Assessing the Viability of Index Insurance as an Adaptation Tool in a Changing Climate Context: Case Study in the West African Sahel

Dissertation Defense, November 24, 2014

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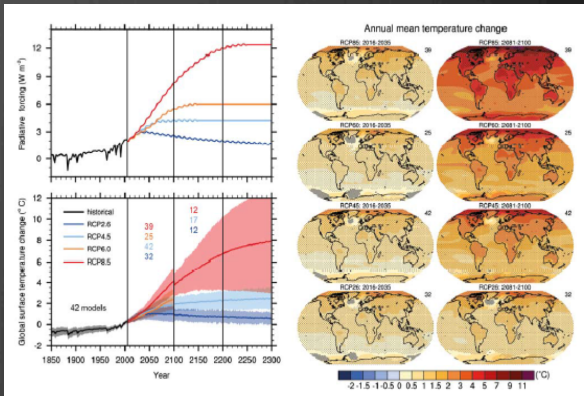
General Outline

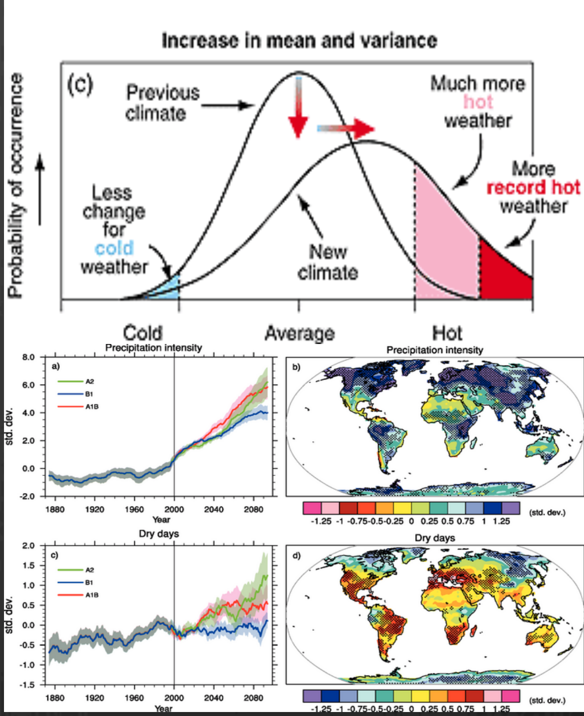
- General Introduction
- Regional Socioeconomic Context
- Regional Climate
- Index Selection
- Niger River Analysis
- Global Climate Model Analysis
- Conclusions/Future Work

Climate Change and Extremes

- Global and regional climate change is real
  - Rising temperatures
  - Rising sea levels
  - Intensification of the hydrologic cycle
- Climate change attribution
  - Fossil fuel combustion (adding GHGs to the atmosphere)
  - Land use changes that alter global carbon cycle and albedo
  - Aerosol impacts
  - Internal feedbacks and natural variability
- Future impacts are highly contingent on degree of emissions and complex dynamical sensitivities within the climate system
  - At least +1C “committed” warming by end of 21st century, at least +2C quite likely, and as much as +4-5C possible in high emissions scenarios
- Extreme events are of particular concern
  - Disproportionate costs (human, economic, ecological)
  - Highly sensitivity to changes in the mean state of the climate



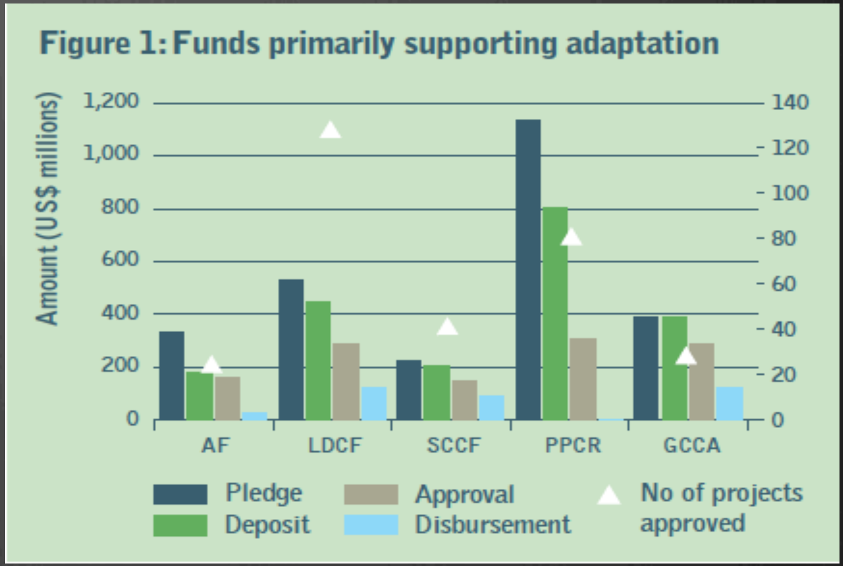
IPCC, 2013



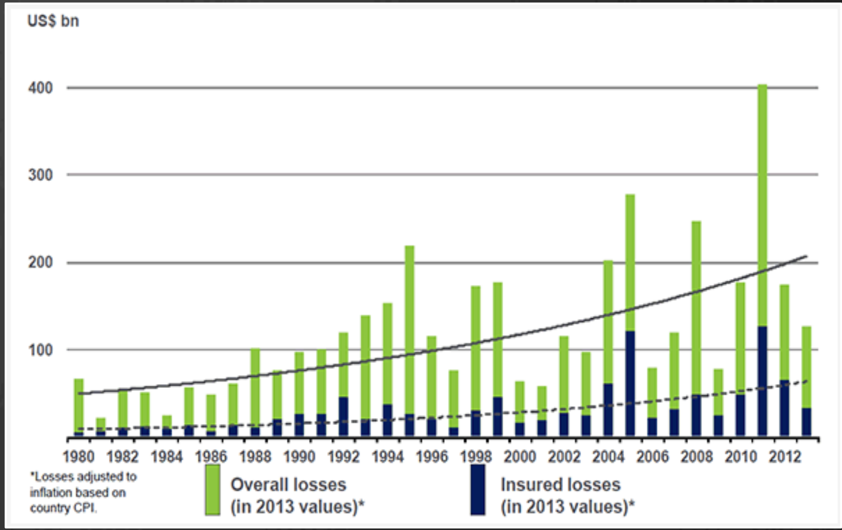
IPCC, 2007

Vulnerability, Adaptation and Insurance

- Climate impacts are felt especially by the global poor who tend to have higher risk exposure and more limited means of coping (double exposures framework – Leichenko and O'Brien)
- Globally, "top down" funding for adaptation to climate change is badly lacking;
  - Committed funding is on the order of low billions of USD, projected costs are on the order of hundreds of billions/year
- Insurance industry has already begun to feel the effects of climate change in rapidly increasing insured losses
  - Increased exposure and value at risk (main cause)
  - Increasing hazard (secondary cause)
- Need for market driven, scalable, bottom up approaches to adaptation
- Need for innovation within the insurance sector to manage non-stationary risks



Schalatek et al. 2012



Munich Re 2013

Climate Change and Insurance Discourse

- In the developed world, climate related risks already effect many forms of insurance and related financial instruments
  - Property/casualty
  - Agricultural
  - Flood
  - Reinsurance
  - Cat bonds
  - Weather derivatives

- Subsidization can distort prices and create perverse incentives

- Index insurance has been explored in a wide range of contexts (primarily in the developing world) over the last decade and a half
  - Projects in the Caribbean, Malawi, Ethiopia, India, Vietnam, Indonesia, Brazil, Mexico, China and others
  - Some initial projects in the West African Sahel in the last three years

- Linking index insurance to credit or loans is often found to be beneficial in implementation (as is sustained stakeholder engagement and simulation exercises)

