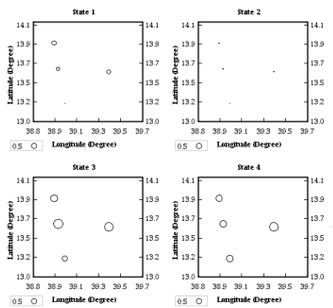
Hidden Markov Model

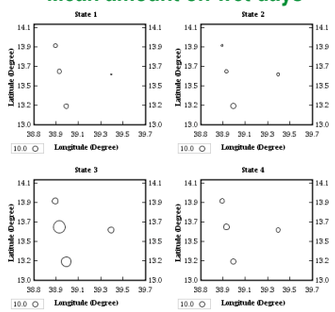
• 4 daily rainfall station records in Ethiopian highlands: Abiadi, Adiha, Hagereselam, Maykental
• June–September season, 1979–07 (considerable missing data)
• simulation using large-scale gridded rainfall product (CMAP) as a prescribed input

HMM trained on rainfall data

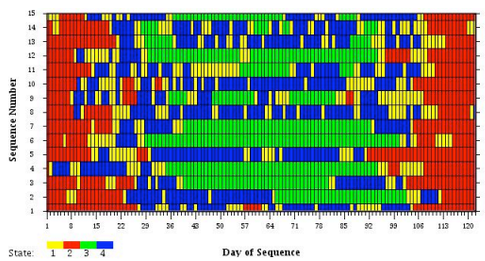
Rainfall probability



Mean amount on wet days



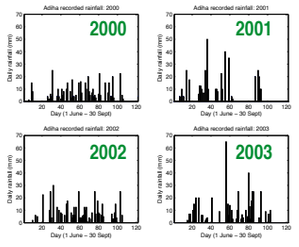
Estimated temporal state sequence



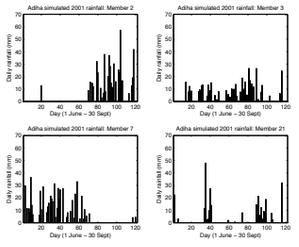
4-state model describes spatial rainfall patterns in the region, as well as its sub-seasonal, seasonal and interannual variability

Adiha rainfall simulations

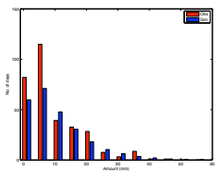
Observed



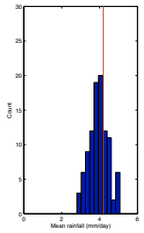
Simulated in 2001



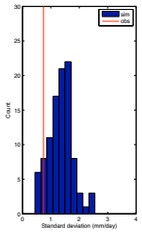
Daily distribution



Mean



Interannual St. Devn



Simulated rainfall captures many of the characteristics of the observed Adiha rainfall, for the 7 years of record (100 simulations)

Teff Contract

Rainfall simulations from HMM and single-station Bayesian stochastic weather generator, fed into insurance contract design for Teff at Adiha, based on (11 Aug – 10 Sep) rainfall total

model	payout frequency	price	STD(rain) (mm)
Bayesian single-station (1000 sims)	17	7.1	60
HMM (100 sims)	9.1	3.7	50
historical data (7 years)	14	3.3	40

Contract Design

• payout frequency is determined by applying the contract to a given rainfall series, calculating payouts as if the insurance had been in place
• payouts are calculated using a linear piecewise function with no payouts if the rainfall sum is above the trigger, a maximum payout if the sum is below the exit, with a linear payment function in between
• price depends on expected payouts, and ability to handle risk determined using the Return on Value at Risk (VaR) method
• VaR is taken as 99%-ile of historical or simulated rainfall
• for teff at Adiha, we chose late-season (11 Aug – 10 Sep) rainfall total as the key rainfall indicator, based on local farmers' experience

Bayesian single-station model yields both highest payout frequency and price – consistent with highest interannual rainfall variability
HMM yields somewhat lower values
historical data is limited by very short 7-yr timeseries – v. large standard error!