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Modeling Approaches to Agricultural Crop Risk Quantification

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RMS Asia Initiative

**Singapore Actuarial Society Conference
“Managing Risk or Rolling the Dice?”**

Crop Risk Assessment, Quantification and Management

- Why is modeling agricultural crop risk important?
- What are the perils?
- What are the approaches for mitigating agricultural risk?
- How is agricultural risk managed?
- What are the modeling approaches and their pitfalls to quantify agricultural risk?
- Concluding remarks

Agricultural Risk

Part of Food Security and other Global Risks

Food Security

■ Definition :

- Food security exists “when all people at all times have access to sufficient, safe, nutritious food to maintain a healthy and active life” (World Food Summit, 1996).
- Food security exists “when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life” (FAO)

Interpretation: Availability at all times of adequate world supplies of basic foods to sustain a steady expansion of food consumption and to offset fluctuations in production and prices.

Largest Crop Producers

The New York Times

February 9, 2011

The World's Largest Crops

China is largely self-sufficient in food production and doesn't export much. But it produces and consumes some of the world's largest crops by far. And if recent droughts in China force the country to begin importing on a large scale, it could push the already rising prices of commodities like wheat even higher.

2009 PRODUCTION OF:

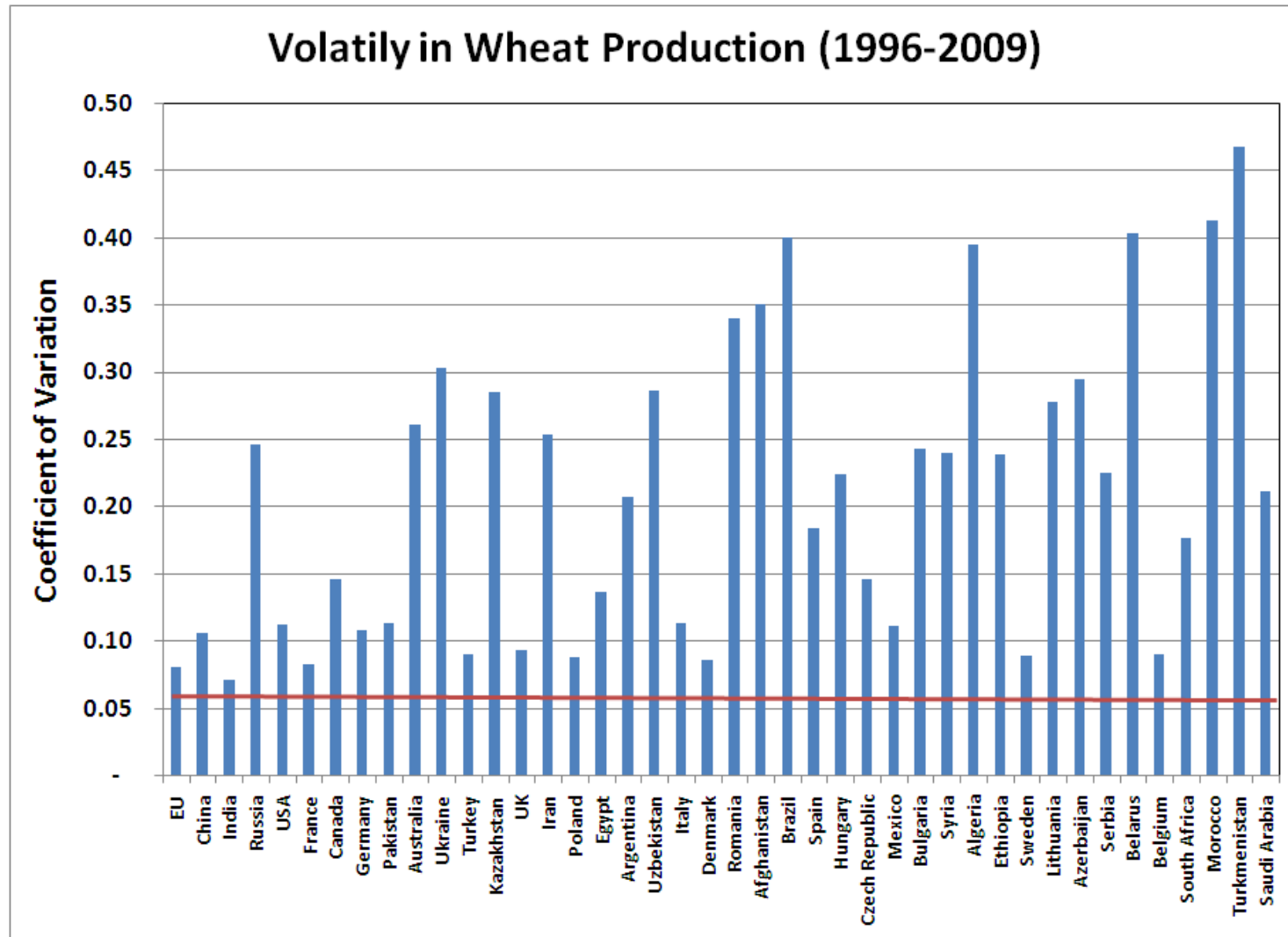
RICE	Millions of tons	World share
China	197	29%
India	131	19
Indonesia	64	9
Bangladesh	45	7
Vietnam	39	6
Thailand*	31	5
Myanmar*	31	4
Philippines	16	2
Brazil	13	2
Japan	11	2
Pakistan	10	2
United States	10	1

WHEAT			
China	115	17%	
India	81	12	
Russia	62	9	
United States	60	9	
France	38	6	
Canada	27	4	
Germany	25	4	
Pakistan	24	4	
Australia	22	3	
Ukraine	21	3	
Turkey	21	3	
Kazakhstan	17	3	

CORN			
United States	333	41%	
China	163	20	
Brazil	51	6	
Mexico	20	2	
Indonesia	18	2	
India	17	2	
France	15	2	
Argentina	13	2	
South Africa	12	1	
Ukraine	10	1	
Canada	10	1	
Romania	8	1	

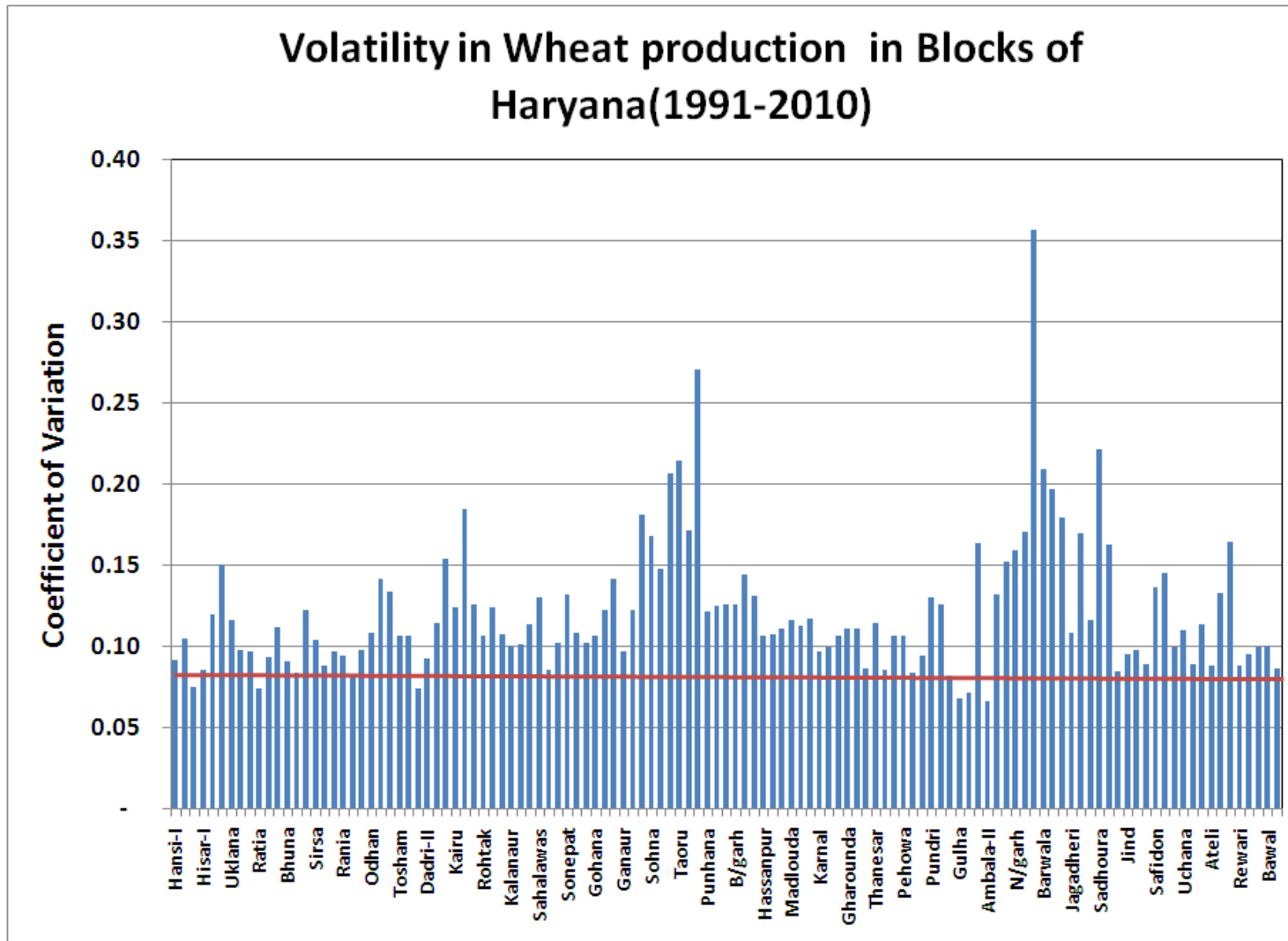
Source: United Nations Food and Agriculture Organization *2008 production.

Volatility in Crop Production (from statistics produced by International Grains Council)



Worldwide

Volatility in Crop Production at Region Level



Impacts of Volatility in Crop Production

- Micro – severe disruption of individual farmers, in particular in low income regions (suicides, etc.)
- Macro – at sovereign/regional level. Governments are the “payers”
- Global – impacts of shortage of crop production can result in socio-economic, political disruption

- Farmers need to adopt new technologies (take more risk)
- Need programs to mitigate the risks to farmers and governments

Agricultural Risk and Associated Perils

Main Agricultural Risks



China: Drought imperils world's biggest wheat crop

Keith Bradsher, New York Times
Wednesday, February 9, 2011



- Flood
- Drought
- Freeze
- Hail

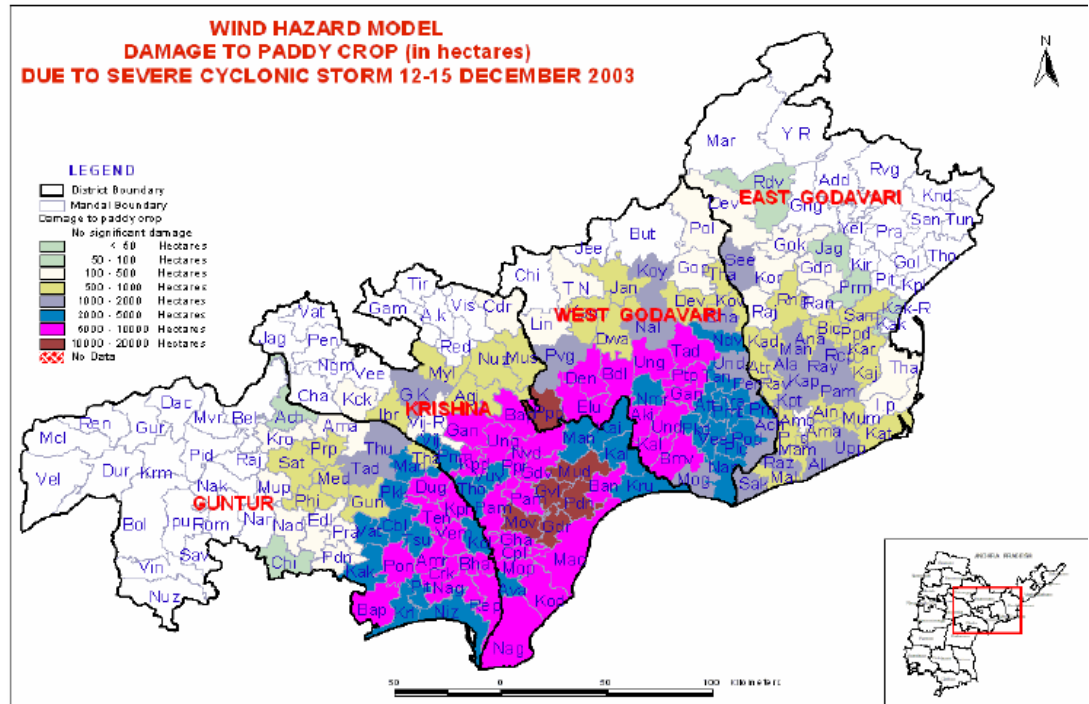
Cyclone And Agricultural Risk



04 February 2011 | 07:14:32 PM | Source: AFP

Flood-ravaged Australia was facing up to \$800 million in crop losses after a horror cyclone smashed through key banana and sugar farms, threatening inflation and exports, analysts said.