Weather Based Index Insurance

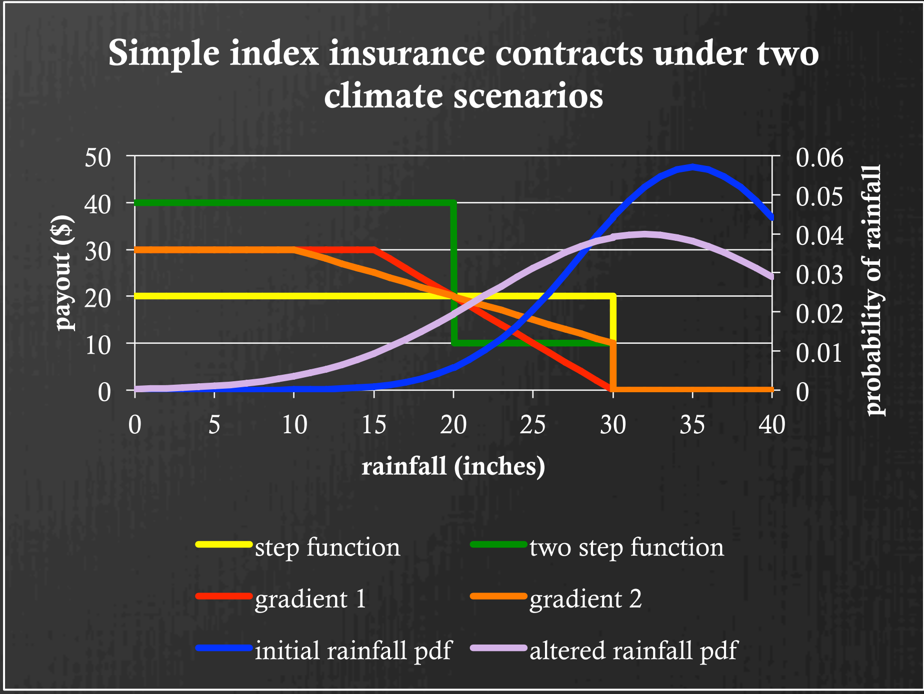
- Definition: Weather/Climate Based Index Insurance is based on a geophysical index correlated with a particular type of hardship (egs. crop losses from drought or flooding) rather than verified losses
  - Potential indices include; rainfall (gauge or satellite), streamflow, reservoir level, temperature, vegetation greenness (NDVI)
- Contracts payout at specified trigger/strike levels (rather than on the basis of verified losses)
- Advantages
  - Fast payout potential (compared to loss insurance)
  - No moral hazard (no incentive to commit insurance fraud)
  - Lower transaction costs (compared to loss insurance)
- Disadvantages/Limitations
  - Only addresses certain types of risk
  - Basis risk (low yield but no payout) – connected to trust
  - Default risk (not enough premium to cover costs) – connected to non-stationary of climate system
- Potential as an adaptation tool in the developing world where insurance infrastructure is limited or non-existent
- Can enable farmers to take riskier, but higher potential yield decisions that can alleviate poverty

- Actuarially fair premium depends on the product of probability and payout function
- Multiple payout functions are possible

$$P_d = \int_0^{rstrike} p(r)\,y(r)\,dr$$

$$P_f = \int_{rstrike}^{\infty} p(r)\,y(r)\,dr$$

Price	Step	2 step	Gradient 1	Gradient 2
Initial (wetter) climate	$4.76	$2.86	$1.72	$3.24
Altered (drier) climate	$8.41	$7.66	$5.40	$7.03



Intent and Motivation

- Scope/Intent: To explore the potential of weather/climate based index insurance as an adaptation tool for farmers in the West African Sahel nations of Mali, Burkina Faso and Niger

- Human/Social Motivation
  - the West African Sahel is one of the poorest regions of the world, and as roughly 80% of the population is engaged in agriculture and/or livestock cultivation (mostly subsistence), faces significant climate related exposure and vulnerability. There is significant human need for effective adaptation to climate risks.

- Natural Science Motivation
  - the West African Sahel has experienced significant climate variability on a range of time scales. Consequently, long term extrapolations about the region's climate are scientifically difficult. Understanding how extreme event frequency and index insurance pricing may respond to this context may prove beneficial regionally and may offer larger lessons to be applied to other index insurance projects elsewhere.

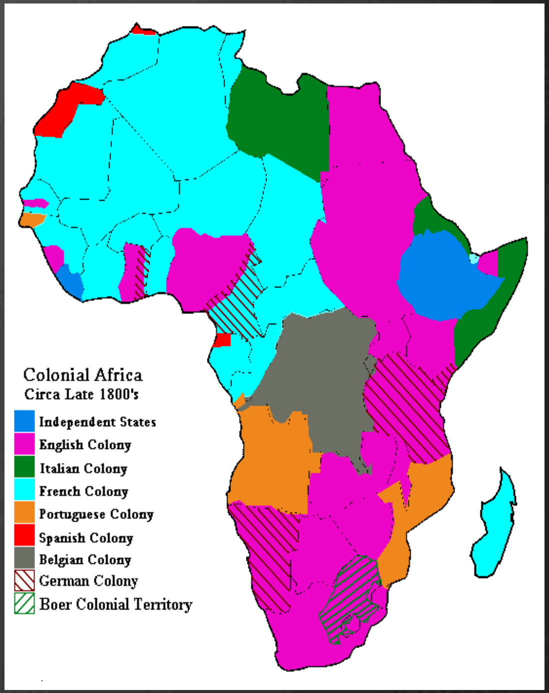
Research Questions

- Social Science Research Questions
  - How has, how can and what are the potential challenges to using index insurance as a means of climate risk management – both broadly and more specifically in a West African Sahel context?
  - Who are the most appropriate potential user populations of index insurance?
  - What is the extent, nature and spatiotemporal variability of adaptive capacity, vulnerability and resilience to climate related risks in the West African Sahel?
  - What are other existing climate risk management practices and how might those approaches interact with proposed or existing insurance policies?

- Natural Science Research Questions
  - What attributes make a geophysical index optimal for index insurance contract design? Taking a historical approach to studying potential indices, what can be learned about their potential performance?
  - How has the region's hydro-climatology varied in the past? What can be learned about the characteristics of the region's past climate and hydrology from existing data?
  - How do potential indices, the implicit payout frequency and price evolution respond to systematic changes in regional hydro-climatology and the region's multi-decadal variability?
  - On the basis of global climate model projections, what are the anticipated changes to the region's hydro-climatic means and variability? What implications do these changes in the mean, variability and shape of the hydro-climatic distributions carry for the long-term viability of index insurance?

Post-Colonial Legacy

- Mali, Burkina Faso and Niger were all former French colonies (very limited freedoms and infrastructure development during colonial era) – gained independence in 1960
- Very diverse populations (many indigenous ethnicities and over 100 languages)
- Post-colonial exploitation through IMF structural adjustment programs, debt burden and appropriation of mineral wealth by multi-national corporations
- Regional politics effected by many factors: internal conflicts between different groups, need to attract foreign investment/need to avoid dependence on foreign aid, climate vulnerability, extremism



empathosnationalenterprises.com

Poverty and Double Exposure

- Global Challenges
  - Per capita GDP low (average between 700 and 1600 USD/year PPP), roughly half the population living on less than $1.25/day
  - Short life expectancy (low to mid 50s), high infant mortality rate
  - Very high fertility rate (TFR above 6 regionally)/young population (median age ~16)
  - ~80% of population engaged in agriculture and/or livestock – mostly subsistence; high exposure to negative impacts of droughts and floods
  - Environmental health risks; meningitis, malaria

- Intra-Societal Challenges
  - Conflicts between farming population and pastoralists (eg. Tuareg "rebellions")
  - Rise of regional "Islamic" extremism – northern Mali 2012, AQIM
  - Strongly patriarchal society; limitations on women's mobility and freedom

Vulnerability and Resilience as Social Constructs

- Drought vulnerability
  - Most of the rural and pastoral populations (famine/ malnourishment risk, food price volatility, weakened immune system ->vulnerability to diseases)
  - Can effect urban areas if the famine is widespread enough
  - Differential vulnerabilities on the basis of gender, wealth, other factors
- Flooding vulnerability
  - Particularly for city dwellers and irrigated farmers (displacement, drowning, crop devastation, disease)
- Farming Adaptations
  - Zai farming
  - Stone lines
  - Improved crop varieties
  - Fertilizer use
  - Labor migration
- Pastoral Adaptations
  - Shifting to smaller livestock varieties
  - Manure fertilizer for pastureland
  - Climate induced migration
  - Labor migration

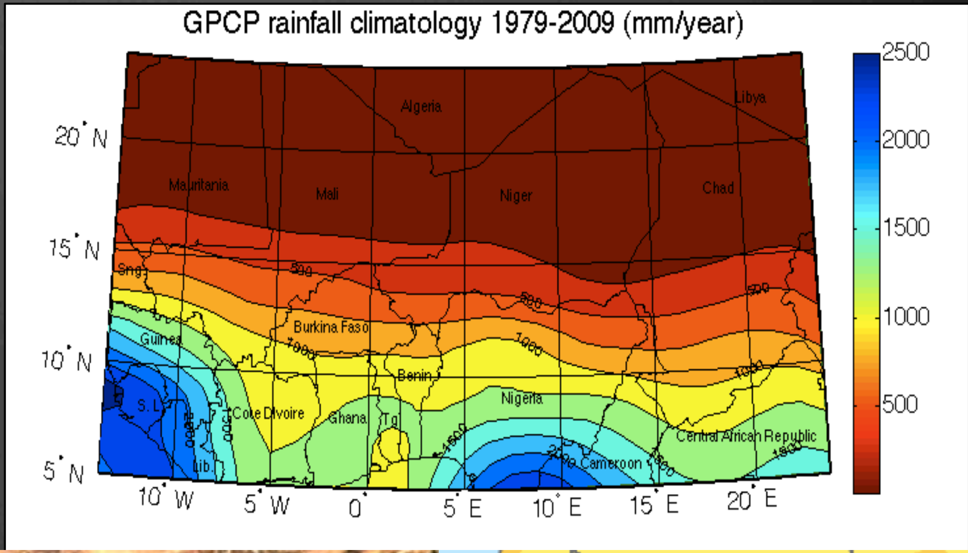
Zai techniques improve soil fertility

Reij et al. 2009

FAO

Regional Climatology: Spatial Patterns

- Strong south to north precipitation gradient (part of global pattern of humid tropics and arid subtropics – Hadley circulation)
- Weaker west to east precipitation gradient
- Precipitation and vegetation cover effect population density



