Designing Financial Instruments for Climate Risk Management: Uruguay Energy System

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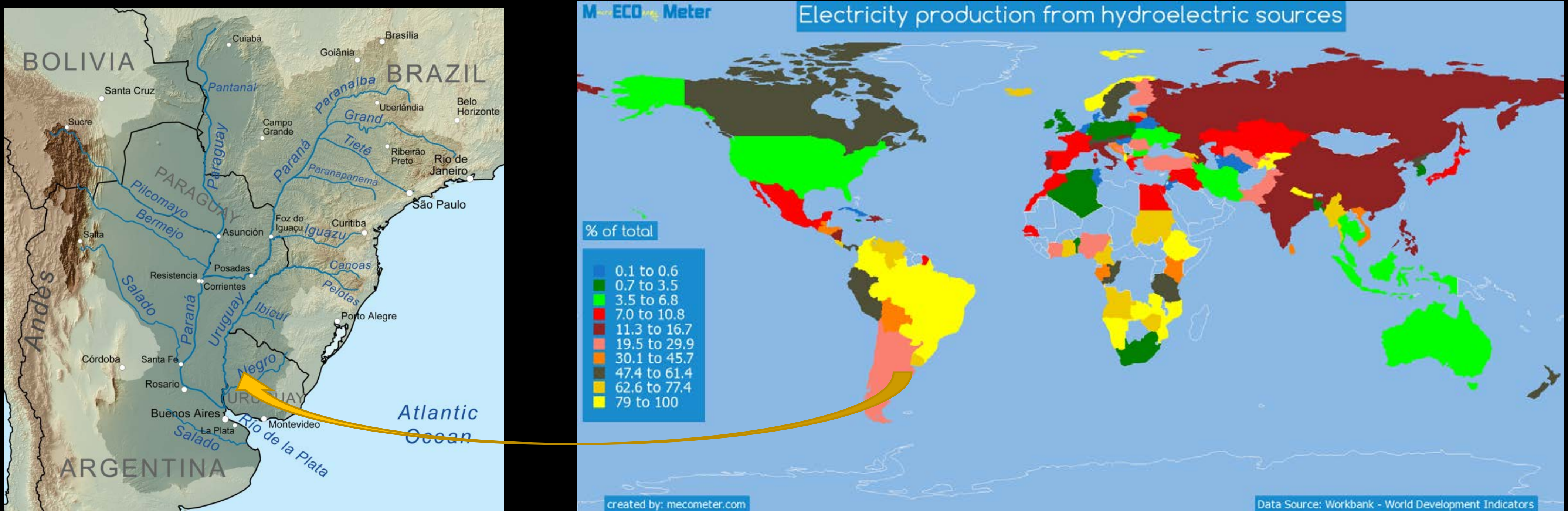


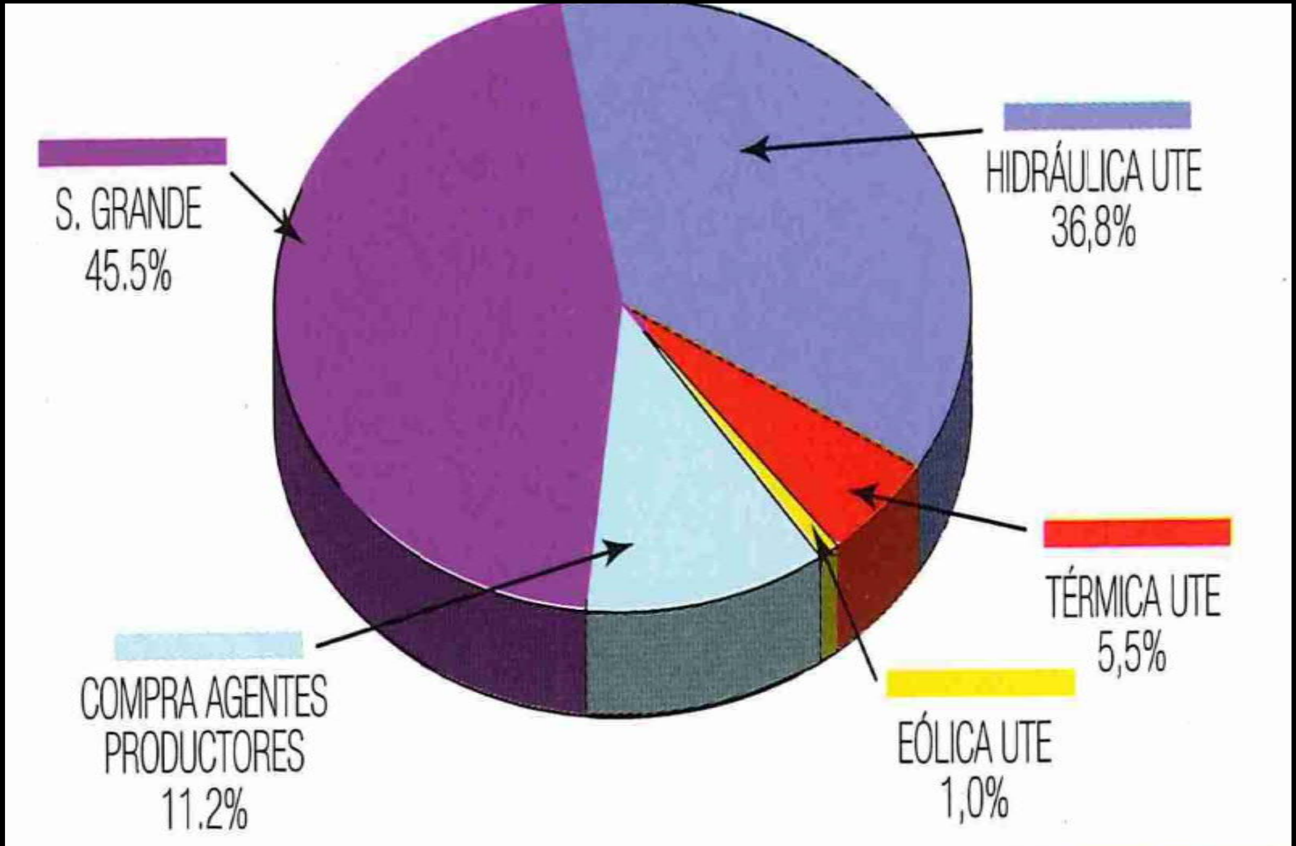
The problem

- Hydro-Energy (Renewables) – Uruguay as an example
  - Intra- and Inter-annual volatility in production
    - Reservoirs to regulate flow – smooth intra-annual variability
    - Hydropower shortfall in droughts – inter-annual and decadal variability
  - Replaced by Thermal sources (purchase Oil) and purchase from Argentina
    - Volatility in Currency Exchange Rates and Oil Prices
    - Much higher costs for energy
    - Limited ability to cover through tariff increases or by using a reserve fund
- Challenge:
  - Optimal Design of Financial Risk Management Portfolio
    - Choice of Parameters of
      - Reserve Fund, Parametric Insurance, Tariff, Reserve Fund Parameters, Loans, Investment, Cash and Current Accounts
    - Stochastic Factors:
      - Inter-annual to Decadal Climate Risk Simulation
      - Simulation of Currency Exchange Rates and Oil Prices