- Extreme winds
- Coastal surge and flooding (salt)
- Inland flooding



Other Perils

There are other perils which cause agricultural losses:

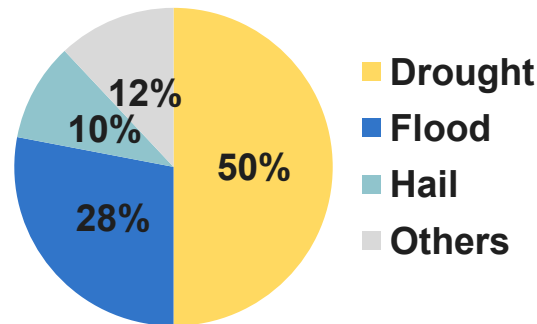
■ Natural Hazards

- Infestation
- Windstorm
- Earthquake
- Landslide
- Cloud Burst

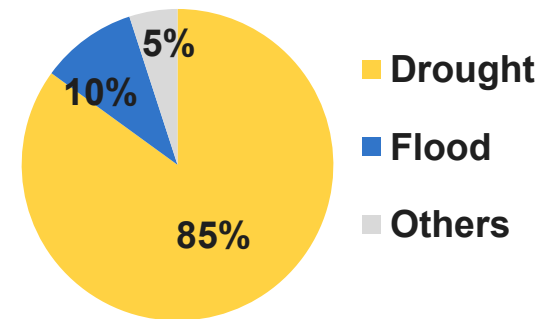
■ Man-Made Hazards

- Chemical and industrial
- Terrorism
- Speculation

**China Crop Losses
(1982-2002)**



**India Crop Losses
(1985-2003)**



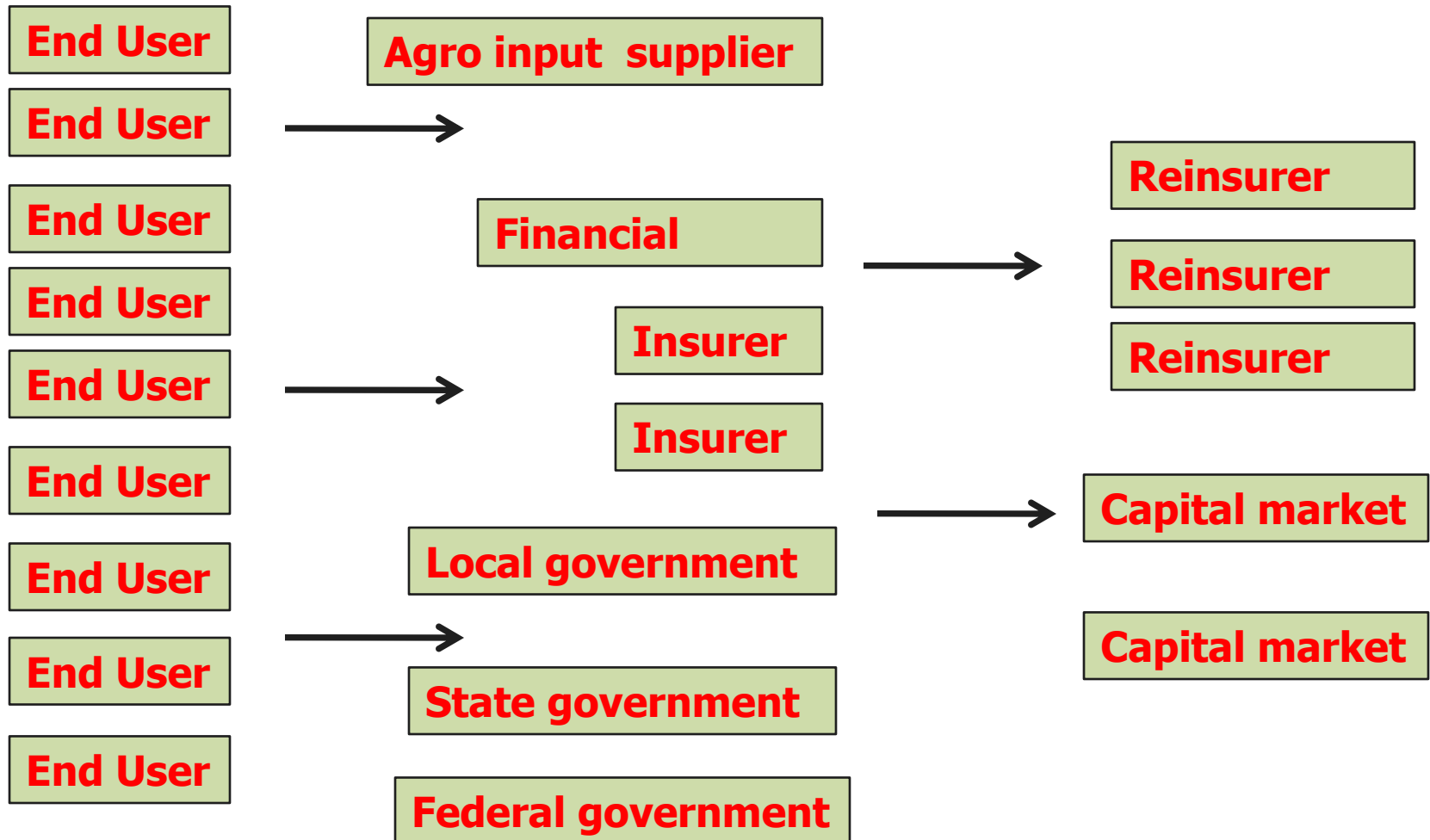
However, the major common perils for Asian agriculture are: drought (deficit rainfall or consecutive dry days), flood (excess rainfall), and temperature extremes in Asian countries

Approaches for Mitigating Agricultural Risk

Avenues for Mitigating Agricultural Risk

- Index-based weather risk insurance
 - Similar to Weather derivatives
 - **Trading contracts based on weather indices that correlate with particular agricultural risks (crop yield losses)**
- Traditional crop insurance
 - Human risk (health, life) for farmers
 - Asset (fixed properties) risk (fire, theft, other damage or losses in case of natural disasters) for farmers
 - **Production or yield risk (multi perils or named perils)**
 - Price risk (risk of falling or raising prices)
 - Institutional risk
 - Financial risk
- **Others avenues** to preempt or to reduce agricultural risks
 - Flood plain management, Irrigation
 - Crop diversification

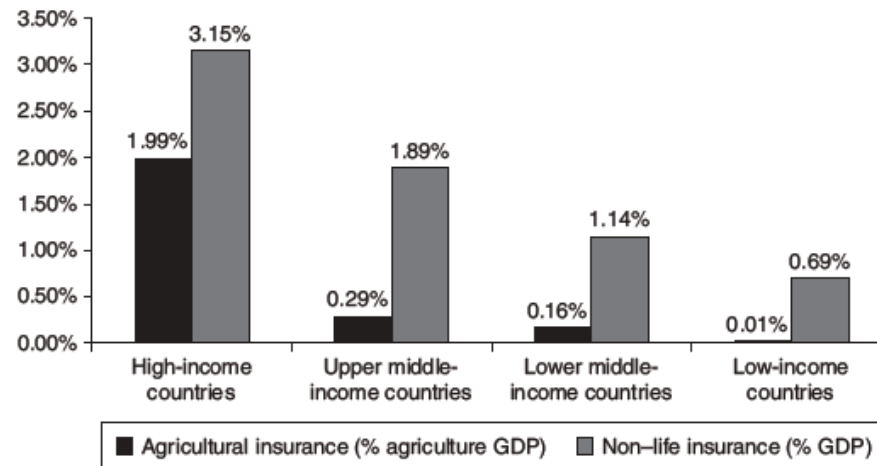
Stakeholders of Crop Insurance



Use of Insurance in Managing Agricultural Risk

- Crop insurance has operated for more than 35 years across more than 200 million hectares of agricultural land (Munich Re, 2009)
- However, most of the large crop producing countries have low market penetration of crop insurance (<10%) because ‘traditional’ crop insurance is not viable for small farming communities

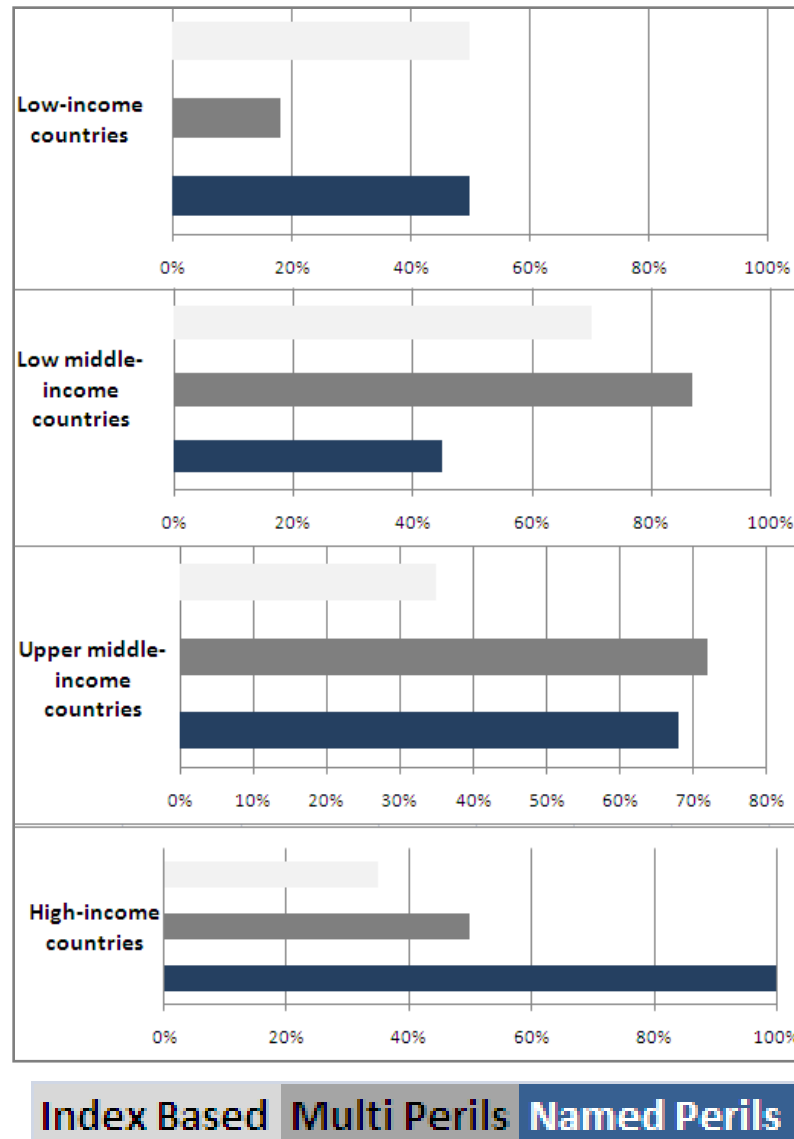
Figure 1.4 Penetration of Agricultural and Non-Life Insurance, by Development Status 2007



Source: Authors, based on Cummins and Mahul 2009; World Bank Survey 2008.