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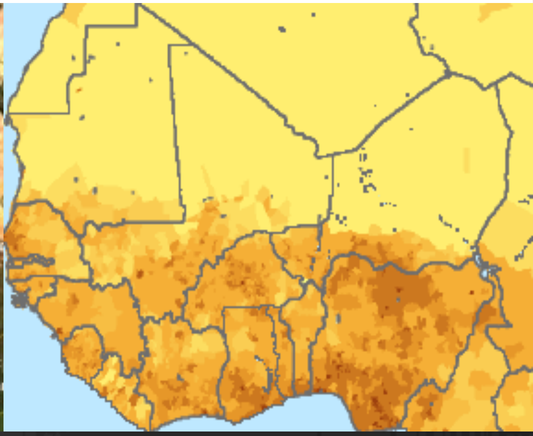
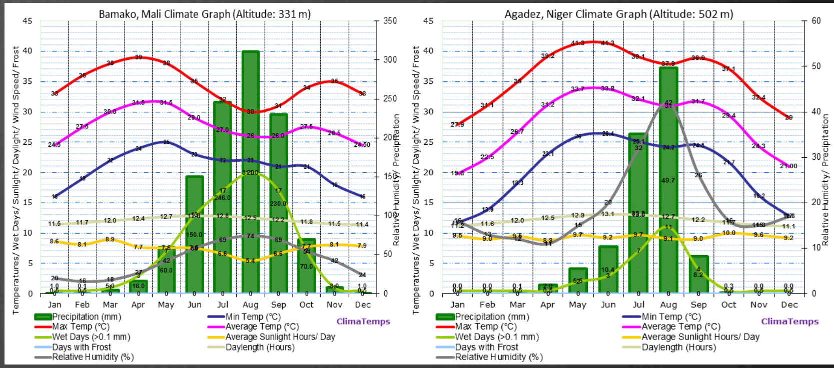


sedac.ciesen.org

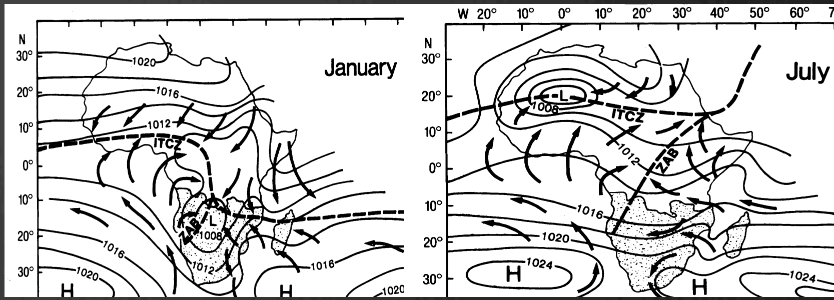
Regional Climatology: Seasonal Cycle

- For the Sahel, rainy season is uni-modal (points further south have bimodal rains) in boreal summer (June-October)
- Hot all year round (every month average highs at least 30C, with April/May highs averaging above 40C in some locations), but temperatures suppressed a little during rainy season and boreal winter
- Planting season for rainfed crops starts shortly after monsoon begins and harvest is in boreal autumn – too dry the rest of the year
- Seasonal cycle can have a "false" onset; dry spell risk within the rainy season is another livelihood vulnerability
- Points further south have more rain per month and a longer rainy season
- Seasonal cycle caused by northward migration of Intertropical Convergence Zone; advection of moisture laden air from Gulf of Guinea into North African interior and convection over thermally induced low pressure region



Bamako, Mali; 12.7N   Agadez, Niger; 17N

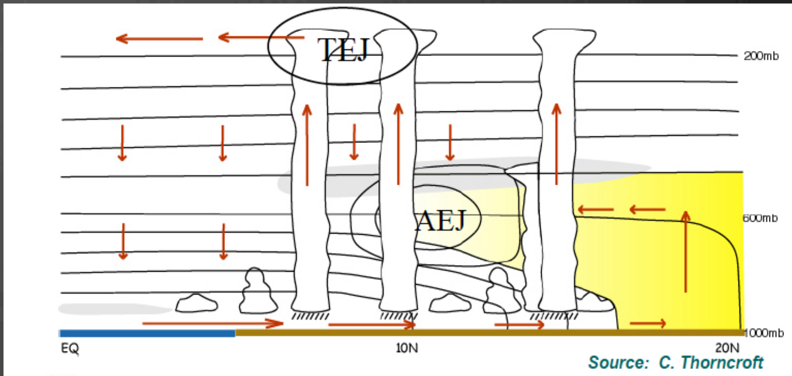
climatemps.com

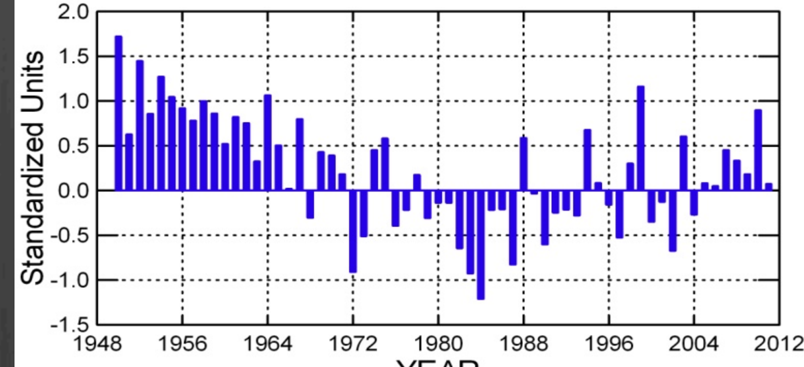


from Trzaska, 2008

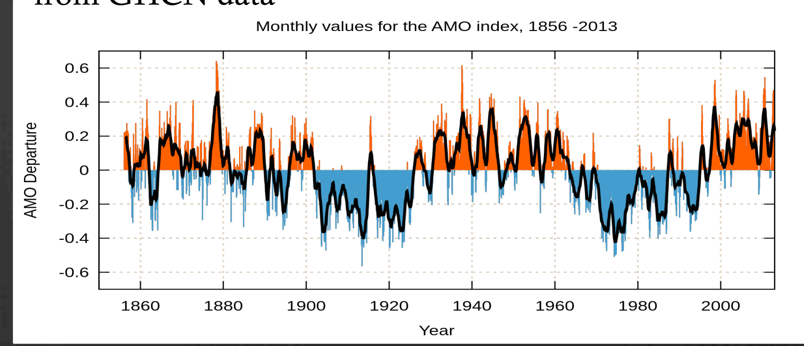
Regional Climate Variability

- Seasonal cycle also modulated by the strength of the Tropical Easterly Jet and the African Easterly Jet
- Inter-annual variability a function of temperature/pressure gradient between Gulf of Guinea and Sahara, some ENSO related variability
- Multi-decadal variability strongly connected to Atlantic Multi-Decadal Oscillation (warm phase connected to wet Sahel and vice versa)
- 30% reduction in regional rainfall from 1950s/60s to 1970s/80s
- Biophysical feedbacks through changes in vegetation cover can self-amplify
- Paleo-climatic evidence of large changes in regional hydroclimatology in the past (African Humid period before 5000 ybp, very dry period after)