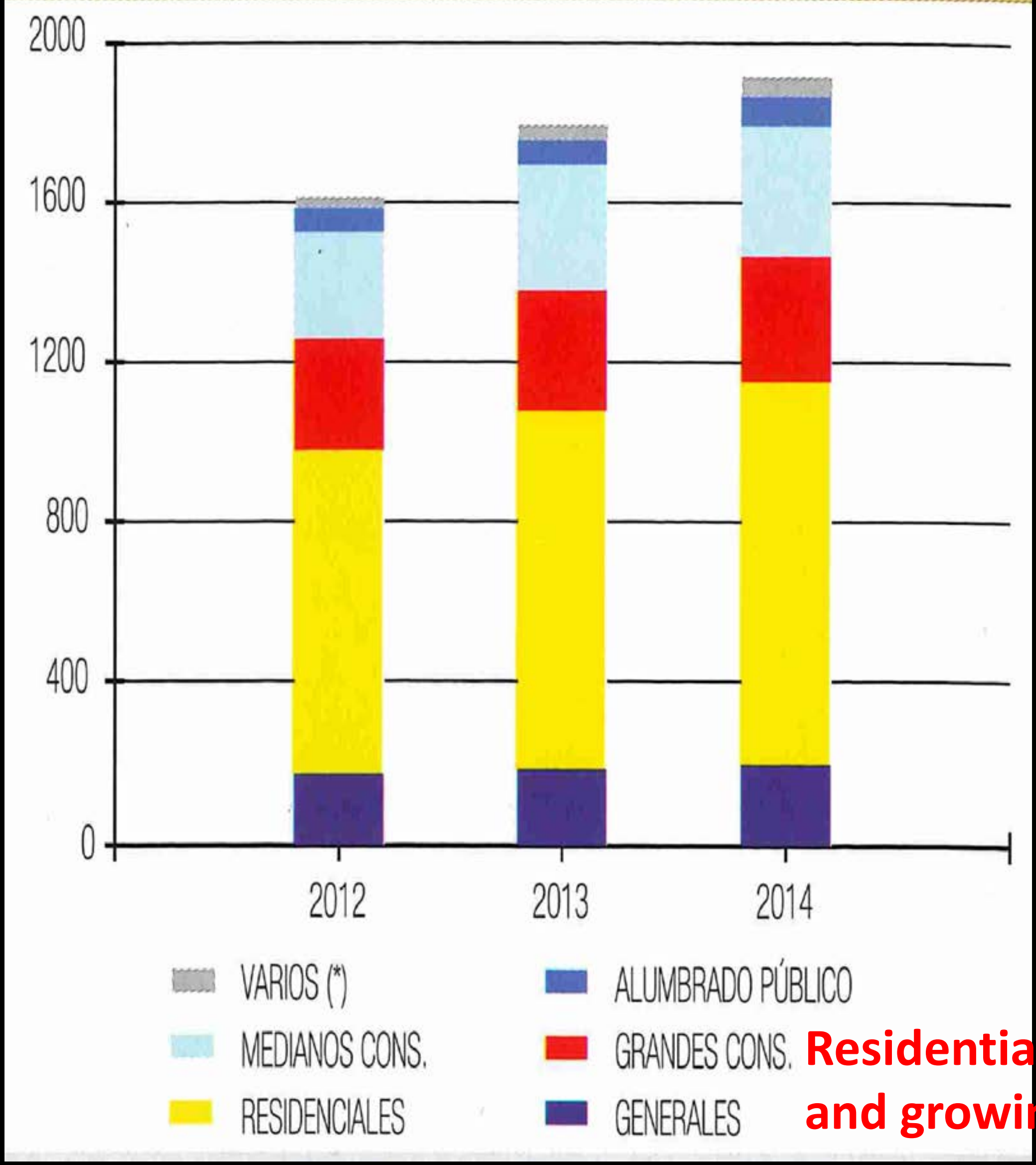
1. ENERGÍA GENERADA E INTERCAMBIADA (GWh)

	2012	2013	2014
PRODUCCIÓN			
Hidráulica UTE	2.814	3.125	4.225
Térmica UTE	3.666	1.795	628
Eólica UTE	65	65	112
Diesel (autónoma e Interconectada)	4	4	0
Fotovoltáica	0	0	1
COMPRA			
A Salto Grande	2.345	4.924	5.256
A Argentina	279	0	0
A Brasil	463	0	0
A Agentes Productores	502	602	1.289
TOTAL	**10.138**	**10.515**	**11.511**
DESTINO			
Brasil	0	0	0
Argentina	91	196	1.123
Uruguay	10.047	10.319	10.388
TOTAL	**10.138**	**10.515**	**11.511**

Uruguay
Energy Production



VENTA DE ENERGÍA ANUAL (en millones de dólares)

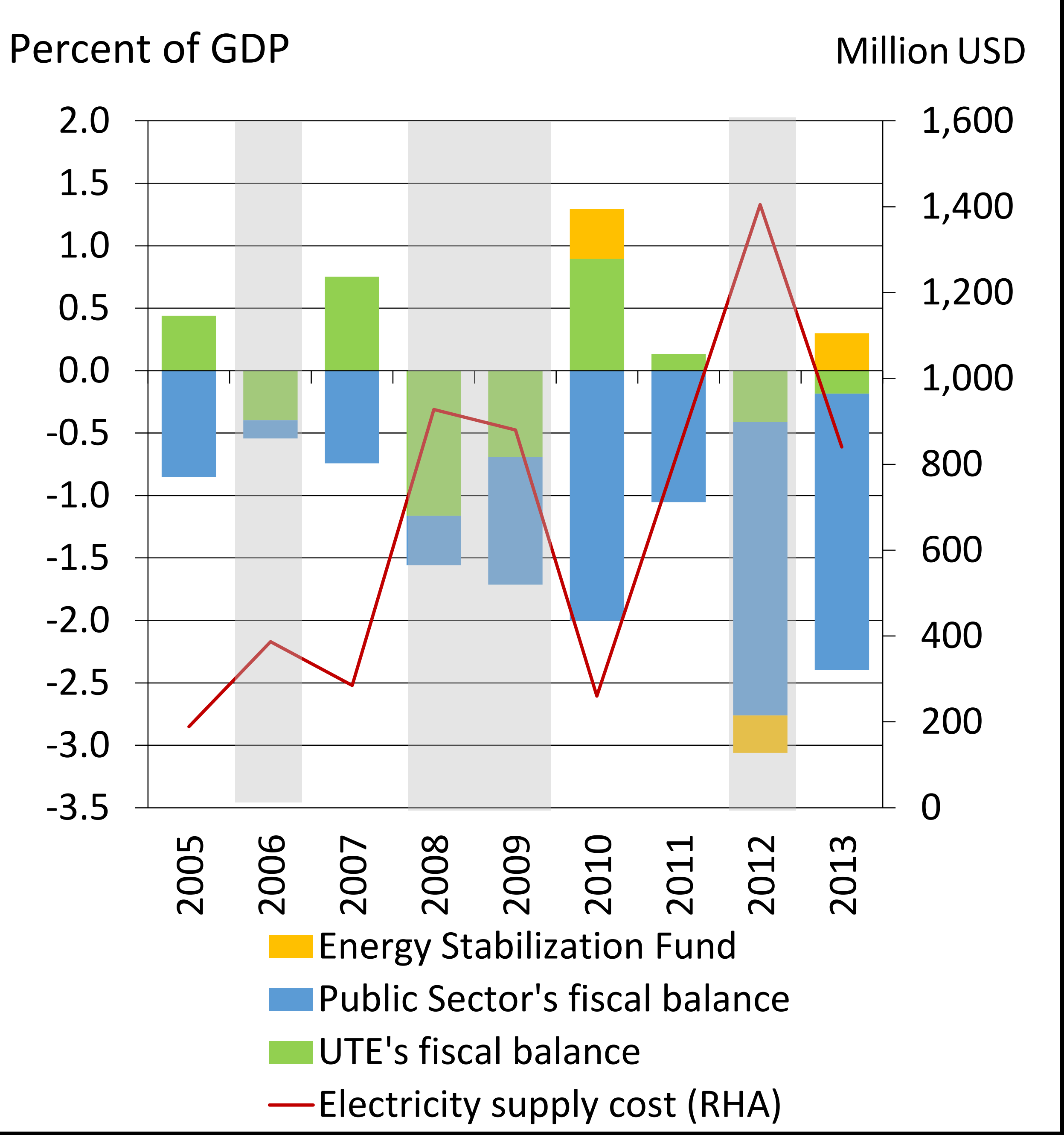


Residential use =41% and growing fastest

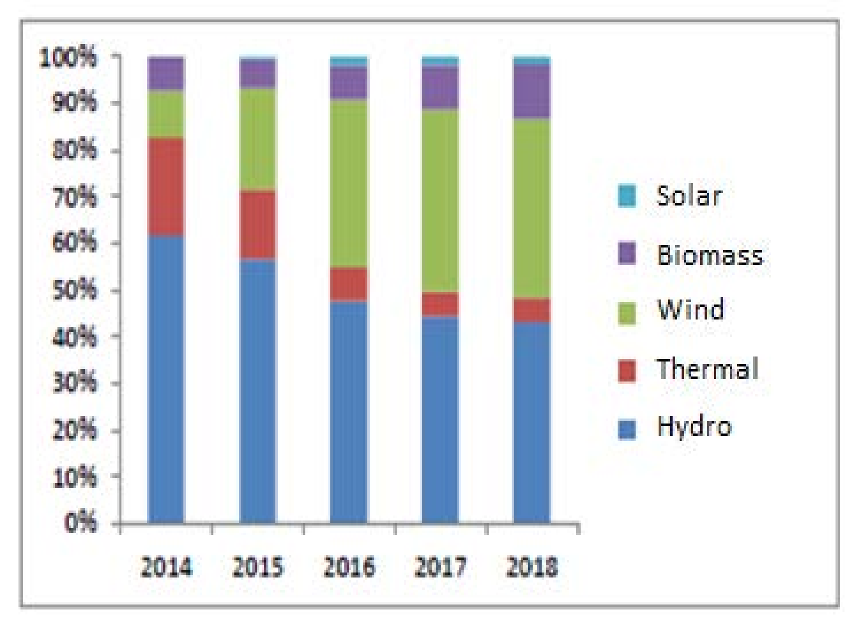
Electricity Revenues and Tariffs by Sector