Availability of Crop Insurance Products in Countries with Agricultural Insurance (from World Bank, 2008)

Percentage of countries that have different types of crop insurance



Main Advantages and Disadvantages of Index Insurance

Advantages

- Less moral hazard
- Few information asymmetries because index based on widely available information
- Transparent and standardized structures
- Easier for risk transfer of wide spread correlated risks
- Low administrative costs
- Government financial liabilities could be budgeted upfront

Disadvantages

- Basis risk
- Sometimes requires understanding of complex statistical properties of indices
- Requires 'agro expertise' in selection of indices for crops and sufficient weather data (spatial and temporal)
- Simulation of correlated indices (spatial and temporal)

Main Advantages and Disadvantages of Traditional Crop Insurance

Advantages

- Minimum basis risk at area level
- Practically all risks covered
- Easy to design

Disadvantages

- Potential large moral hazard
- Limited historical data on crop yield
- High administrative costs
- Potential delays in claim settlements

Managing Agricultural Risk

Technical Approaches for Managing Agricultural Risk

■ Exposure Management

- Identify & manage insured values at the **village, district, county, state, region levels** per season and crops
- Identify exposure concentrations (**potential hotspots**)
- Monitor new submissions against existing exposure

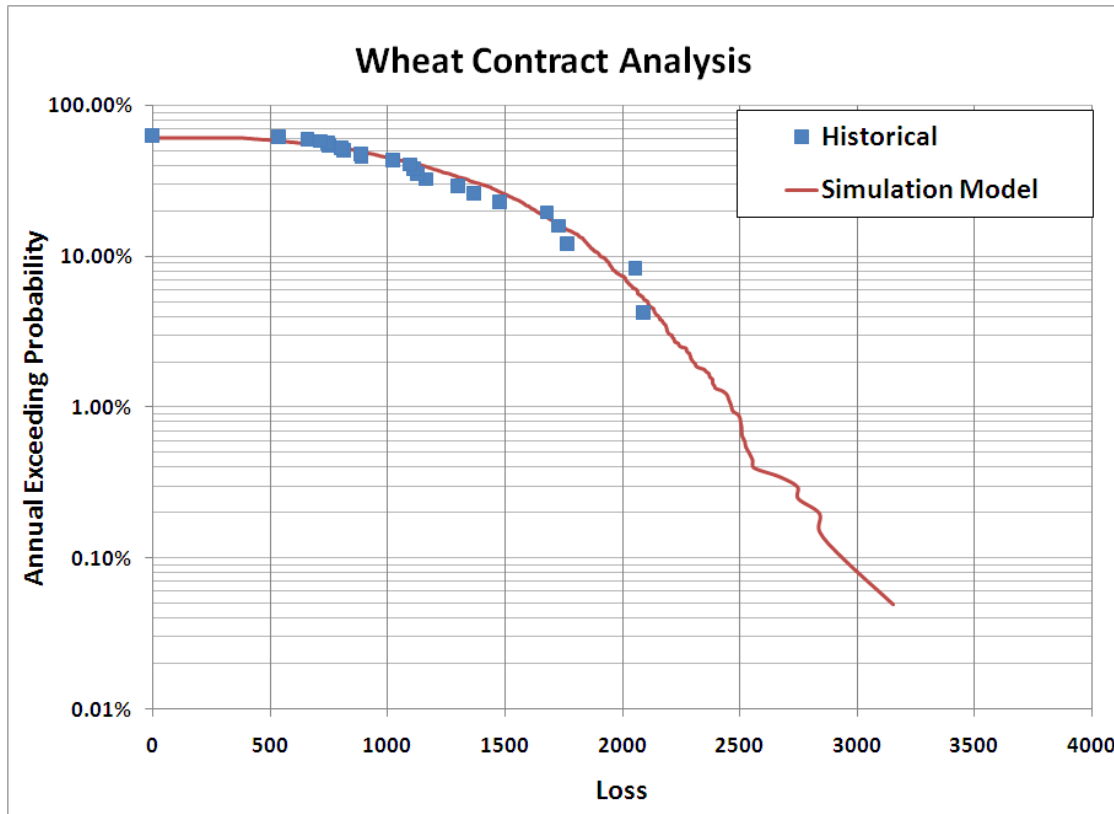
■ Historical Loss (Burn) Analysis

- Manage losses of benchmark historical scenarios to “acceptable” loss levels
- Create “what-if” scenarios

■ Stochastic and Probabilistic Loss Modeling

- Probabilistic risk metrics (OEP, AEP, AAL)
- Assist underwriters in risk selection
- Evaluate reinsurance needs and options
- Determine key drivers of risk

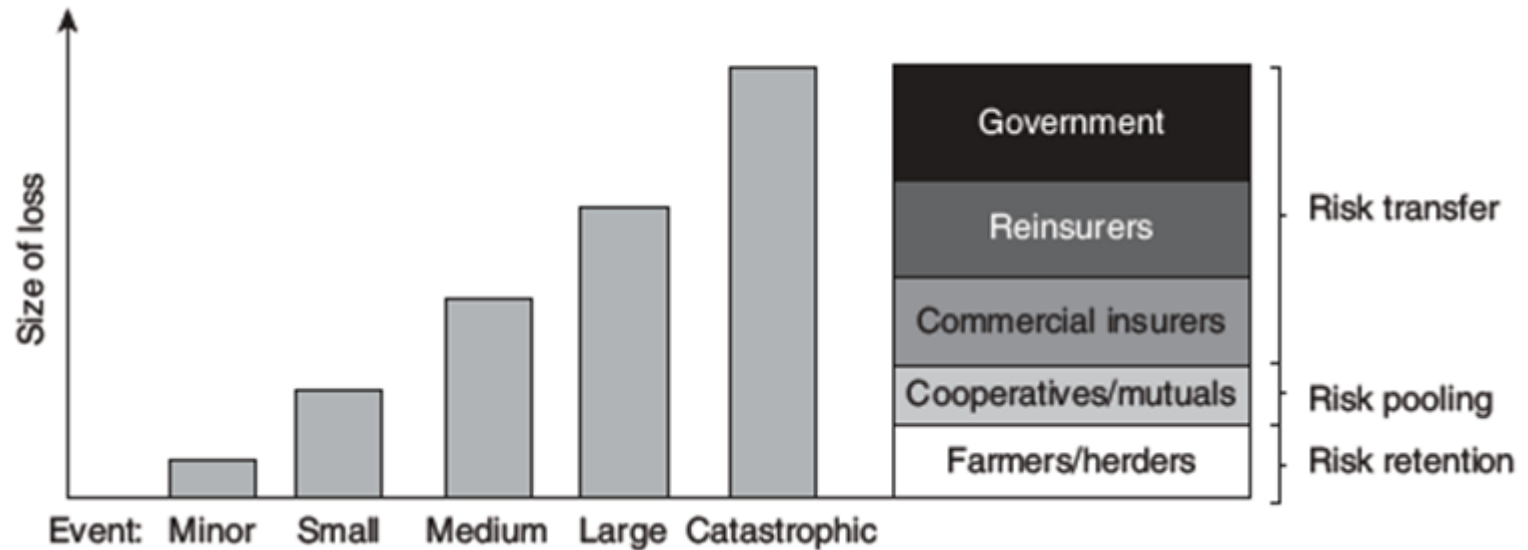
Analysis Framework: the EP Curve



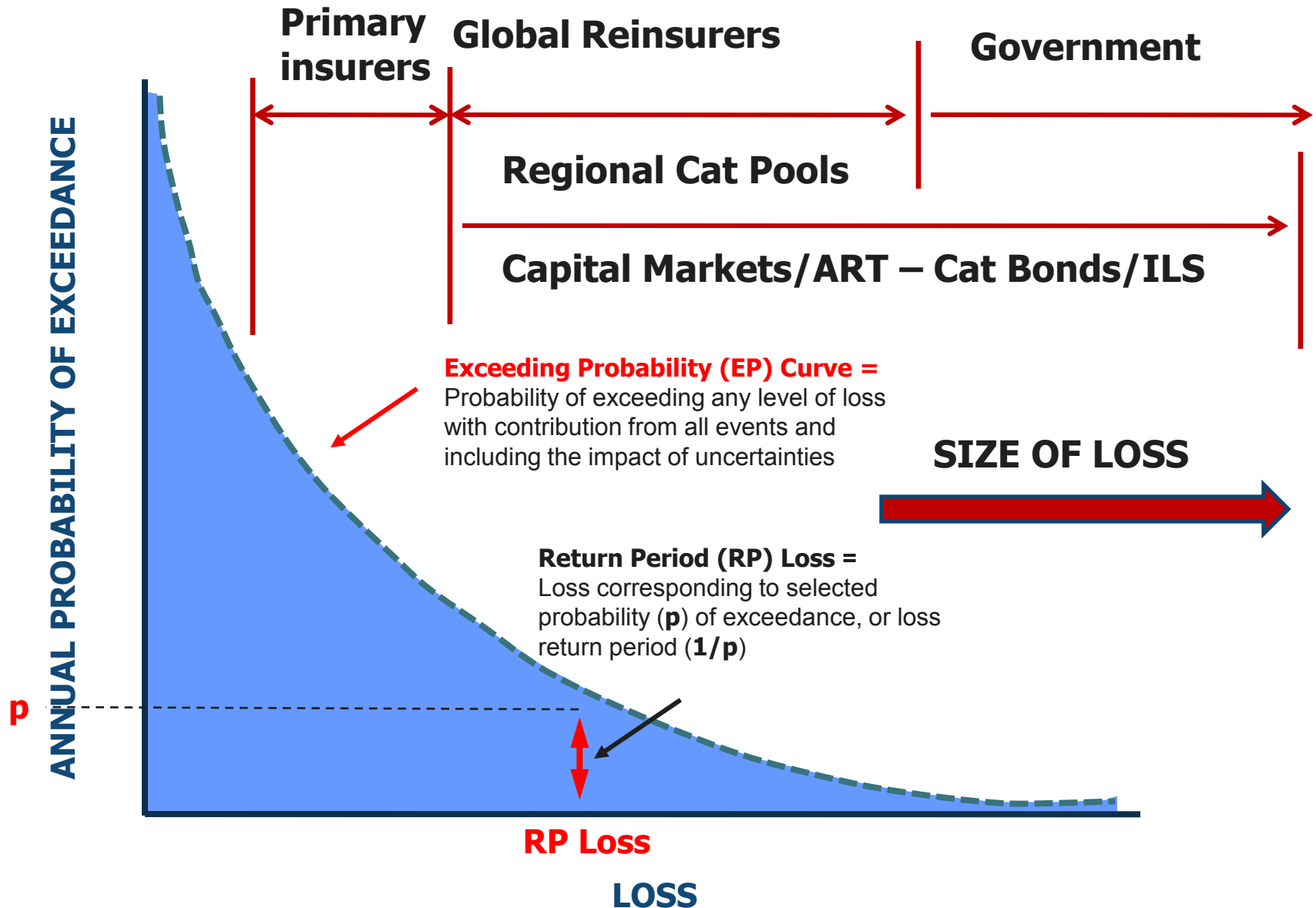
Metrics after Franchise/Deductible	Loss	Loss Ratio
PML	2,093	27%
Expected Loss	1,124	15%
Standard Deviation	509	7%
Adjusted Expected Loss	1,279	17%
ROC	22%	
Risk Premium	1,456	19%