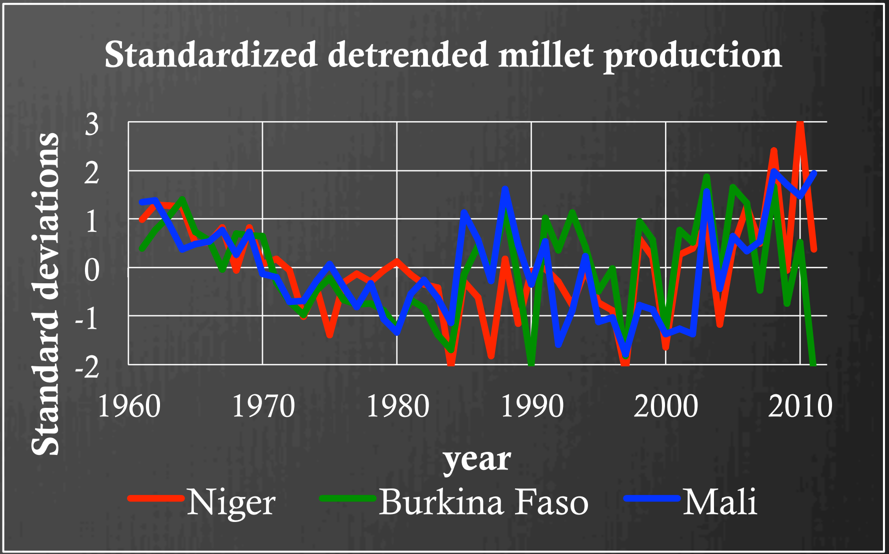
from GHCN data

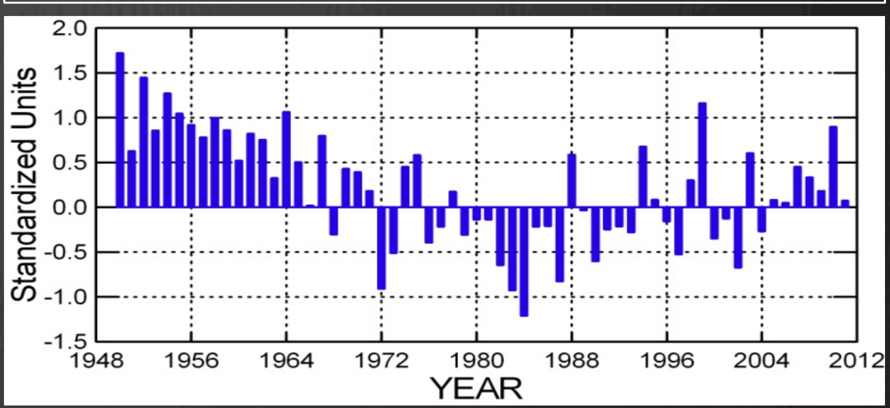


Climate Data Center, NOAA

Index Data

- Agricultural
  - FAOSTAT data* (1961-2011) for national production, yield and area harvested (millet, irrigated rice)
  - Countrystat data (1984-2011) for subnational production, yield and area harvested
- Meteorological (rainfall)
  - NOAA Precipitation over Land (PRECL); interpolated gauge product (1948-2012)
  - Global Historical Climate Network (GHCN); station (1950-present)
  - Global Precipitation Climatology Project (GPCP); satellite (1979-2012)
- Hydrological
  - Streamflow records from three locations along the course of the Niger River (Koulikoro, Dire and Niamey) from the Niger Basin Authority (1950-2009)
- Remotely Sensed
  - Normalized Difference Vegetation Index (NDVI) from the Advanced Very High Resolution Radiometer (AVHRR) (1981-2010)
- ENSO indices
  - NINO1+2, NINO3, NINO3.4, and NINO 4 (1950-present)

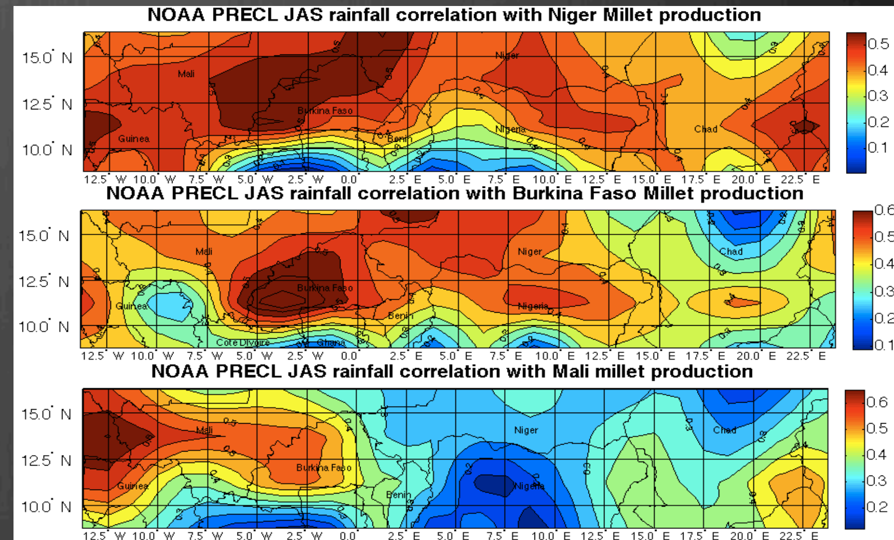




- Focus on national scale data because of better length/ consistency of record
- Focus on millet because it is the most widely grown crop in the region for subsistence
- Focus on irrigated rice because it is the most vulnerable to flooding
- Raw production data is strongly trended because of the four fold increase in population over the last 50 years

Correlation Analysis: Ag/Met&Hyd

- Robust correlations between NOAA PRECL JAS rainfall and de-trended millet production for all three nations (basis for drought risk insurance)
- Nationally aggregated GHCN JAS rainfall indices also showed correlation with de-trended millet production (basis for drought risk insurance)
- GPCP was not as robust
- NDVI showed some correlation, but wasn't generally as robust
- ENSO showed weak correlations
- December/January streamflow in Niamey showed a pronounced negative correlation with Niger irrigated rice production (basis for flood insurance)

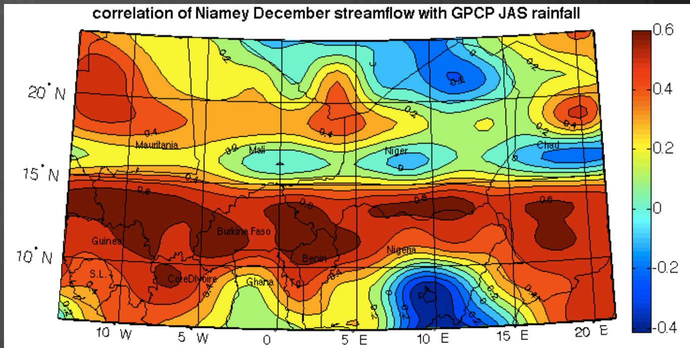


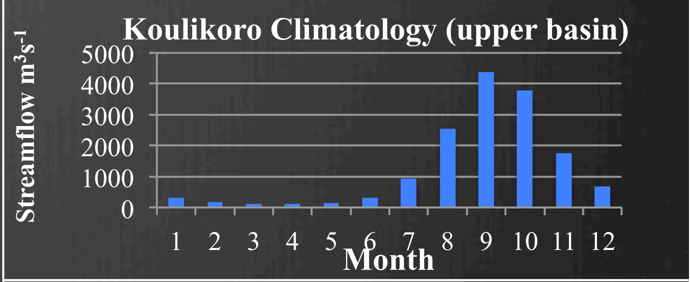
Pearson correlation	Niger GHCN	Burkina Faso GHCN	Mali GHCN
millet area	**0.39**	**0.436**	0.273
millet yield	**0.533**	**0.444**	0.244
millet production	**0.48**	**0.616**	**0.493**

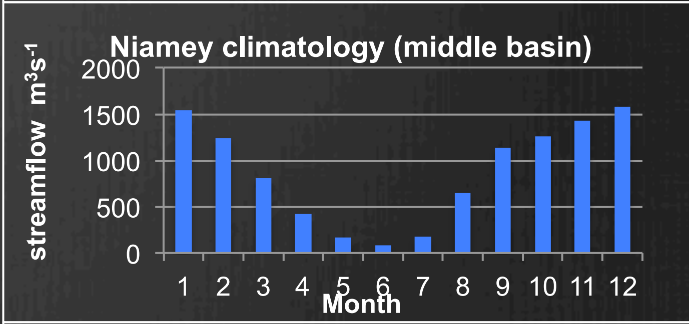
Pearson correlation	Koulikoro September	Dire November	Dire December	Niamey December	Niamey January
Rice area	**-0.437**	**-0.449**	**-0.477**	**-0.527**	**-0.418**
Rice yield	**-0.286**	-0.243	-0.262	-0.223	**-0.317**
Rice production	**-0.505**	**-0.534**	**-0.550**	**-0.571**	**-0.534**

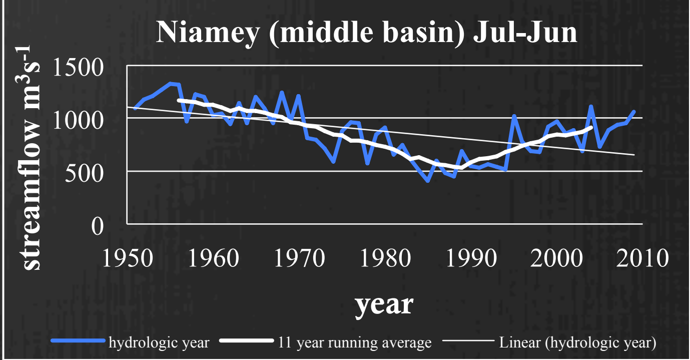
Niger River Analysis

- Historical Analysis
  - Rainfall across 12-15 N especially correlates well with Niamey streamflow
  - Peak flood month depends on point in course of river (upper basin is September, but Dec/Jan in Niamey)
  - Streamflow over time mimics rainfall pattern
  - Strong autocorrelation (0.5-0.75)
  - Much more streamflow variability since 1970s than in 1950s and 1960s (partly rainfall and partly runoff coefficient)