6. PRECIO MEDIO DE VENTA EN EL MERCADO INTERNO (CENTAVOS DE DÓLAR POR kWh) (**)

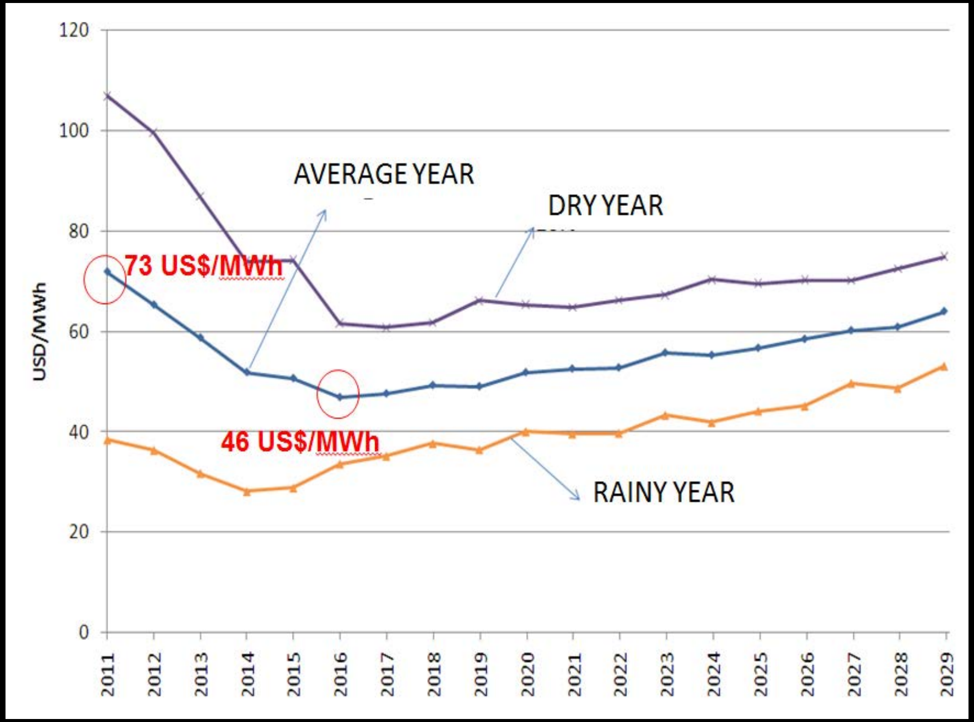
CATEGORÍA TARIFARIA	2012	2013	2014(*)
General	23,38	24,58	25,43
Residencial	25,01	27,08	28,71
Consumo Básico Residencial	16,16	18,12	19,03
Alumbrado Público	25,75	27,66	29,16
Doble Horario Residencial	19,06	20,90	22,42
Doble Horario Alumbrado Público	19,63	21,29	22,43
Grandes Consumidores	12,47	13,62	14,06
Medianos Consumidores	18,84	20,24	21,28
Zafra Estival	18,15	19,67	23,95
Precio Prom. Ponderado (Weighted Average)	19,66	21,27	22,38
Tipo de cambio promedio anual (Exchange Rate (31.17 now))	20,306	20,465	23,207

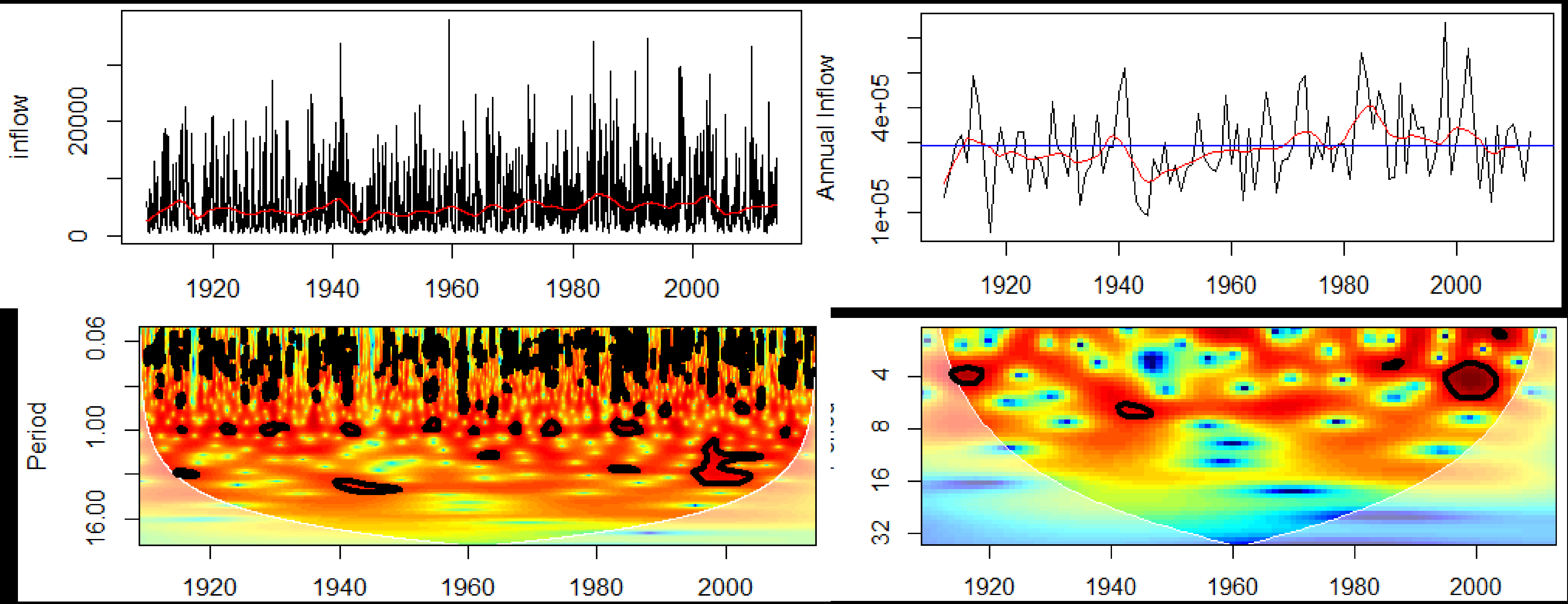


Energy Generation Costs and Fiscal Balances, 2003-13



Electricity Costs based on Projected Energy Mix vs Climate





Inflow into Hydropower reservoirs in Uruguay

Note: high seasonality and intra-annual variability, decadal variations, ENSO influence