- Exceedance probability (EP) loss estimates enable a range of risk management decisions
- Includes quantification of uncertainty to support pricing and risk loading

Agricultural Risk “Layering” (from World Bank, 2008)



Risk Transfer Layers



Quantification of Agricultural Risk

Different Methodologies for Assessing Agricultural Crop Risks

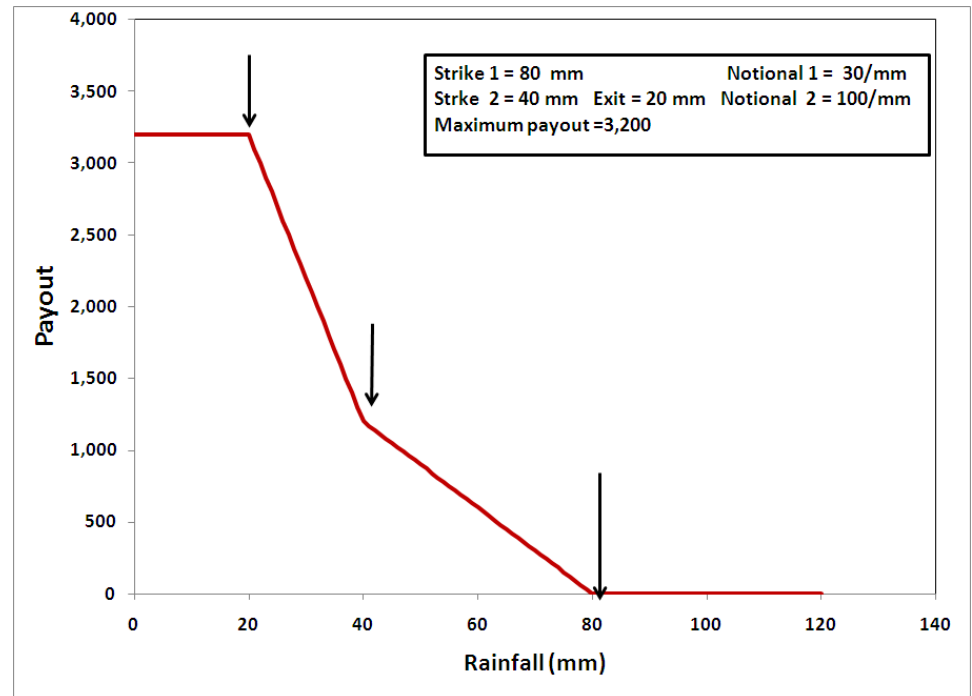
- Statistical Weather Based Index modeling methodologies
- Statistical Crop Based modeling methodologies
- Crop Life-Cycle Based modeling methodologies
- Physical simulation of perils
 - Weather systems (wind storms, rainfall, flood, hail, cyclones, etc.)

Weather Based Crop Insurance (1)

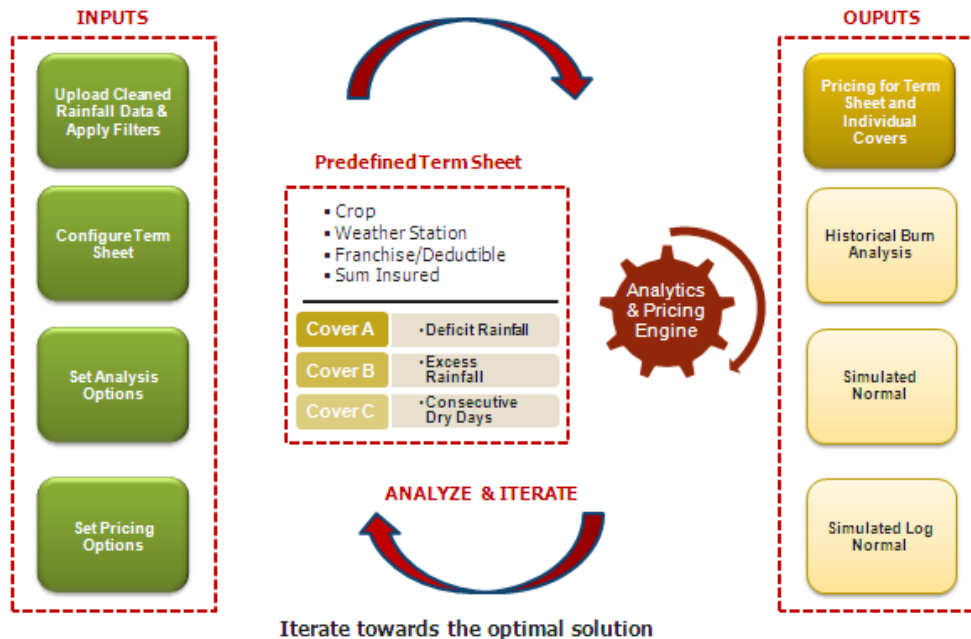
- Identification of weather station(s) with sufficient long historical 'clean' records
 - Limited amount of missing or erroneous data
 - Limited homogeneities (station moves) and maintenance of instruments (calibration). Availability of metadata sets
- One or more triggers for one or more weather variables over defined 'risk periods' dependent on the crop life cycle (sowing, growing, development, harvesting), defined by agro experts; e.g.
 - Cumulative precipitation between August 1th and August 31th < 50 mm (deficit rainfall)
 - Cumulative precipitation over 2 days between August 1th and August 31th > 75 mm (excess rainfall)
 - Number of consecutive days with daily rainfall <2mm between September 1st and November 30th

Weather Based Crop Insurance (2)

- A payout (loss) function is positive when the index is above or below an index level (strike) up to some limit
- A financial unit payout (notional or tick) that determines the amount of payment to be made as function of the deviation of the observed index from the strike
- A maximum financial liability or total risk

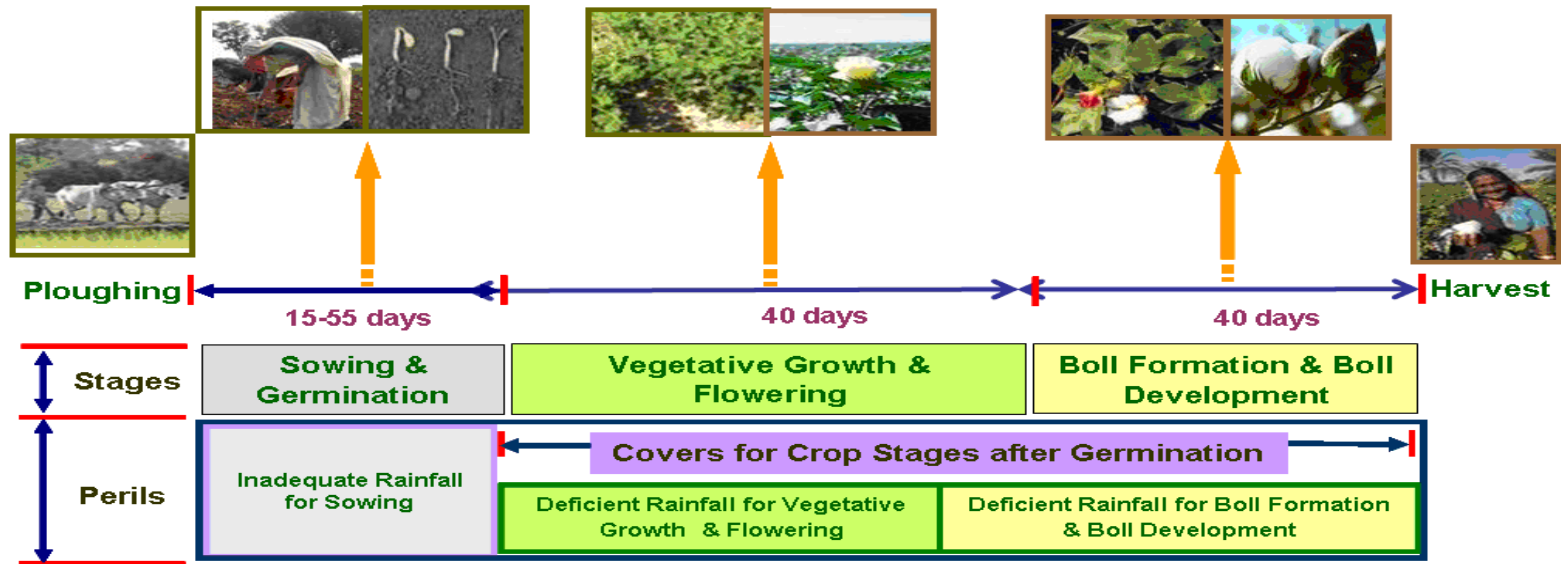


Weather Based Crop Insurance- Methodology



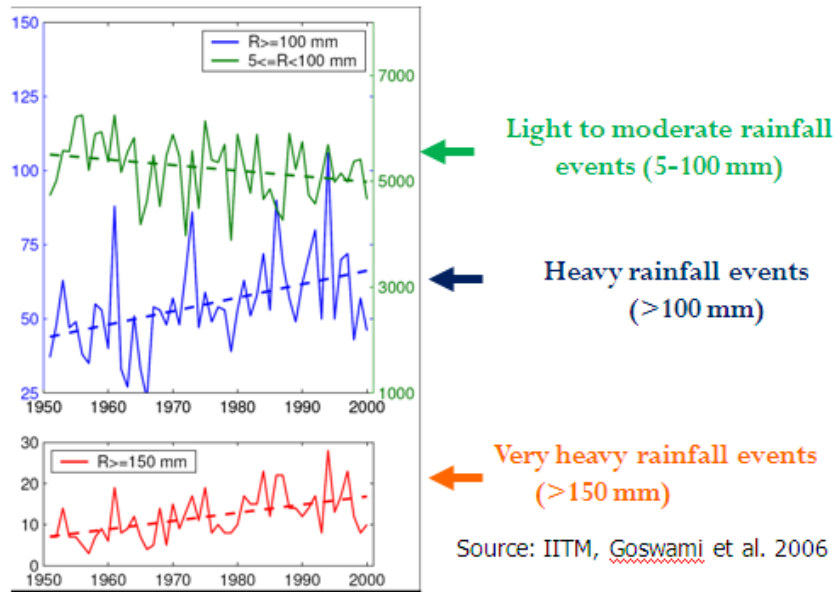
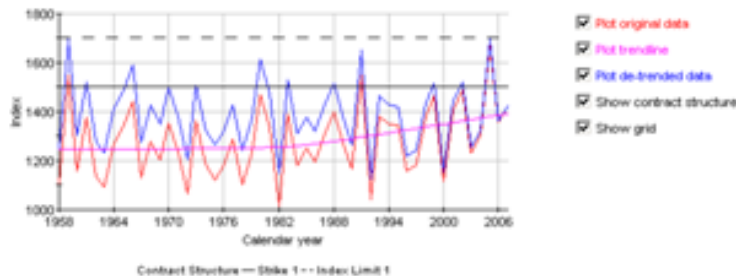
- Retrieve weather data and cleaning (discontinuities, errors, missing data, etc.)
- Estimate annual indices
- Perform historical analysis
- Perform detrending if needed
- Fit probabilistic distributions
- Simulate probability distributions of indices
- Estimate payouts and statistics
 - Historical (burn) analysis
 - Probabilistic analysis