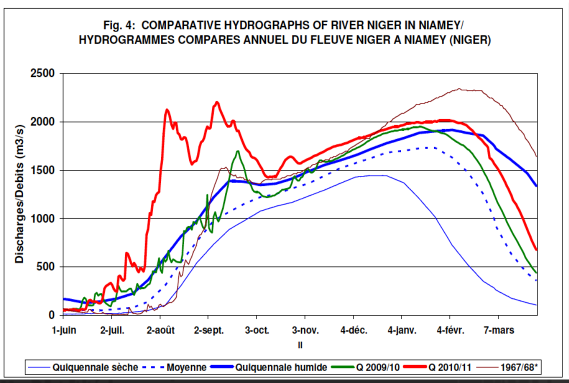


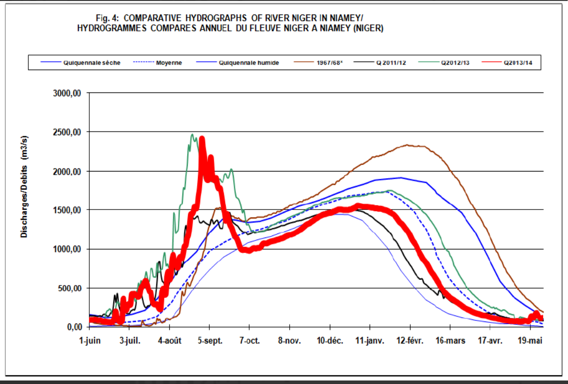


Recent Flooding

- Extreme flooding in JASO in middle and lower Niger Basin in recent years (2010, 2012 and 2013)
  - Displacing hundreds of thousands
  - Other related flooding events in Senegal, Burkina, etc.
  - Correlated to heavy but not truly exceptional rainfall

Guardian



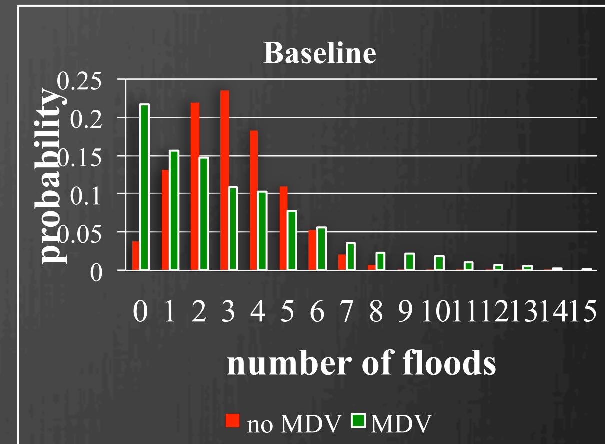


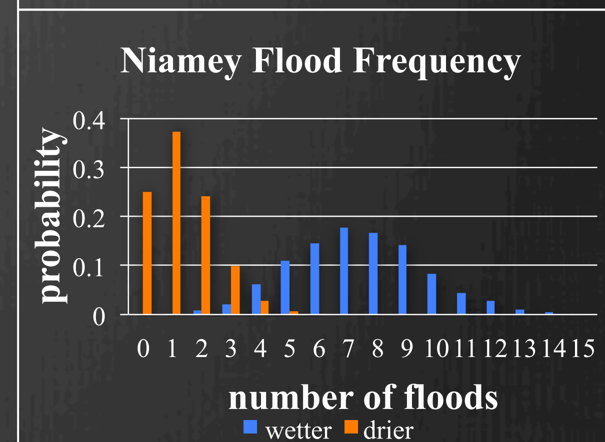
Niger Basin Authority

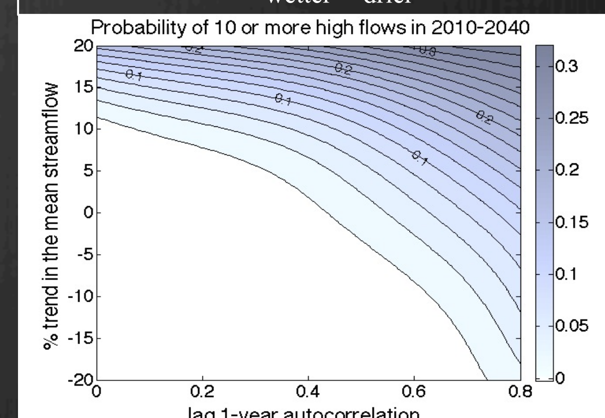
dutchwatersector.com

Monte Carlo simulation with and without MDV

- 1000 31-year streamflow simulations (2010-2040); (stochastic inter-annual variability sampled from the normal distribution)
- +/-20% trend in mean streamflow
- 90th%ile streamflow (1 in 10 flood) was explored
- Frequency of a given number of threshold crossing flood events is shown
- Multi-decadal variability is modeled with an autoregressive process from lag-1 year autocorrelations ranging from 0 to 0.8 on a spectrum from -20% trend to +20% trend in mean streamflow
- Expected value of extreme events highly sensitive to trend
- Probability of a large number of extreme events (10+ in a 30 year period) is highly dependent on trend and MDV





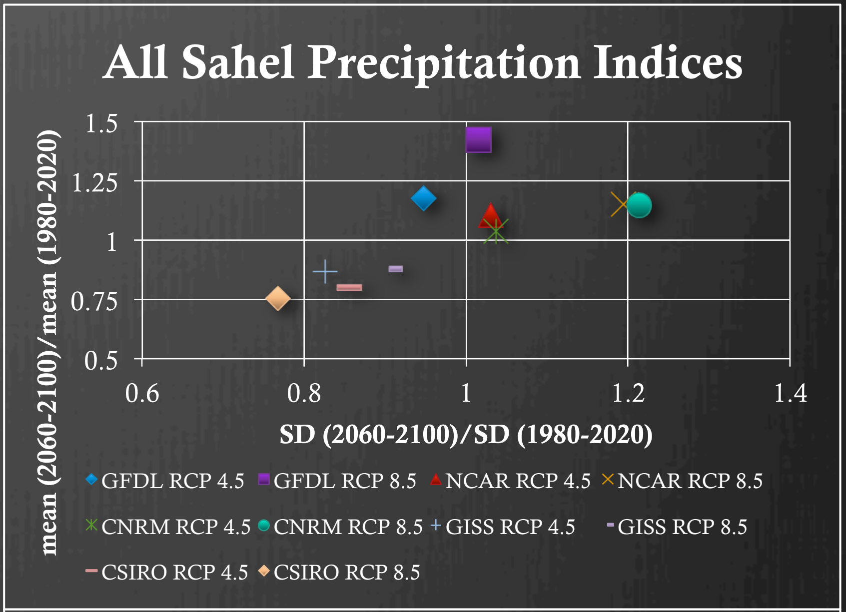


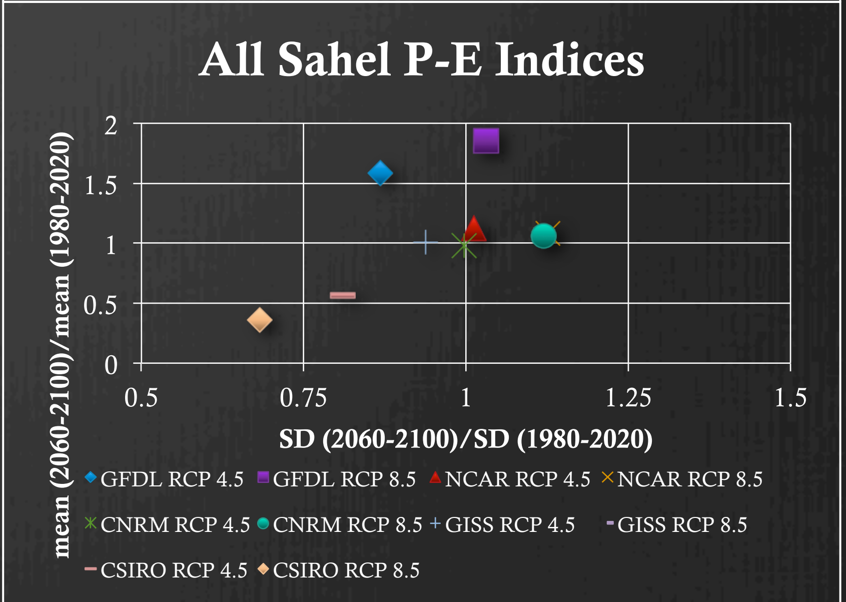
Scientific challenges for modeling West African Climate dynamics

- Uncertainties in future and dynamics of AMO
- Uncertainties in future of ENSO and other tropical SSTs
- Sharper temperature contrast between Sahara and Gulf of Guinea will increase wind velocities (moisture flux), but higher temperatures also imply higher threshold for precipitation
- Biophysical feedbacks on moisture availability, strength of African Easterly Jet
- Uncertainties about evaporation; higher temperatures imply higher potential evaporation, but actual evaporation depends on water available
- Global Climate Models (GCMs) don't reach a consensus on projected trends for regional hydro-climatology; need to engage models with diverse outcomes