Instruments

Energy Stabilization Fund FEE, 2010

WB Weather & Oil Price Insurance 2013

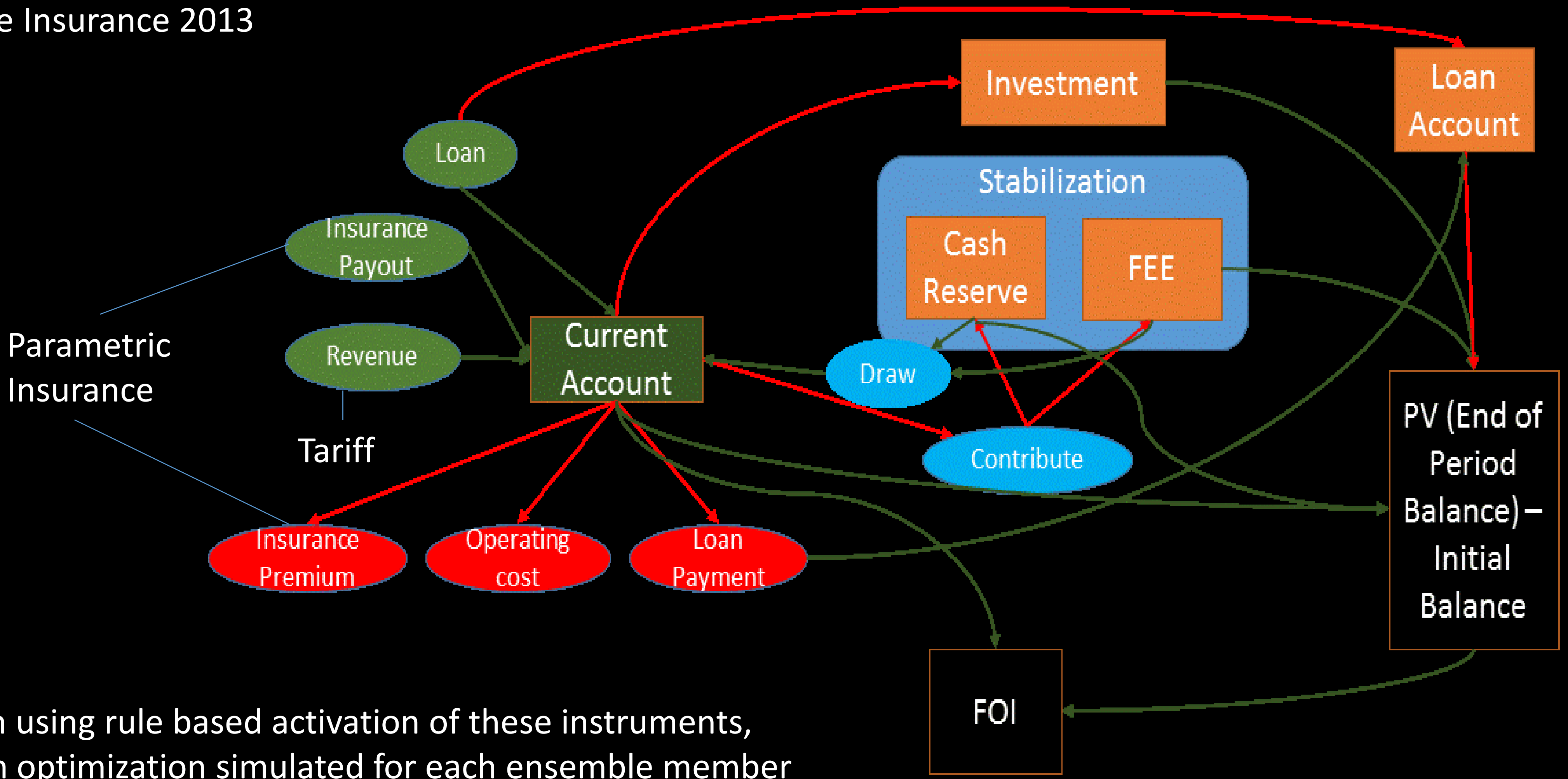
Cash Reserve

Investment

Current Account

Loans

Monthly Cash Flows over Planning Period follow operating rules

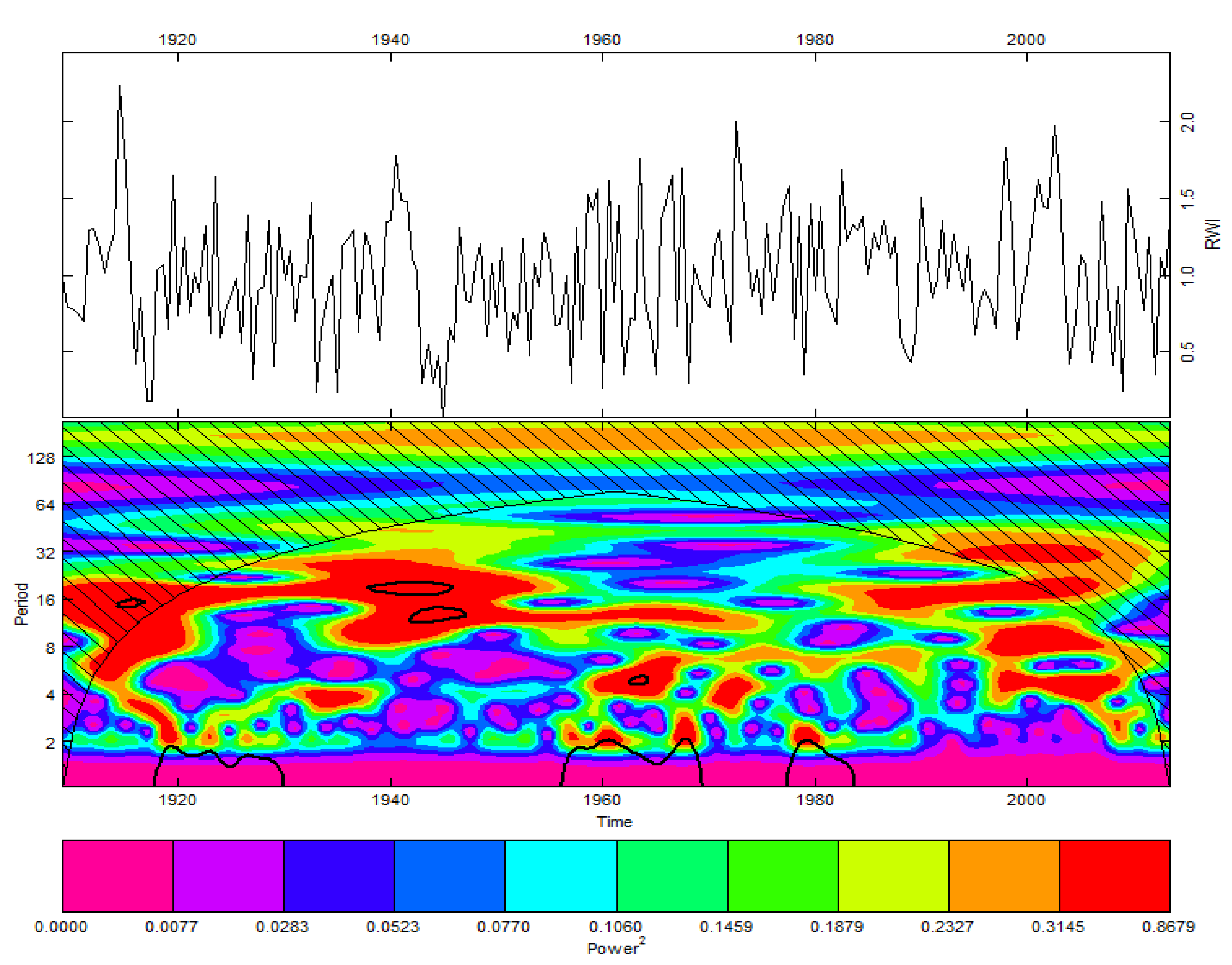


Entire System operation using rule based activation of these instruments, and hydropower system optimization simulated for each ensemble member from stochastic climate, oil market and currency exchange models

Parametric Insurance Payout

- Based on a “UPHEI Index” trigger
- Derived from a calibrated water balance model that converts monthly precipitation at 39 rain gauge stations with 35 years of data to monthly inflows into the 3 major reservoirs. The monthly inflow is then mapped to a daily inflow by assuming that the average rate of inflow can be used each day.
- The main reason for the use of this procedure is to define the UPHEI index so that it is based on independent data, beyond what is collected by UTE.

UPHEI Index and its wavelet spectrum



Design Optimization

Minimize Expected value of Net Present Value of (Costs-Revenues)
over all design parameters and a stochastic ensemble[1] of ns members
over a planning horizon T

$$E[NFOI] = \frac{1}{ns}\sum_{s=1}^{ns}\left\{\begin{array}{c} CAB_0^s + CRB_0^s + FB_0^s + IB_0^s - LB_0^s - \dfrac{CAB_T^s + CRB_T^s + FB_T^s + IB_T^s - LB_T^s}{(1+WAC)^T} + \\ \displaystyle\sum_{t=1}^{T} \frac{CP_t^s + PI_t^s + G_t^s + CCR_t^s + CCF_t^s + CCI_t^s + CDF_t^s - LP_t^s - DCR_t^s - DCF_t^s - IP_t^s - R_t^s}{(1+WAC)^t} \end{array}\right\}$$

[1] Simulations can be generated from

- A climate informed stochastic model for streamflow
- Models for the co-variation of currency exchange rates and oil prices

Decision Variables

For the current UTE model, the decision variables are all for the *index insurance* parameters:

- *Ts* = Strike level for each semester in GWh from UPHEI;
- *Ms* = Maximum value of the semi-annual payment in oil barrels (bbl) or in million US$ (MUSD);
- *Ma* = Maximum value for the annual payment in million US$;
- Ns = Oil Barrels to use per GWH produced

For the extended model considered, the additional decision variables are:

Tariff

Gr = $/MWH rate to be charged when a Green condition exists
Yr = $/MWH rate to be charged when a Yellow condition exists
Rr = $/MWH rate to be charged when a Red condition exists
Tg1 = Threshold at which there is a transition from a Green to a Yellow pricing tier, expressed in terms of either the % of total stored energy (tariff structure option 1) or of the % of Cash balance (or stabilization fund balance) as a function of the cap on the cash reserve (or stabilization fund)
Tg2 = corresponding threshold for transition from a yellow to green condition
Ty1 = corresponding threshold for transition from a yellow to red condition
Ty2 = corresponding threshold for transition from red to yellow condition