Example of a Weather Based Contract Term Sheet



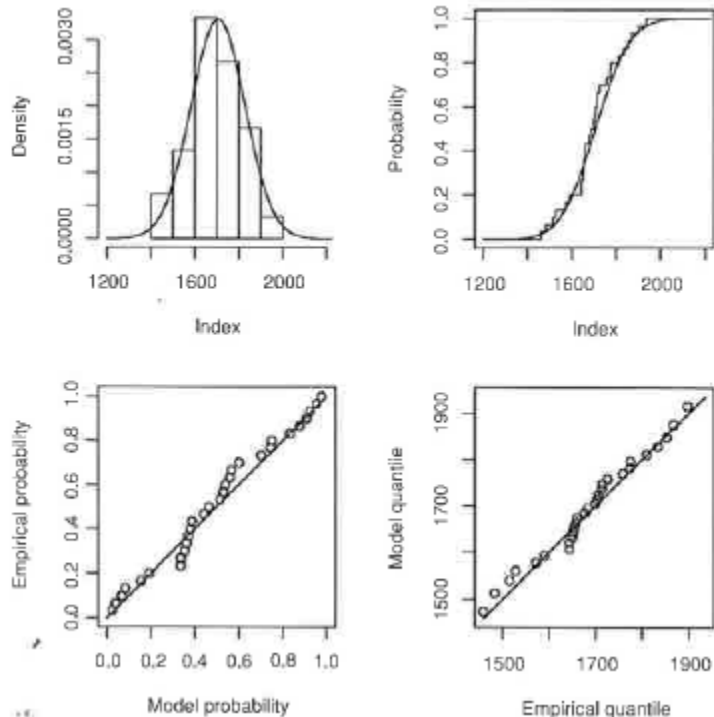
Details of Weather Perils Covered	Phase 1	Phase 2	Phase 3	Phase 4
	15 th June-10 th July	11 th July-31 th July	1 st August-25 th August	26 th August-15 th October
Deficit Rainfall Cover	Covered	Covered	Covered	Covered
Excess Rainfall Cover	Covered	Covered	Covered	Covered
Consecutive Dray Day Cover	1 st July- 31 st August			

Trending Weather Indices



- One solution does not fit all
 - indices or weather variables
- Different possible trends in the underlying daily weather variables (precipitation, temperature)
- Most common trends
 - Linear
 - Piecewise linear
 - Quadratic
 - Exponential
 - Moving average
 - Loess
- Number of years

Statistical Modeling of Indices

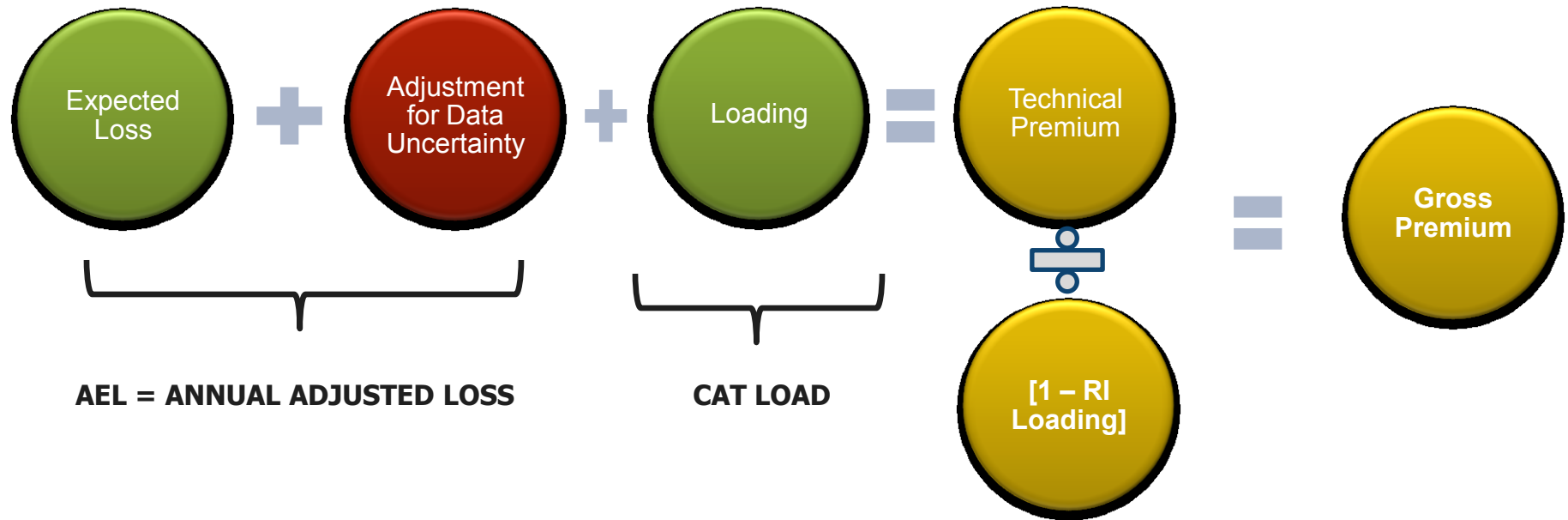


- Discrete or continuous distributions
- Parametric or non parametric distributions
- Generalized extreme value models
- Testing goodness of fit
- Confidence intervals
- Standard numerical tests
 - Chi-squared (hard to fail)
 - Kolmogorov-Darling (hard to fail)
 - Anderson-Darling
 - Shapiro-Wilk (normal assumption)

Simulation of Correlated Indices and Payouts

- Choleski factorization, singular value decomposition (valid with normal distributions)
- Rank correlation (Spearman correlation)
- Copulas
- Empirical approaches minimizing errors on simulated and observed marginal means and variances of indices

Pricing Methodology



□ Adjustment for Data Uncertainty

= F[Confidence interval, Number of years of data, Missing Data]

= $\beta \times \sigma / [\text{sqrt}[N(1-j)]]$

□ Loading

= $\beta \times [\text{PML}(1\text{-in-}T\text{years}) - \text{AEL}]$ or

= $\zeta \times \sigma$

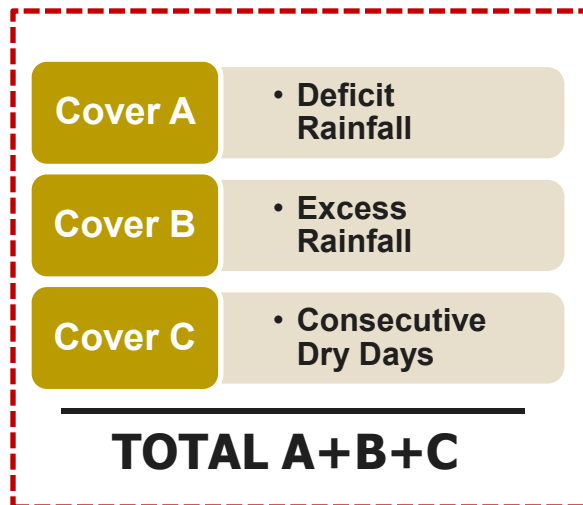
□ RI Loading %

= Reflects Commission for Distribution, Overheads and Administrative Cost

Pricing Outputs: Historical Burn Analysis – A sample

OUTPUTS BASED ON HISTORICAL BURN ANALYSIS: TOTAL & BROKEN DOWN BY COVER

Cover A+B+C			Cover A			Cover B			Cover C		
Historical			Historical			Historical			Historical		
Metrics before franchise/deductible	Loss	Loss ratio	Metrics before franchise/deductible	Loss	Loss ratio	Metrics before franchise/deductible	Loss	Loss ratio	Metrics before franchise/deductible	Loss	Loss ratio
Mean	704	3.9%	Mean	165	2%	Mean	465	7%	Mean	74	2%
Stdev	732	4.1%	Stdev	252	3%	Stdev	678	10%	Stdev	181	6%
Max	2,785	15.5%	Max	808	10%	Max	2,000	29%	Max	500	17%
Mean + X stdev	1,143	6.4%	Mean + X stdev	316	4%	Mean + X stdev	872	12%	Mean + X stdev	183	6%



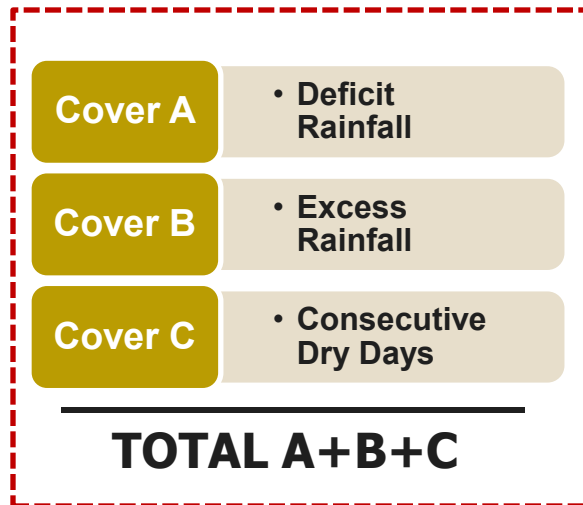
PRICING & METRICS

Metrics after franchise/deductible	Loss	Loss Ratio
PML	2,785	15.5%
Expected Loss	699	3.9%
Standard Deviation	736	4.1%
Adjusted Expected Loss	890	4.9%
ROC	20.4%	
Risk Premium	1,276	7.1%
Gross Premium	1,702	9.5%

Pricing Outputs: Simulation – A Sample

OUTPUTS BASED ON SIMULATIONS: TOTAL & BROKEN DOWN BY COVER

Cover A+B+C			Cover A			Cover B			Cover C		
Simulation with lognormal normal distributions			Simulation with lognormal normal distributions			Simulation with lognormal normal distributions			Simulation with lognormal normal distributions		
Metrics before franchise/deductible	Loss	Loss ratio	Metrics before franchise/deductible	Loss	Loss ratio	Metrics before franchise/deductible	Loss	Loss ratio	Metrics before franchise/deductible	Loss	Loss ratio
Mean	360	2.0%	Mean	154	2%	Mean	81	1%	Mean	126	4%
Stdev	781	4.3%	Stdev	559	7%	Stdev	455	7%	Stdev	302	10%
50%	2	0.0%	50%	-	0%	50%	0	0%	50%	-	0%
90%	1,023	5.7%	90%	230	3%	90%	51	1%	90%	500	17%
95%	1,883	10.5%	95%	1,264	16%	95%	209	3%	95%	1,000	33%
99%	3,837	21.3%	99%	1,264	16%	99%	209	3%	99%	1,000	33%
Max	4,547	25.3%	Max	5,231	65%	Max	5,000	71%	Max	1,000	33%
Mean + X stdev	829	4.6%	Mean + X stdev	489	6%	Mean + X stdev	354	5%	Mean + X stdev	307	10%