GCM data

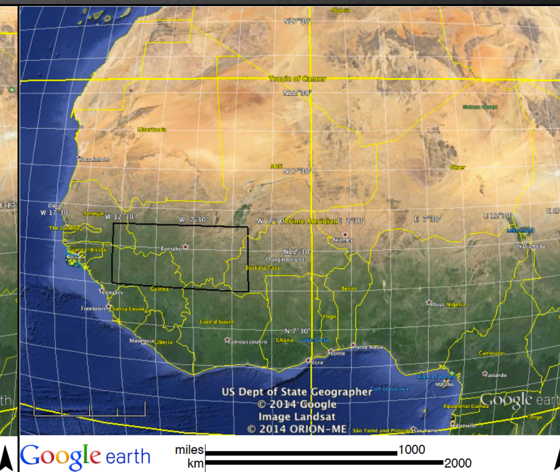
- JAS precipitation, evaporation and precipitation-evaporation (P-E)
  - GFDL CM3 (coarse res): strong wetting
  - NCAR CCSM4 (fine res): moderate wetting
  - CNRM CM5 (fine res): moderate wetting
  - GISS E2H (coarse res): moderate drying
  - CSIRO MK 3.6 (intermediate res): strong drying
- All Sahel Indices (10-20N, 15W-20E)

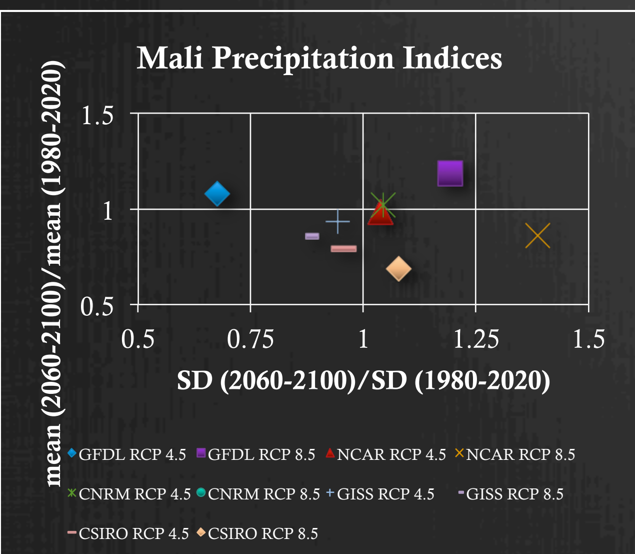


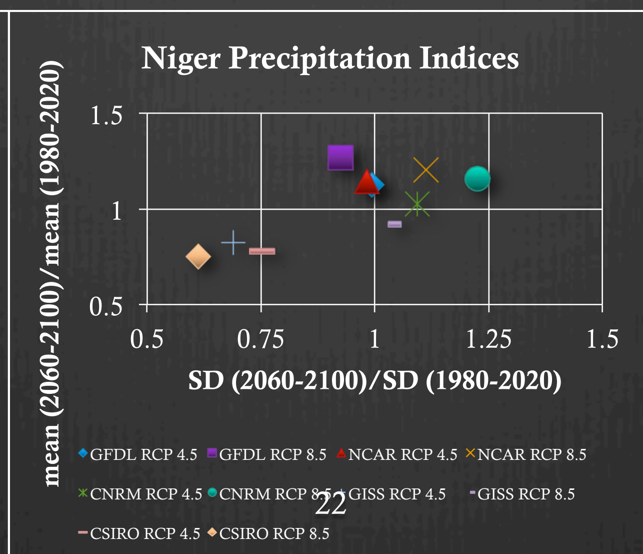


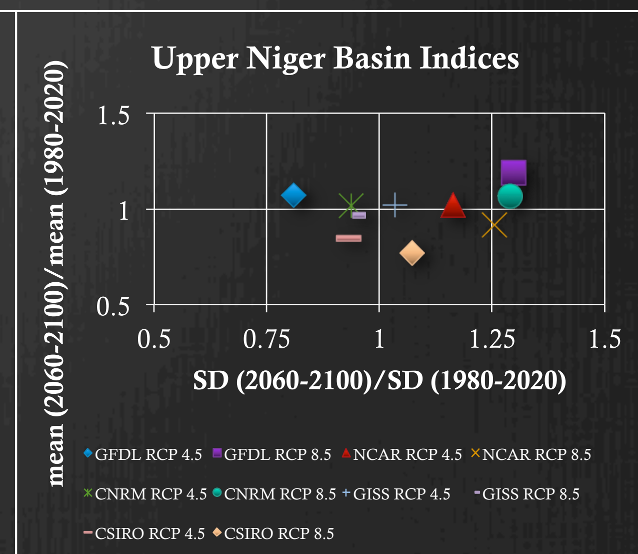
GCM Country/Region Specific Indices

- Mali (12-4W, 12-15N), Burkina Faso (5W-2E,12-15N), Niger (0-15E, 12-15N)
- Upper Niger Basin (13-4W, 10-14N); based on rainfall/ streamflow correlation
- Generally drier trends for Mali than for Niger



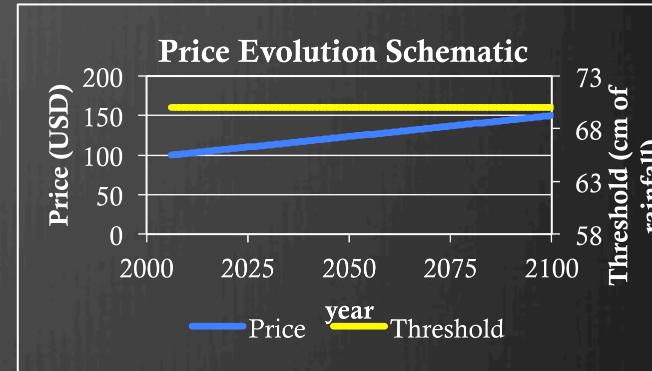


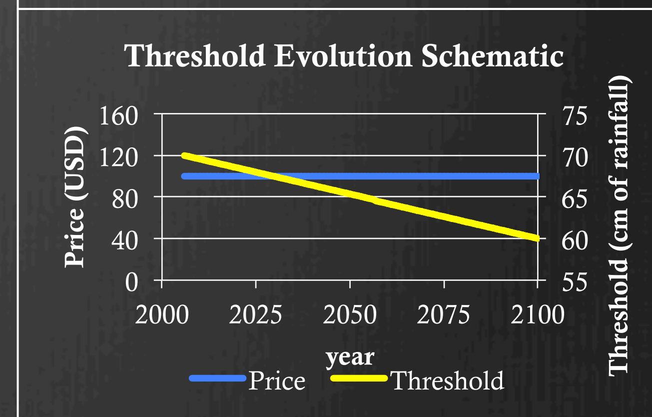


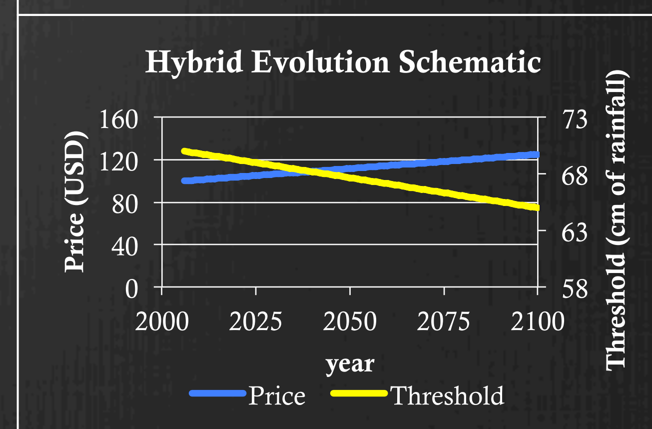


Index Insurance Evolution Under Climate Change

- Price evolution: threshold stays the same, but premium price evolves with a changing climate
- Threshold evolution: premium price stays constant, but the strike level at which the insurance pays out evolves with the changing climate
- Hybrid evolution: premium and threshold are both allowed to vary
- Practically, there may be limitations to either; preferences would depend on data quality/modeling capability, availability of alternative adaptations and stakeholder interests