Cash Reserve

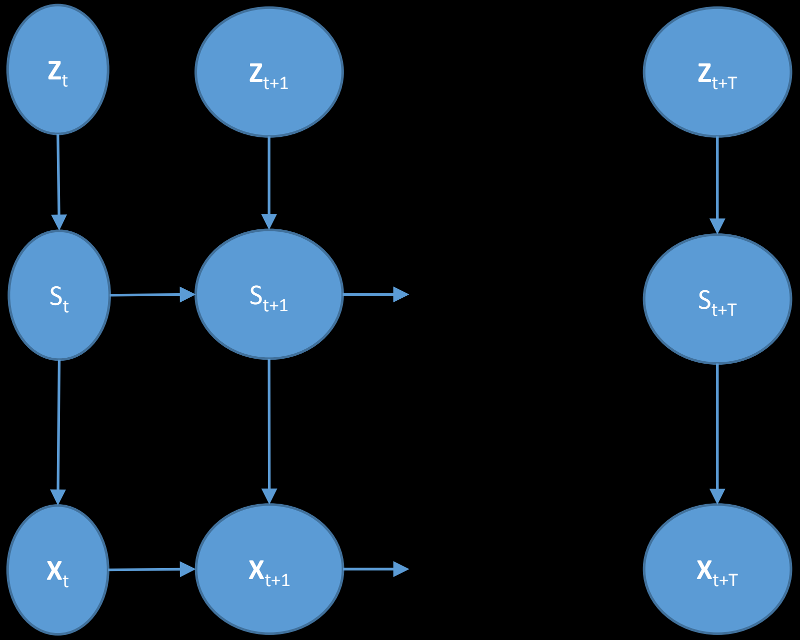
CC= cap on cash reserve

FEE

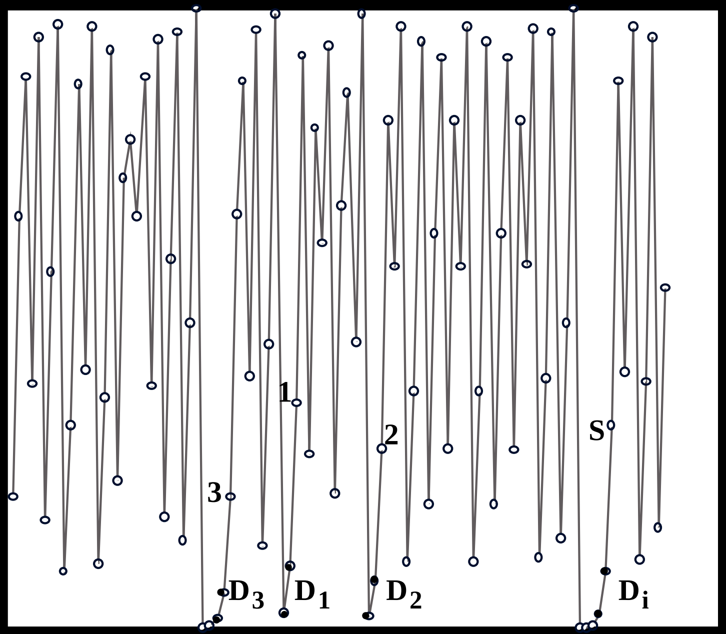
FC= Cap on stabilization fund
Tf1 = minimum threshold at which contributions to the FEE are to be made, expressed as a percentage of the GHR_A relative to the GHE_A (currently 65%)
RM1= The minimum rate of contribution as a function of the FC (currently 6.5%)
Tf2= secondary threshold at which contributions to the FEE are to be made, expressed as a percentage of the GHR_A relative to the GHE_A (currently 100%)
RM2= the maximum rate of contribution as a function of the FC (currently 8.5%)
TV = threshold for variable contributions as a % of the GHR_T/GHE_T (currently 115%)

Stochastic models for climate/streamflow, currency exchange rates and oil prices

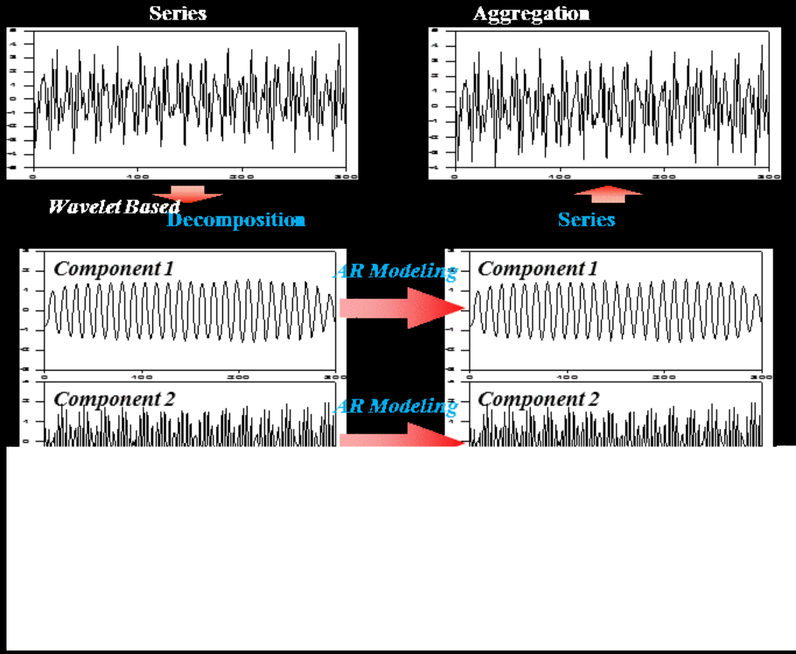
Non-homogeneous Hidden Markov Models



K-nn Block Bootstrap



Wavelet Autoregressive Models



Periodic Autoregressive Models

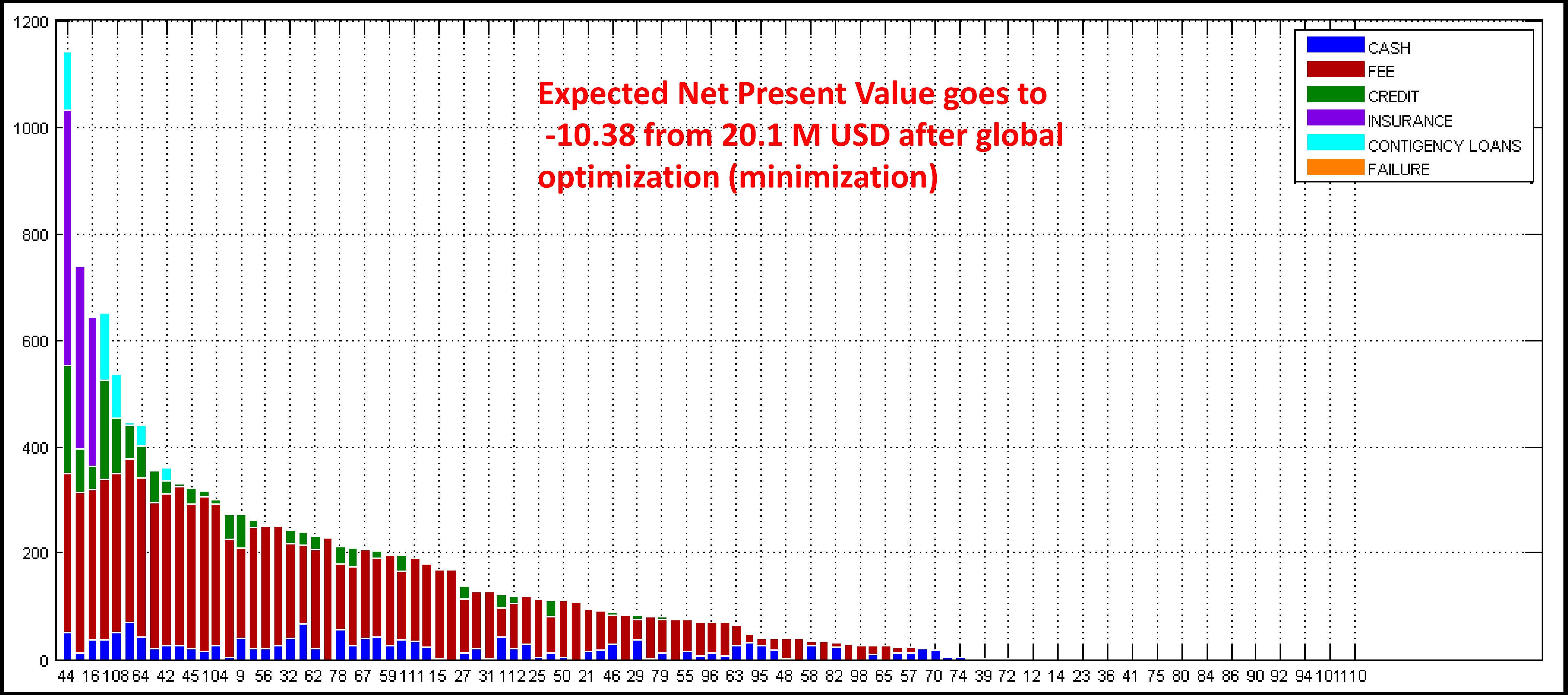
Mean Reversion Models

Predictive model of insurance premium

- Based on Expected Loss at strike points for UPHEI, and maximum payout
- Assumptions as to Taxes, profit percentage for insurance company

$$\text{Premium} = \frac{NPR * PMax * F\left(\frac{EL}{PMax}\right) + (1 - Tax)(EL + SW + ER * PMax)}{(1 - Tax) + NPR * F\left(\frac{EL}{PMax}\right)}$$