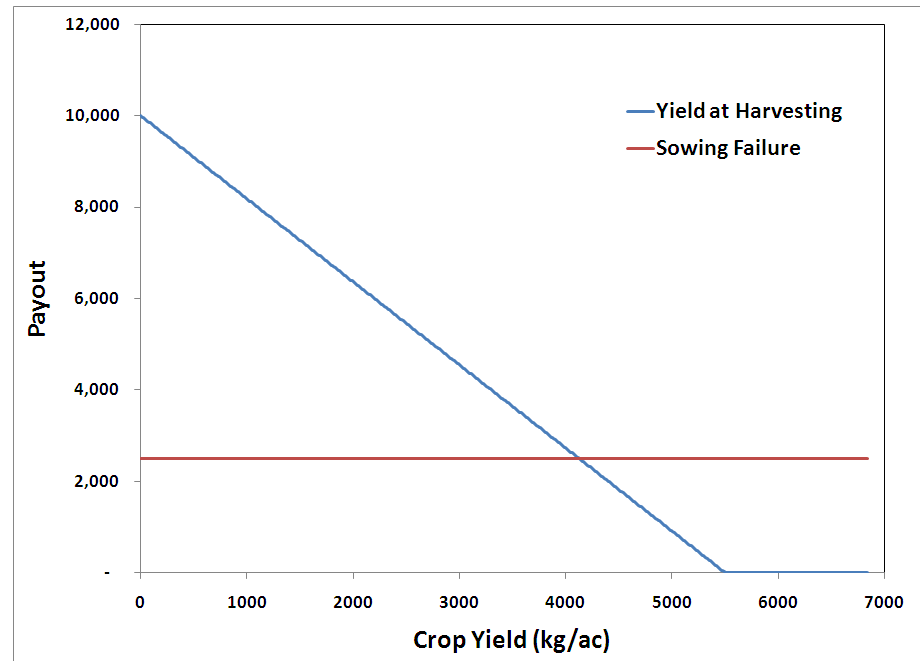


PRICING & METRICS

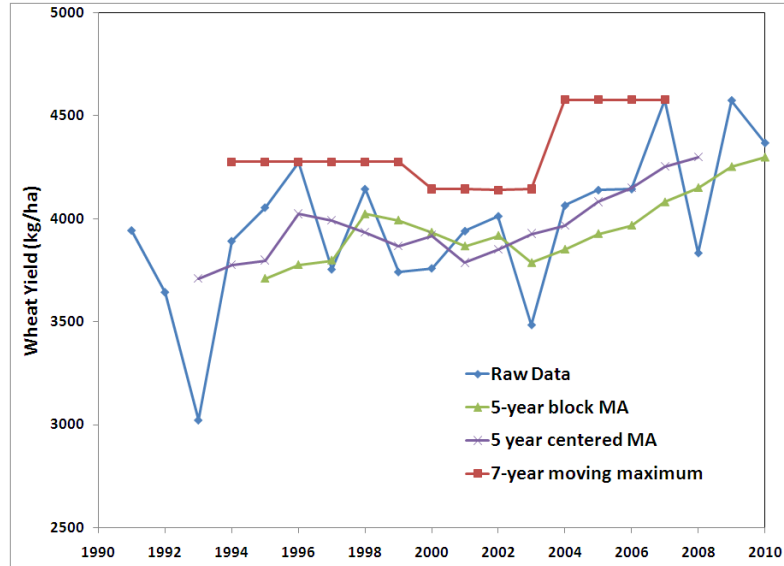
Metrics after franchise/deductible	Loss	Loss Ratio
PML	3,837	21.3%
Expected Loss	353	2.0%
Standard Deviation	784	4.4%
Adjusted Expected Loss	557	3.1%
ROC	13.5%	
Risk Premium	998	5.5%
Gross Premium	1,330	7.4%

Crop Yield Insurance

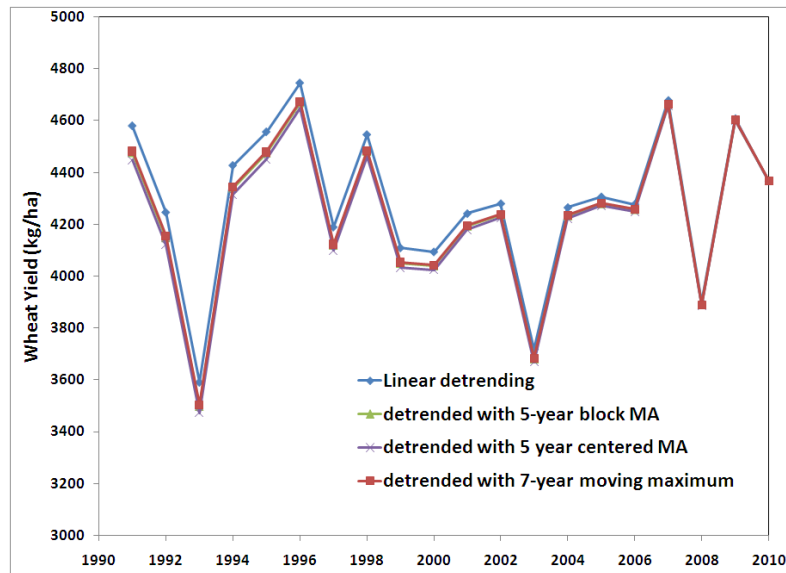
- Define a 'reference' or 'normal crop yield'
 - e.g. a percentage of the average yield of past 7 years (excluding cat years). Percentage can be 100% or less
- Payment is function of actual yield
- Special clauses if sowing failure
 - e.g. 25% of insured value as payment



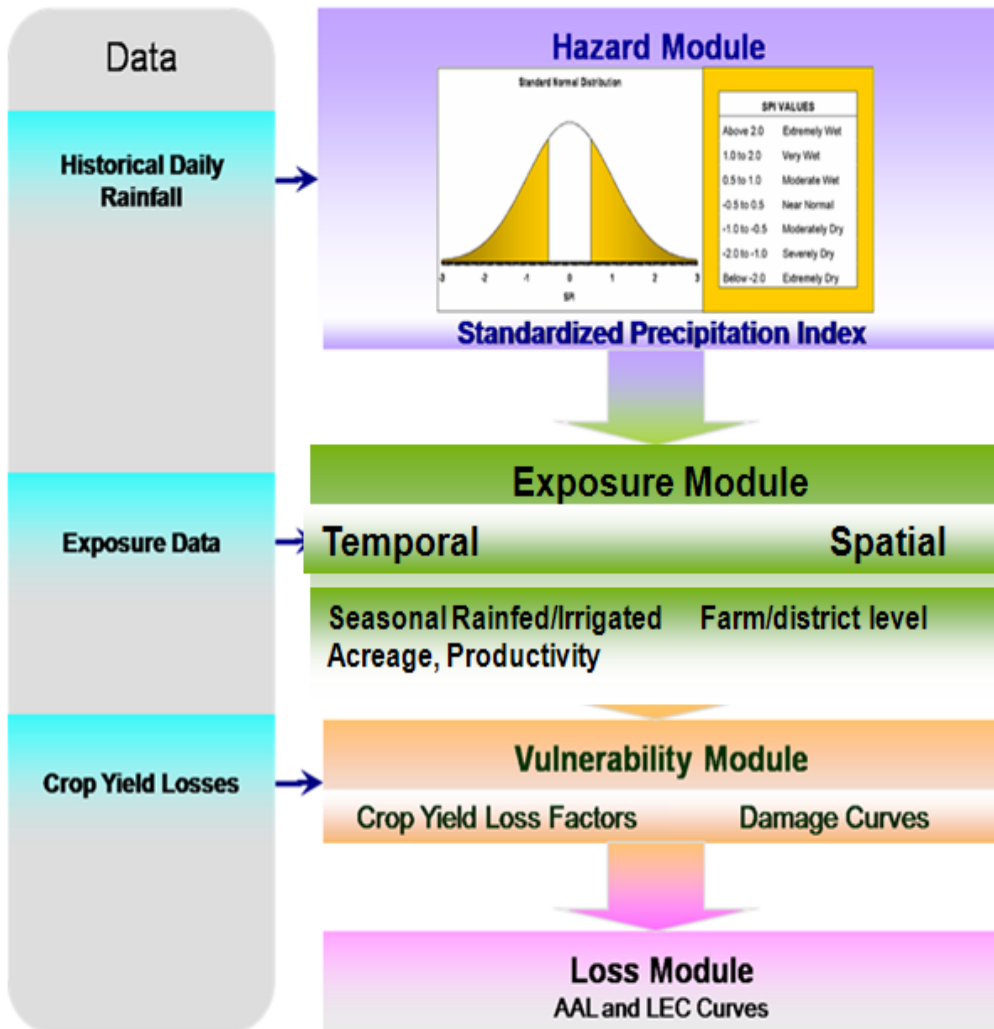
Crop Yield Insurance – Methodology 1



- Collect crop yield data
- Detrend crop yield data
 - Weather trends
 - Extreme events
 - Technology trends
- Simulate crop yield



Crop Yield Insurance – Methodology 2



■ 5 building blocks

- Simulation hazard module
- Hazard module
- Exposure module
- Vulnerability module
- Loss module

■ Steps

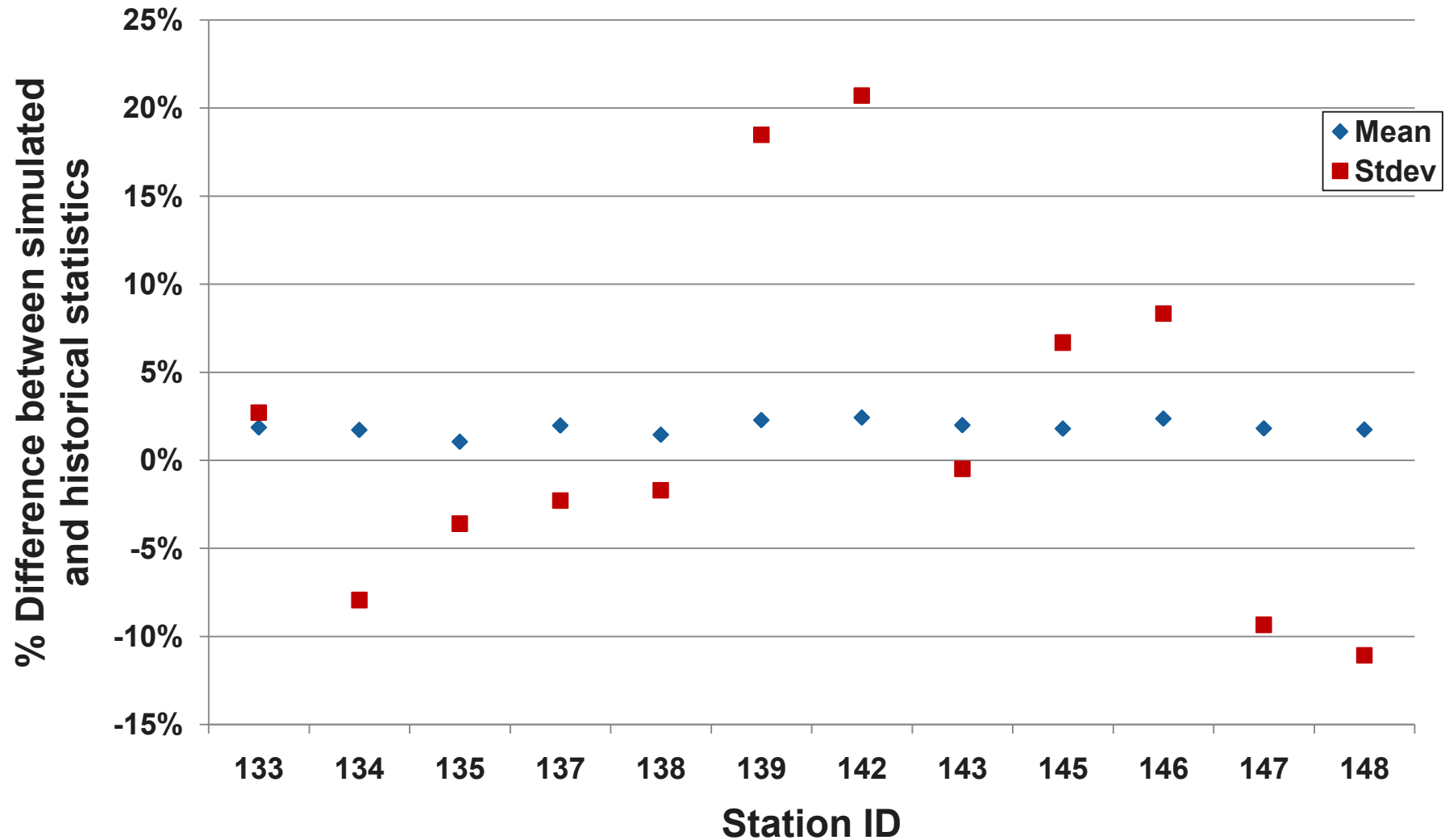
1. Simulating weather
2. Developing weather index
3. Correlate weather index to crop yield (vulnerability) and financial loss
4. Perform simulations
5. Estimate risk metrics