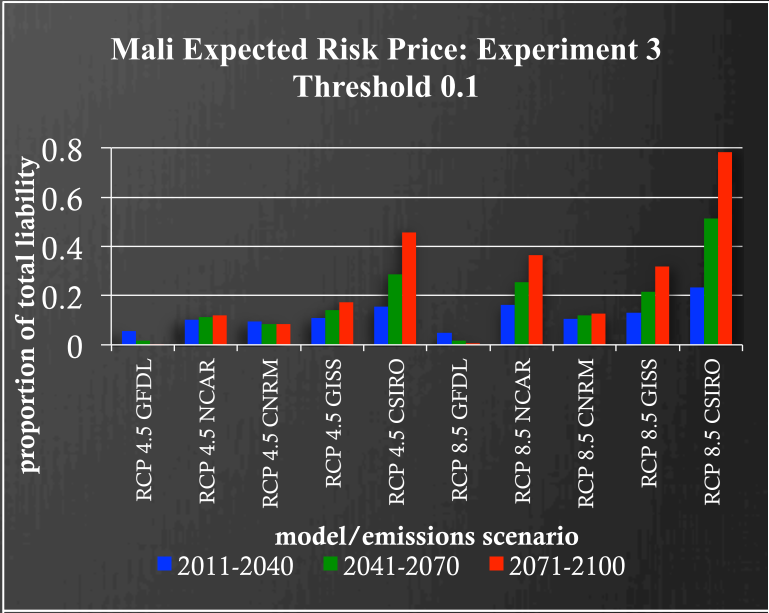


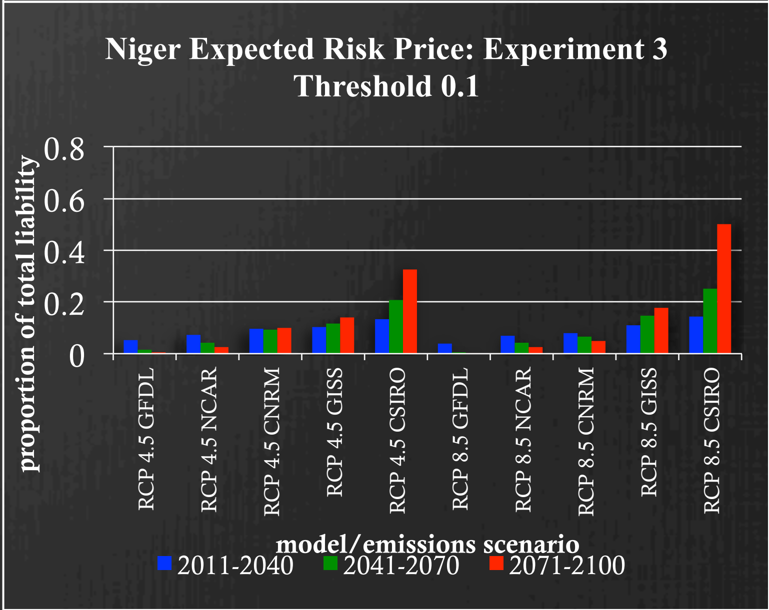




Monte Carlo Simulations with GCM data

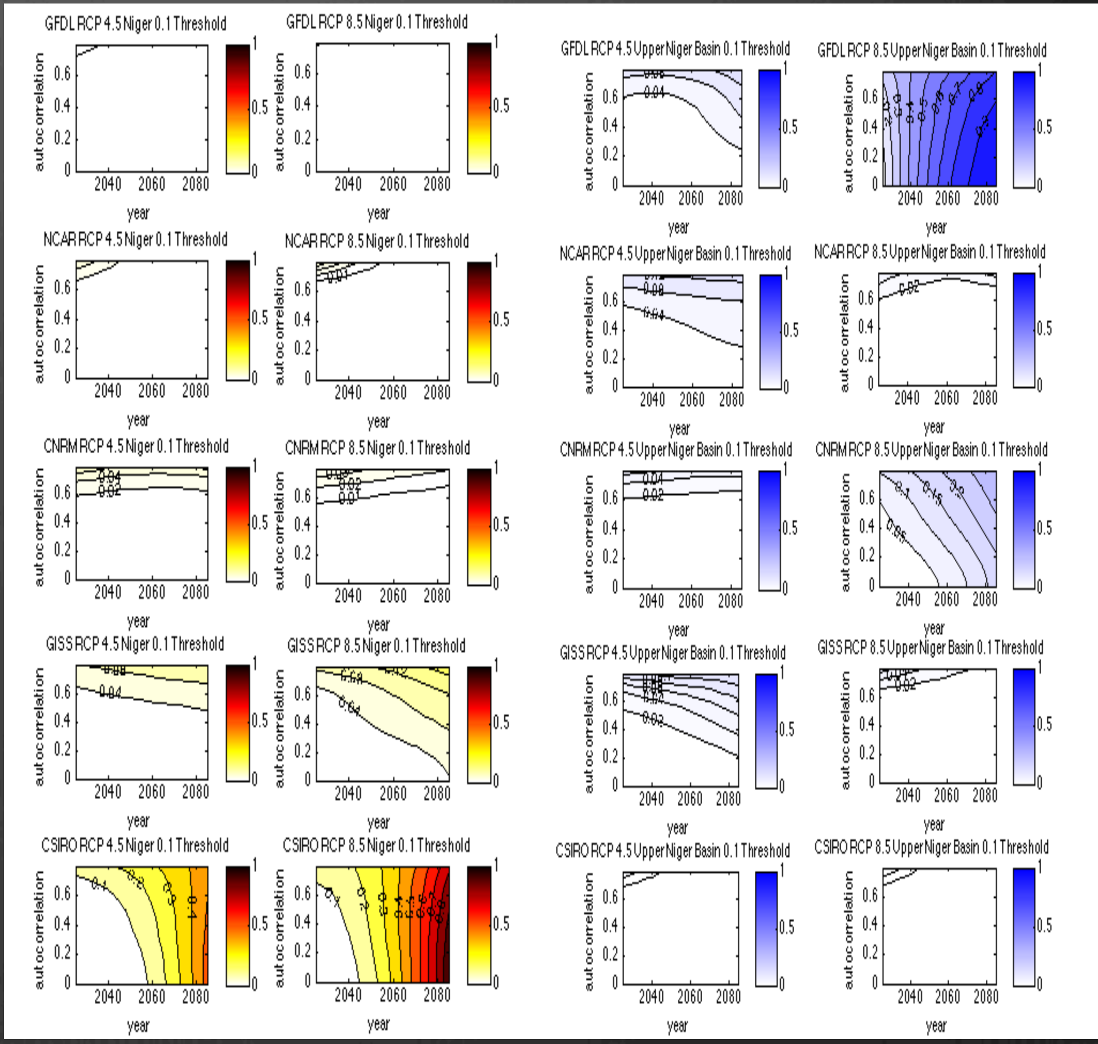
- 1000 95 year Monte Carlo simulations (stochastic, normally distributed inter-annual variability) with trends in the mean and SD of precipitation based on GCM output
- Experiment 1: standard deviation change only
- Experiment 2: mean change only
- Experiment 3: standard deviation and mean changing
- All Sahel index threshold 0.2, 0.1, three country specific boxes (drought frequency) and Upper Niger Basin box (flood frequency)
- Step function insurance model – in an evolving index insurance framework, actuarial premium is (total liability*expected probability of payout)
- Mean changes more important than variability changes in affecting probability of extreme events and expected risk/actuarial price





GCM trends, MDV and default risk

- Changes in mean and standard deviation from GCMs imposed from Experiment 3
- Lag 1 year autocorrelation ranging from 0 to 0.8 to simulate MDV
- Probability of 10+ extreme events in a 30 year period modeled
- Results are model, threshold and region dependent
- Trend in mean matters more than trend in variability
- Most extreme scenarios cause new "normal" to be beyond extreme event threshold



Probability of 10+ droughts in 30 years

Probability of 10+ floods in 30 years

Conclusions

- Rainfall based drought index insurance has potential to address losses experienced by millet farmers across the region
- Stream-flow based flood index insurance has potential to address losses experienced by irrigated rice farmers in Niger
- Actuarial price of insurance/expected frequency of payout is more dependent on trends in mean rainfall or stream-flow than trends in variability
- Even from a neutral state, multi-decadal variability has a significant impact on the probability of a large number of extreme events in a short period (default risk); this may effect index insurance loading costs
- Modeling study results are highly heterogeneous depending on time horizon, model forcing and sub-region dynamics
- An adaptive framework based on an evolving understanding of regional climate and sustained stakeholder engagement is encouraged
- The most extreme climate scenarios (+/20% or more change to the mean) are likely to render index insurance financially unsustainable or limit practical utility
- Index insurance, even in more modest climate change scenarios is not a panacea – must be integrated with other adaptive practices, international investments and local knowledge

Future Work

- Pursue index insurance for risks to livestock for pastoralists
- Integrate sensitivity to gender related vulnerability (insurance for female cowpea farmers)
- Pursue index insurance for reservoir/water management
- Integrate with existing and/or developing index insurance
  - Engage user preferences for contract evolution and strike level decisions
  - Link contract design more explicitly with loans or credit
  - Engage different types of contract design more explicitly based on preferences and best practices
- Model water balance more explicitly – factoring in the impact of heat stress on crop production
- Represent MDV through more sophisticated means (ARMA, ARIMA, dynamical models (as dynamical understanding matures))
- Seek better understanding of hydrological response to precipitation as a function of land cover change
- Model temporal evolution of higher order statistical moments (skew, kurtosis)
- Explore paleo-climate record to understand historical analogs

Literatures

- Climate change and extremes (IPCC, Meehl, Field)
- Adaptation, vulnerability, hazards (Mitchell, Leichenko, O'Brien, Adger, Ribot)
- Insurance/index insurance (Mills, Kunreuther, Osgood, Skees)
- Political ecology, post-colonial discourse (Watts, Batterbury, Tschakert)
- Gendered discourses of vulnerability and resilience (Schroeder, Alidou, Tall)
- West African and tropical climate dynamics/variability (Giannini, Ward, Sultan, Ali, Ndiaye, Lebel, Charney, Cane)
- Statistical methods, extreme event quantification (Katz, Zwiers, Kharin)
- Global and regional climate modeling (Biasutti, Gianinni and others)

- -Siebert, A., (2014). Hydroclimate Extremes in Africa: Variability, Observations and Modeled Projections", Geography Compass, Vol. 8 (6), pp. 351-367.
- -Siebert, A. and Ward, M. N. (2013). "Exploring the frequency of hydroclimate extremes on the Niger River using historical data analysis and Monte Carlo methods". ***African Geographical Review***, online publication.
- -Siebert, A. and Ward, M. N. (2011). Future occurrence of threshold crossing seasonal rainfall totals: methodology and application to sites in Africa. ***Journal of Applied Meteorology and Climatology*** **50**, 560–578.