Use of instruments (period 2015-2016) for Optimizing climate insurance parameters that minimize E[FOI] keeping all other instruments at current values (simulated climatology + fixed currency & Oil prices)



Climate Variability and Change over SE South America

Climate changing on all timescales

- Unusually large trend for P, not captured by IPCC models

Decadal variability is important

- Dynamical predictions are new, and don't have much skill (possibly showing promise over SESA??)
- Alternatively can characterize variability, to test systems and risks
- Recent drought and Decadal Variability

El Niño variability still important in the region

- New research on long-lead ENSO forecasts (3-4 years out)
- Better management of year-to-year management in combination with informed decadal-scale planning/contracts

Climate Variability & Change in SE South America - DJF

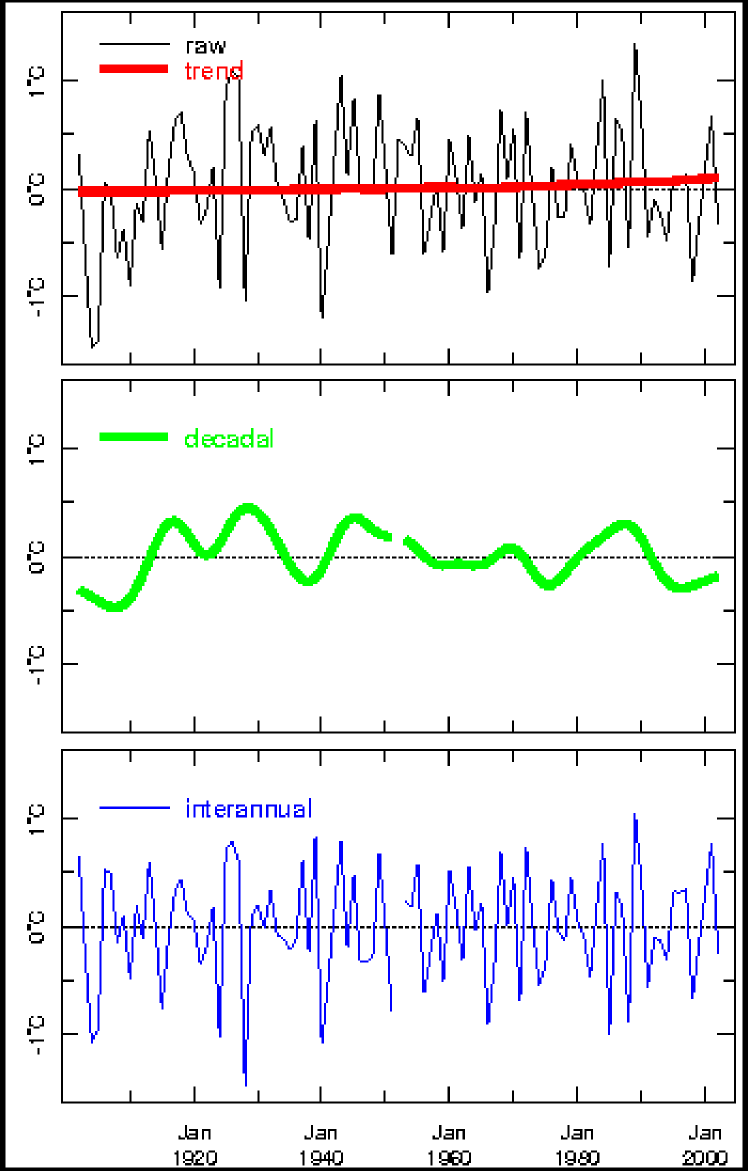
TEMPERATURE

PRECIPITATION

~0%

17%

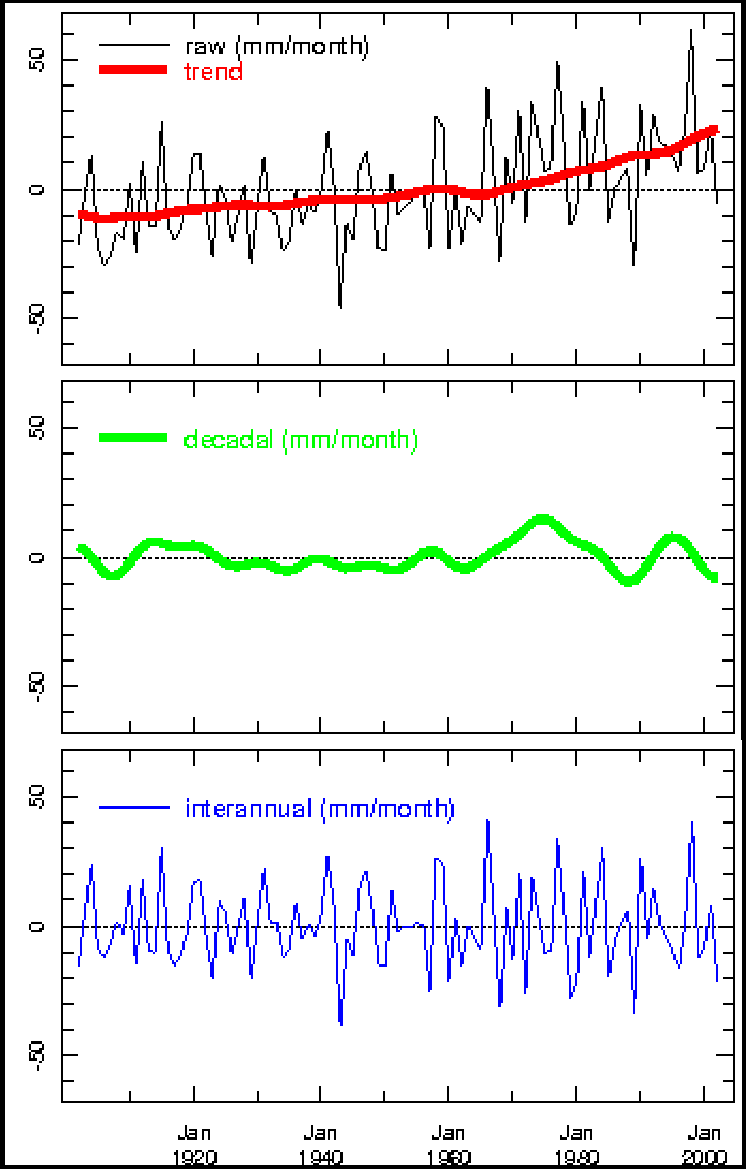
80%



21%

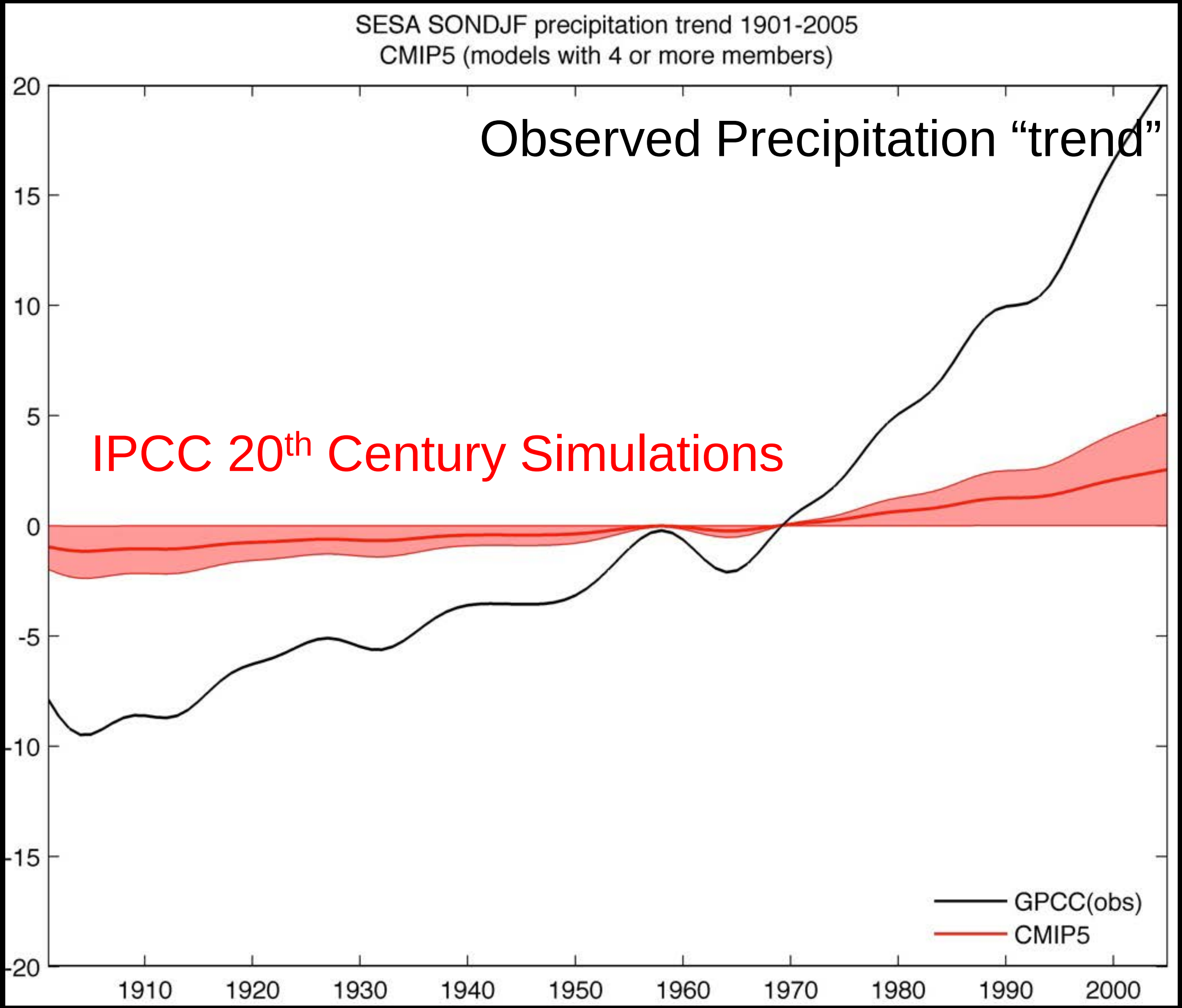
8%

69%



Models may not get correct magnitude of trend

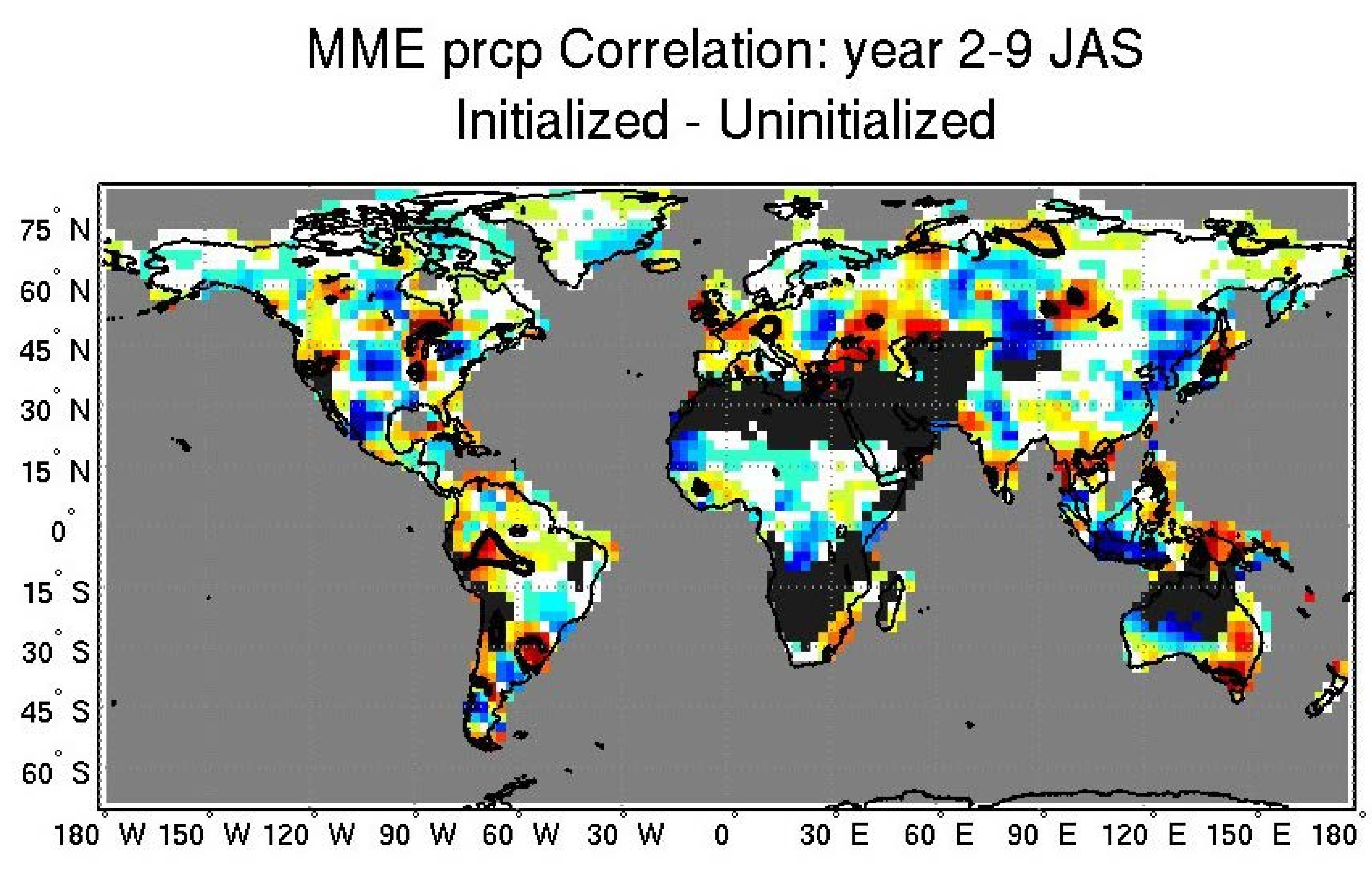
Precipitation Changes over SE South America (Sep-Feb 1901-2005)



(Gonzalez et al. 2014, *Clim. Dyn.)*

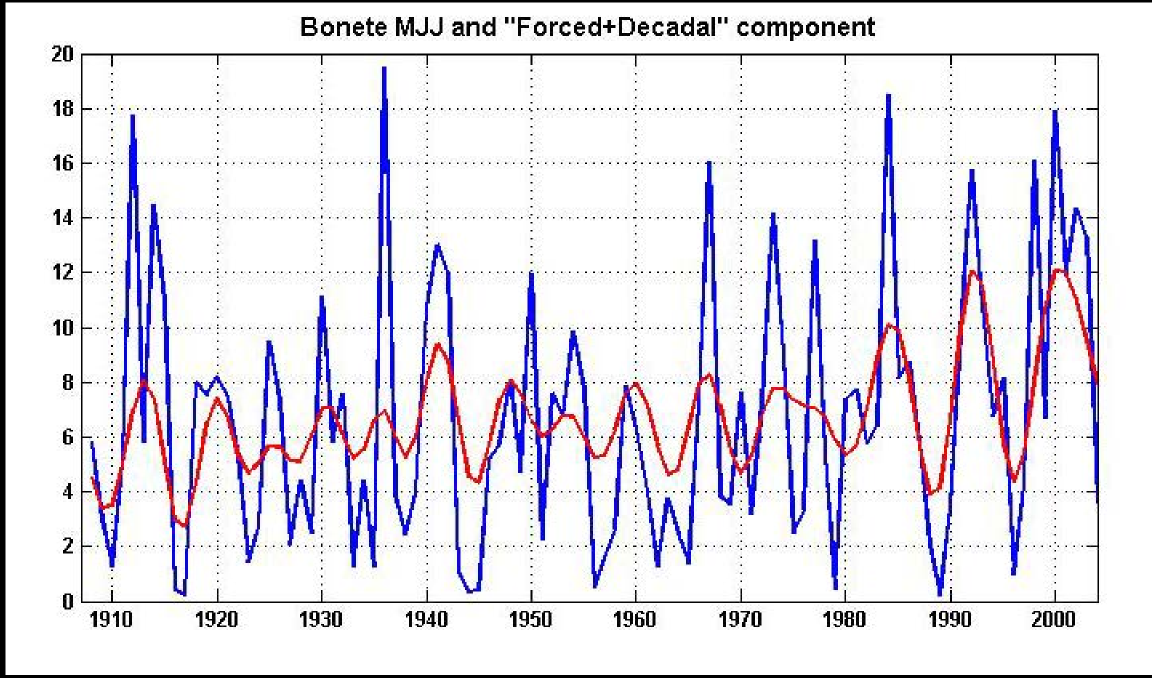
Decadal Predictions: *Skill??*

Multi-model Ensemble (12 models: Equal Weighting)