Weather Simulation

Methods for simulating weather variables based on station data

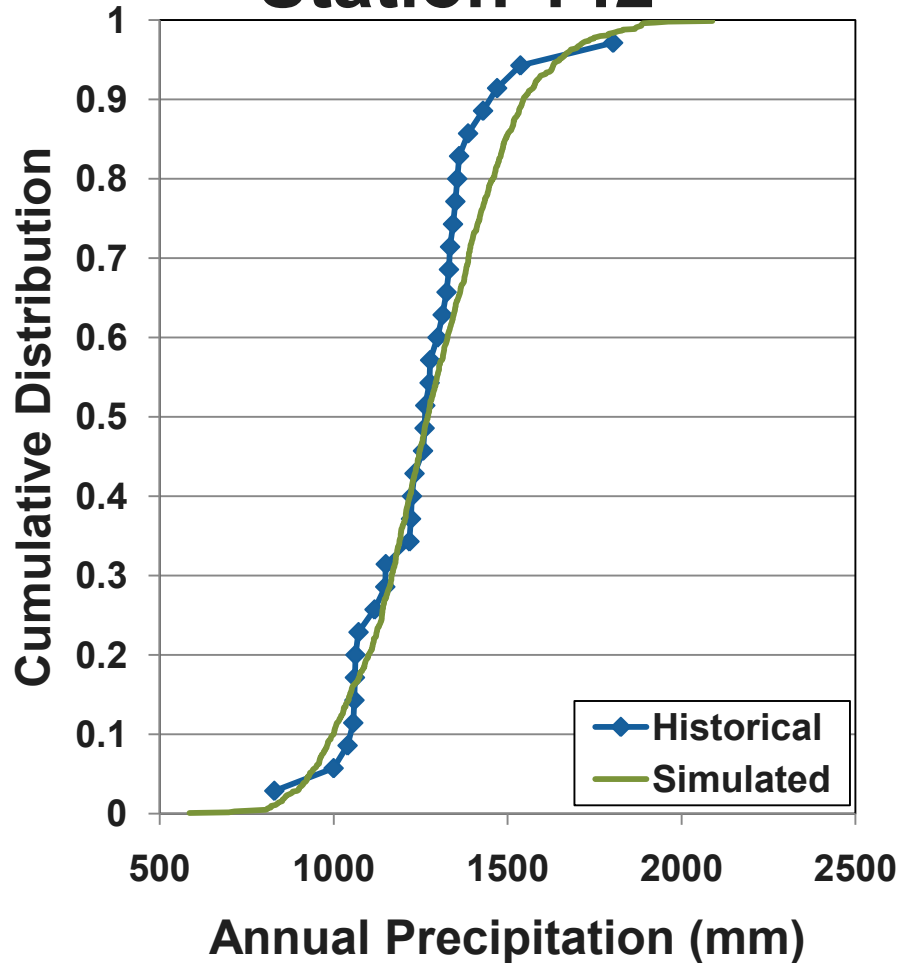
- Minimum amount of data (temporal and spatial)
 - 12, but 30 years **continuous daily data** would be optimal
- Simulation of weather variables at a location
 - Modeling using different probability distributions
- Simulation of weather variable across locations (preservation of spatial correlation among the stations)
 - Modeling using statistical techniques from historical time series using different methodologies accounting for correlation (from Spearman correlation to copulas approaches)
 - Modeling using stochastic techniques that use station time series to de-aggregate spatial weather patterns and re-aggregate them using principal component analysis with simulation of deviations from long term means
- Choice of simulation type will depend upon:
 - Spatial coverage of available stations data
 - Data quality of weather data

Testing results across stations

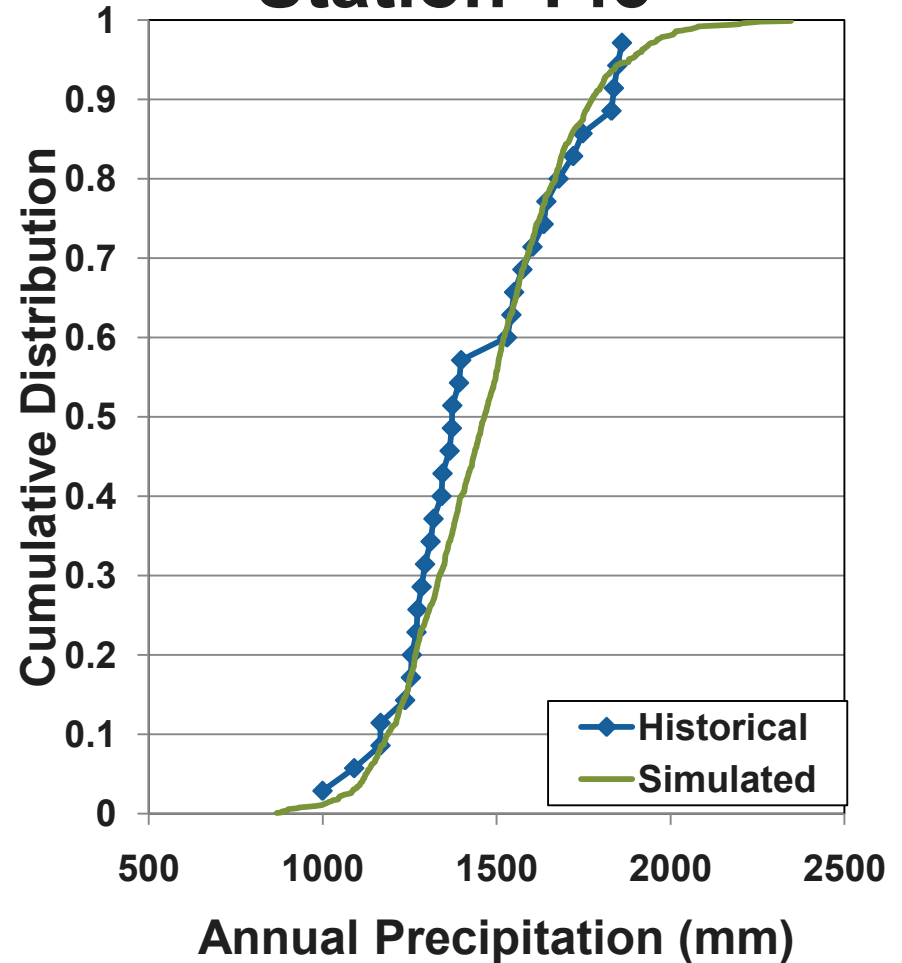


Testing results across stations

Station 142



Station 143

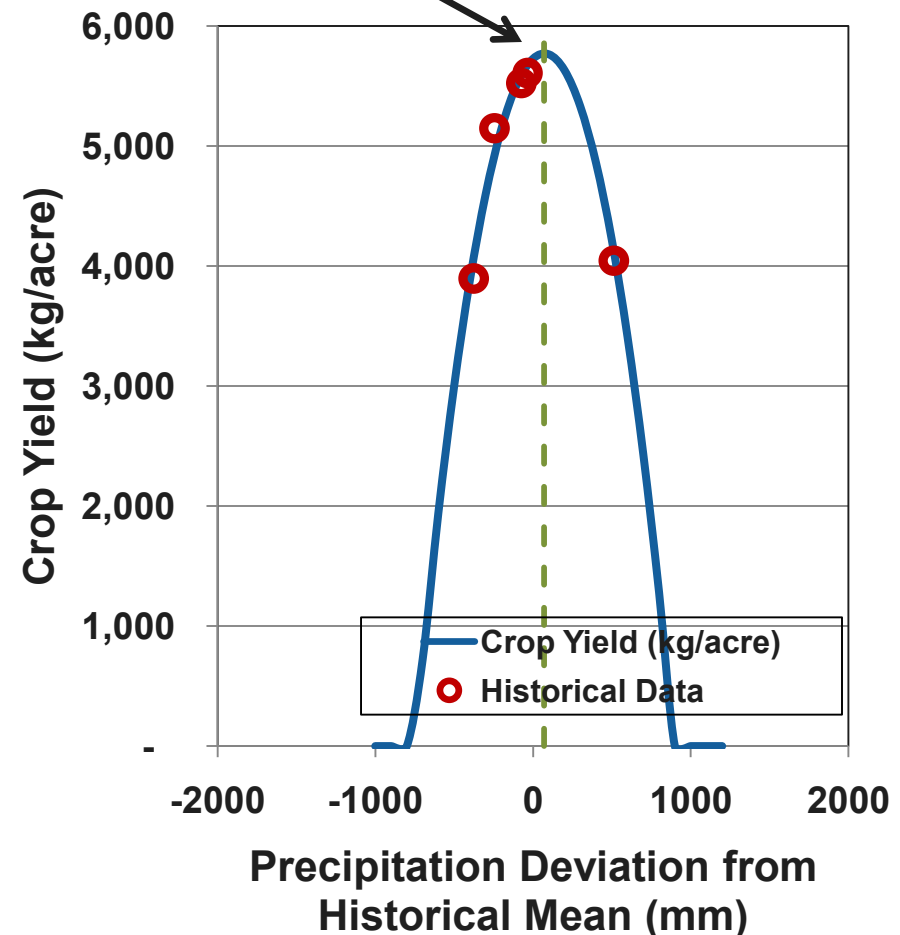


Development of Correlation between Precipitation and Crop Yield

- From 34 years of data, calculate the rainfall deviation of the station vs. mean rainfall
- Fit a relationship between crop yield and rainfall deviation from the historical mean