Thanks Merci Fofo

- Advisor(s): Professor David Robinson, Dr. M. Neil Ward
- Dissertation committee: Professors Robinson, Ward, Leichenko, Rennermalm
- Professor Ken Mitchell, CAS director Professor Ousseina Alidou
- Geography Department
- African Center for Meteorological Application to Development (ACMAD); Mohamed Kadi, Lazreg Benaichata, Dr. Leonard Njau: AGRHYMET; Abdou Ali, Bonaventure Some: Niger Basin Authority (ABN); Ibrahim Olomoda: UNDP GEF office; Katiella Mai Moussa
- AMMA (2012), WCRP (2010, 2011), AAG Climate Specialty Group (2012), IRI (2006-2008), Columbia MA program in Climate and Society (2005-2006)
- Extended family and friends
- Parents

Gerrity Skill Score analysis

- Need for a metric of skill beyond correlation analysis to retrospectively model specific match between payouts and impacts
  - "false payouts" (i.e. when the index value triggers a payout, but impact is not that adverse) is a concern to the insurer from the standpoint of long term viability and default risk
  - "false failures to pay"/basis risk (i.e. when the impact is adverse, but there is no payout) will undermine trust in the index insurance and will effect participation rates
- The Gerrity Skill Score is a metric that measures this skill more explicitly than Pearson correlation
  - GSS = 0 has no skill (same as guessing on the basis of climatology), GSS = 1 has perfect skill, GSS = -1 is wrong every time;
  - GSS> 0.3 relatively good
  - Niger and Burkina millet/GHCN
  - Niger and Burkina millet/NOAA PRECL
  - Niger rice production/Niamey Dec. streamflow

$$a_q = \frac{1-\sum_{r=1}^{q} p_r}{\sum_{r=1}^{q} p_r}$$

$$s_{ii} = \frac{1}{\kappa}\left(\sum_{q=1}^{i-1} a_q^{-1} + \sum_{q=i}^{\kappa} a_q\right)$$

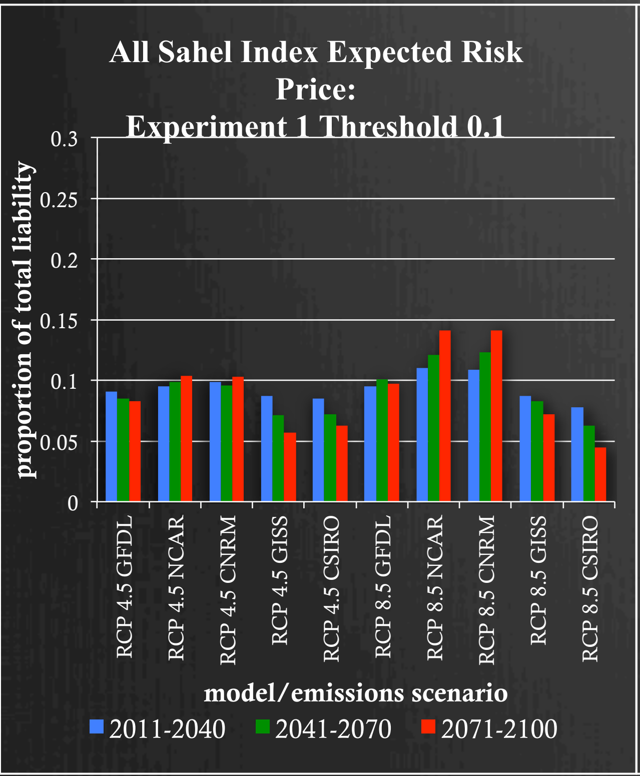
$$s_{ij} = \frac{1}{\kappa}\left(\sum_{q=1}^{i-1} a_q^{-1} - (j-i) + \sum_{q=j}^{\kappa} a_q\right)$$

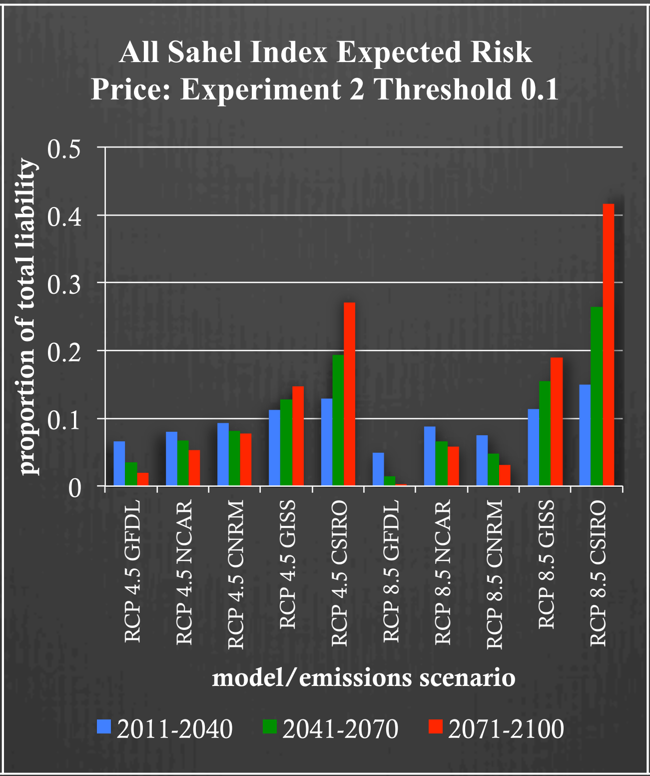
$$GSS = \Sigma p_{ij} s_{ij}$$

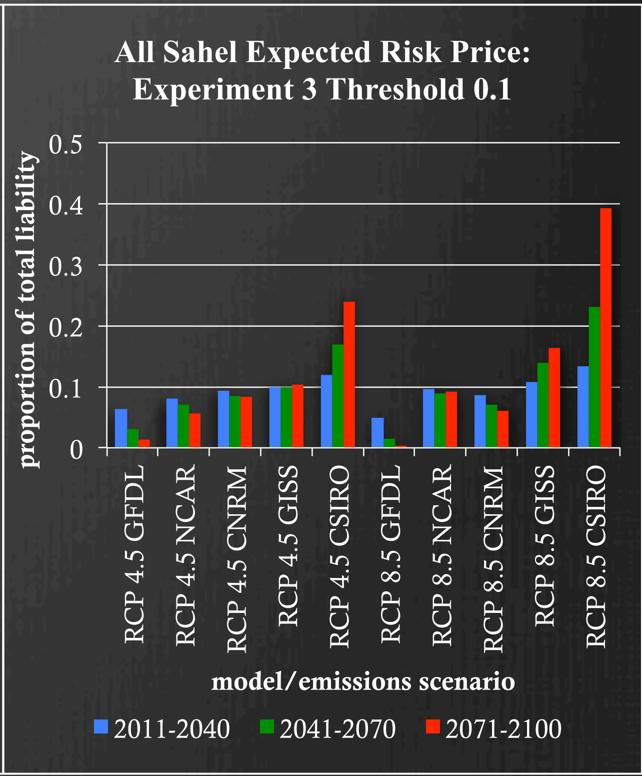
	Niger millet production	Burkina Faso millet production	Mali millet yield	Niger rice production
GHCN	0.557	0.756		
streamflow			0.395	0.352*
correct payouts	3	4	3	2
False payouts	2	2	5	3
Failures to pay	2	1	3	3

Gerrity score with NOAA PRECL	Niger	Burkina Faso
Millet yield	0.473	0.485
Correct payouts	3	2
False payouts	1	6
Failures to pay	3	1
Millet production	0.379	0.49
Correct payouts	2	3
False payouts	1	5
Failures to pay	3	2

Experiments 1, 2 and 3







More GCM/MDV results