Normal Yield

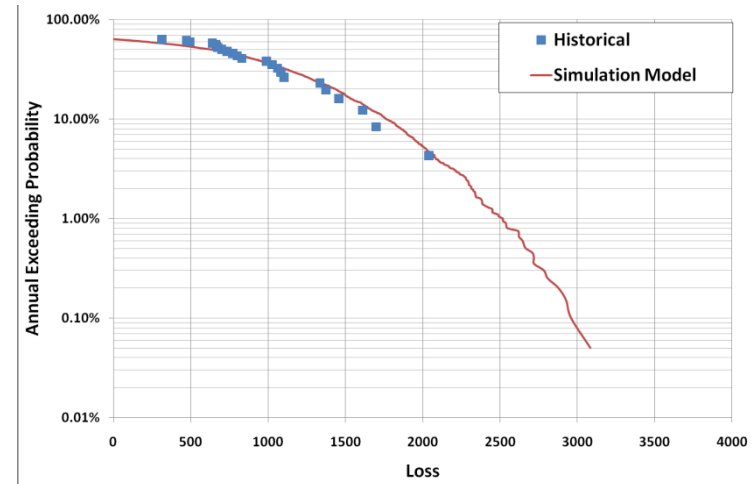
Rice Crop



Probabilistic Loss Assessment

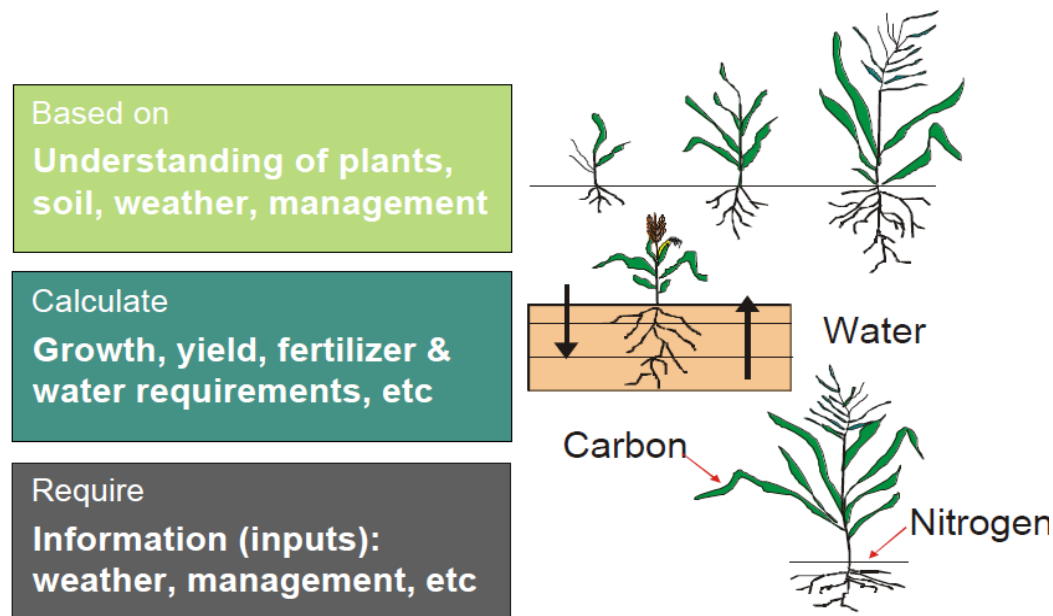
Given the simulated precipitation data for each station, perform the following:

1. Calculate precipitation values for each county for each year
2. Simulate crop yield deviations from their means at county level for each simulated year.
3. Aggregate “crop yield reductions” from counties to province for each simulated year.
4. Calculate risk metrics (AAL, St dev, OEP/AEP) on “crop yield reduction”



Crop Life-Cycle Based Models – Complex Modeling

- Complex numerical models that account for: weather, soil type, moisture, crop growth stages (from sowing to harvest), nutrients including fertilizers, drainage, diseases, etc.
- Assess physical vulnerability quantitatively at site level (e.g. EPIC model)

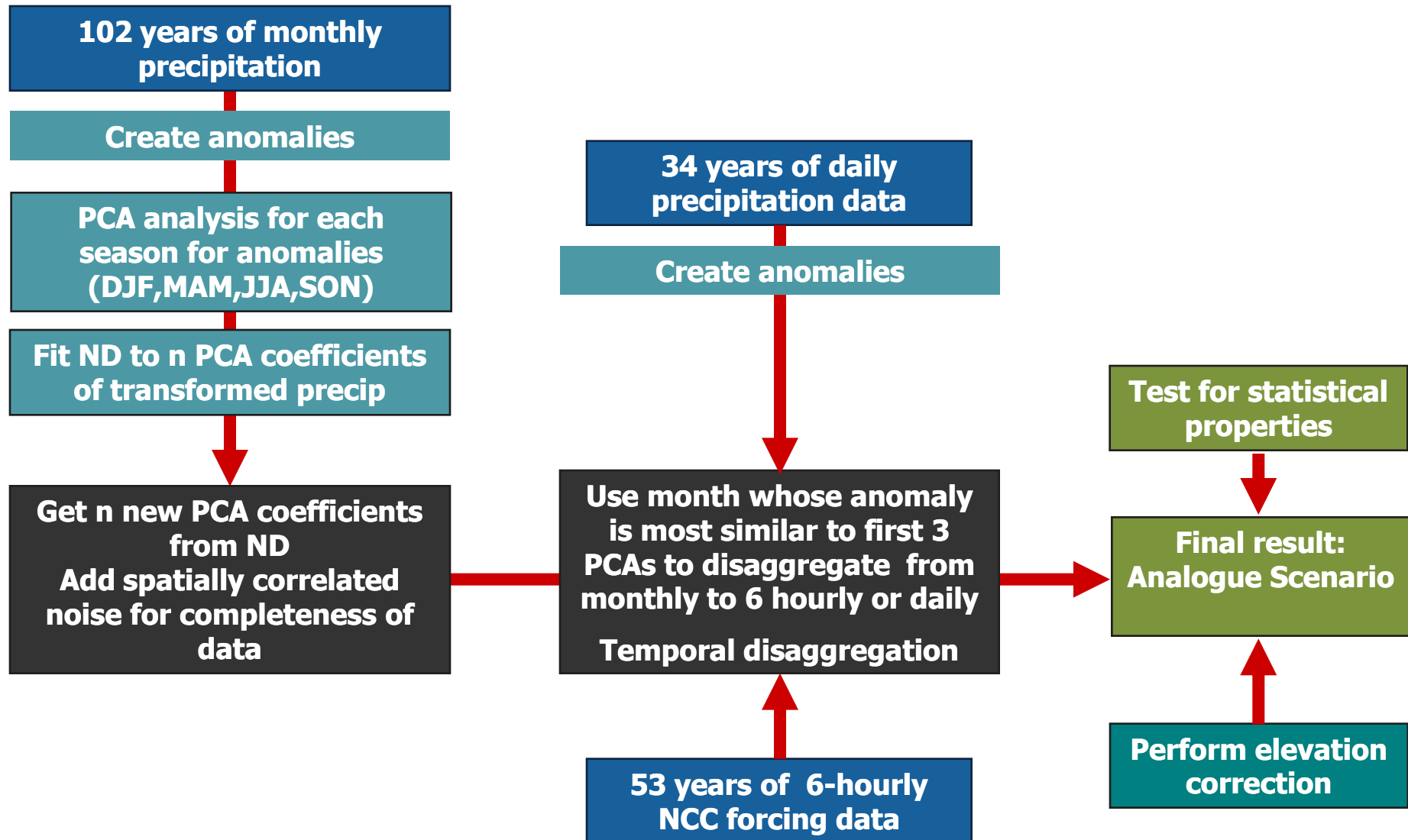


Still More Complex Methodologies – Modeling Physical Processes

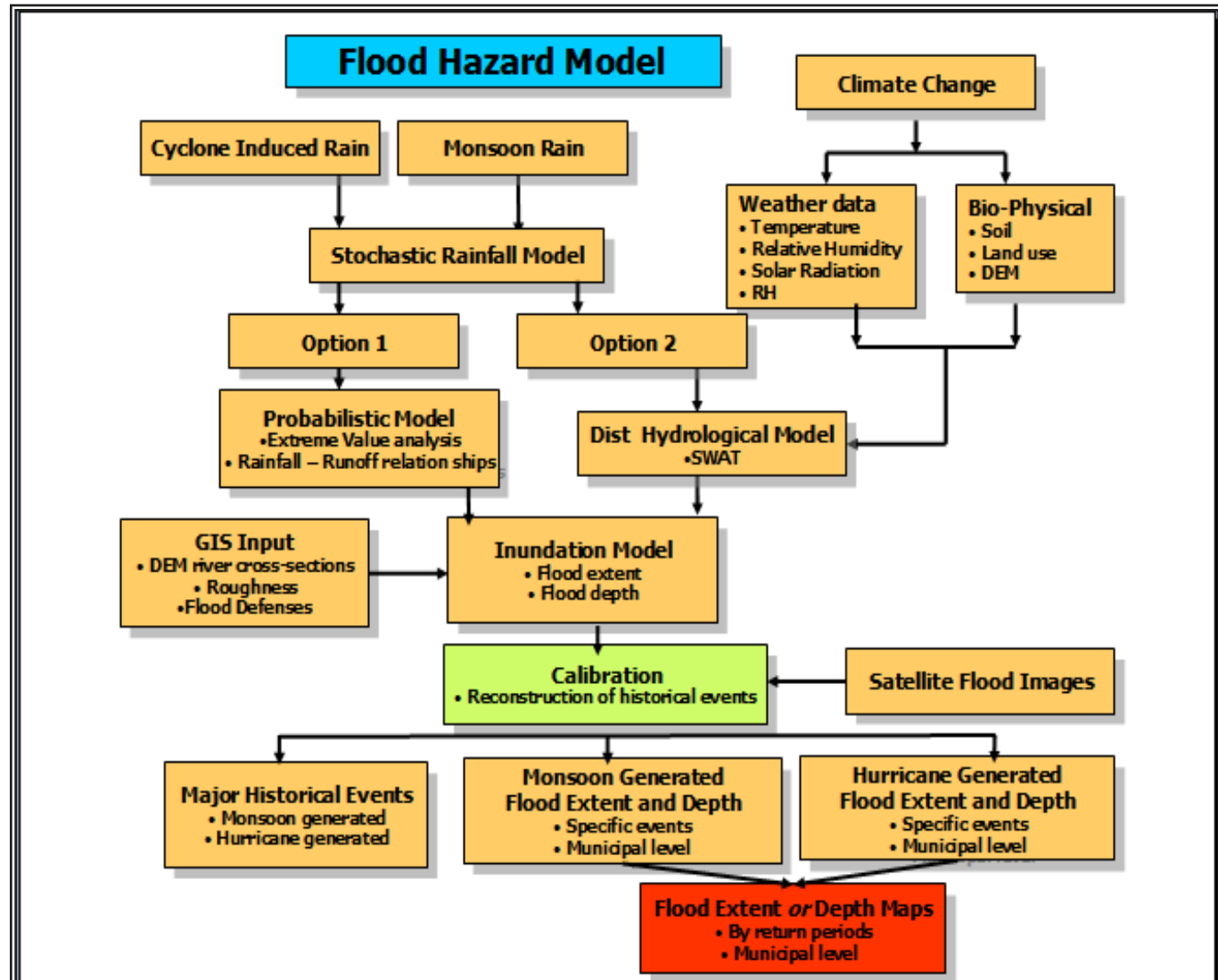
- Advances in numerical modeling lead to more sophisticated modeling techniques
- However, more data, that may not be available, are needed for calibration
- More time consuming to develop
- Require specific expertise

Stochastic Precipitation Model

PCA Based Analogue Monte-carlo Simulations



Flood Risk Model- A Methodology



Concluding Remarks

- Some methodologies based on objective and independent risk quantification models are presented
- Expertise in multiple fields needed
- Choice of statistical approaches may lead to large differences in results
- Best suited models depends on data and specific country operating environment:
 - Design covers magnitude and frequency of adverse weather
 - Design based on Actual Crop requirements (field conditions)
 - Probabilistic models function of hazard, exposure and vulnerability; $f(h, e, v)$
 - Design to offer risk quantification solutions for all key stakeholders

THANK YOU !