(based on Goddard et al. 2012, Climate Dynamics; See also http://clivar-dpwg.iri.columbia.edu)

Hydropower and Decadal Climate Variability



Data Courtesy of
R. Terra and A. Diaz

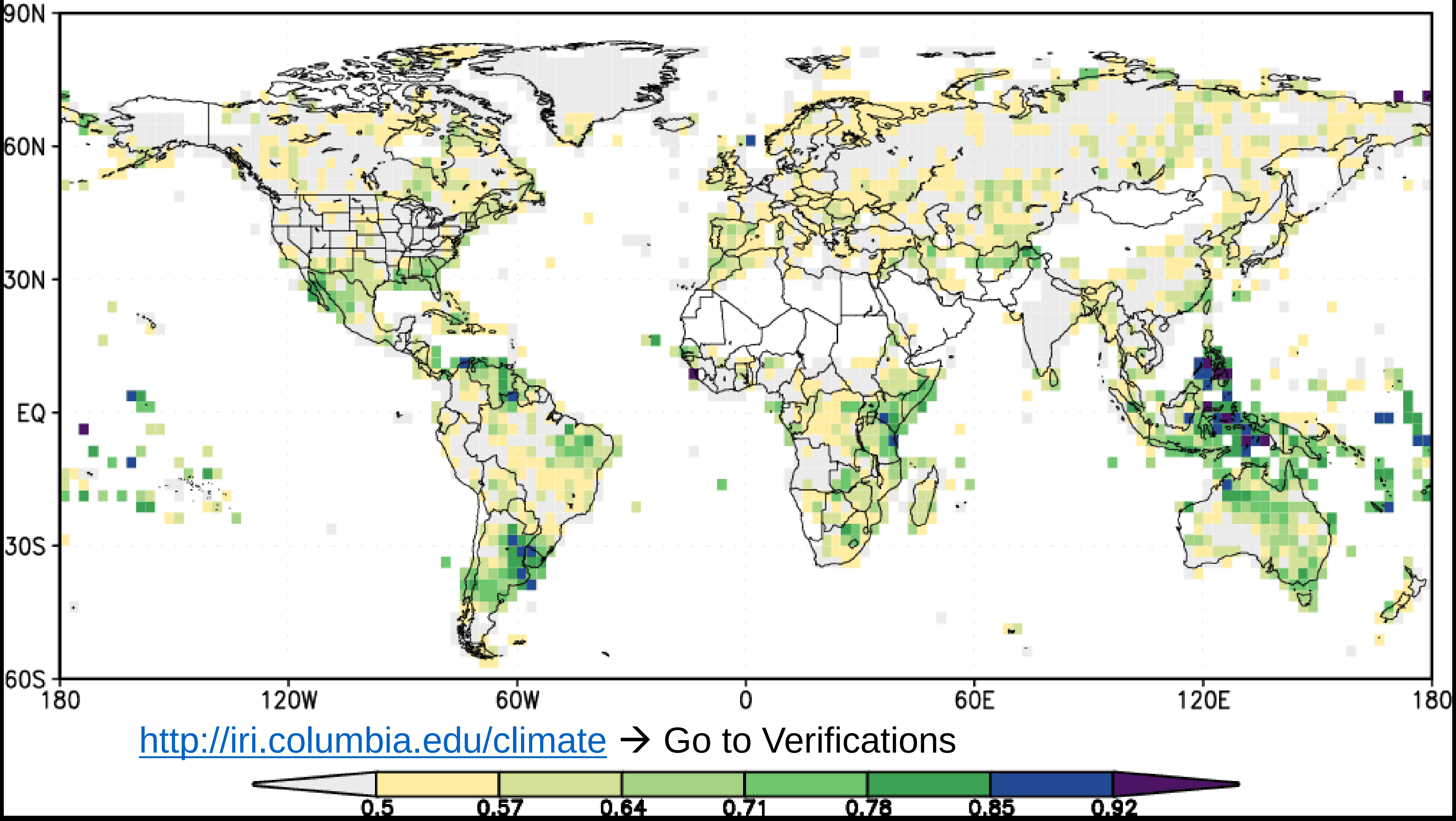
1) Improving year-to-year management:

How do decadal fluctuations modulate ENSO impacts in the region?

2) Long-term planning of water & energy contracts (typically 5-10 years):

Can mean and variability for next 5-10 years be predicted within ‘some level of confidence’?

Seasonal Rainfall Forecast verification - OND



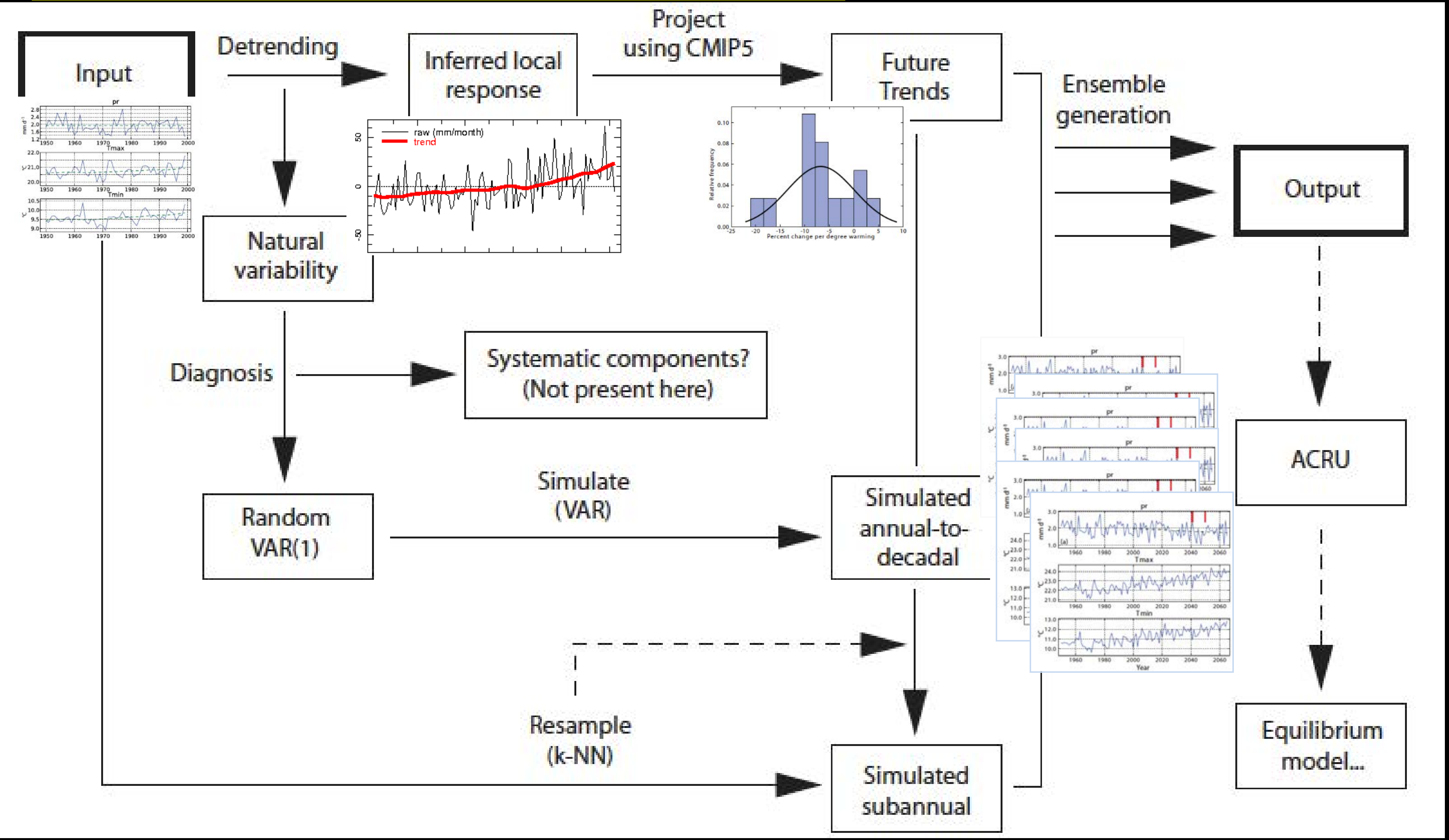
http://iri.columbia.edu/climate → Go to Verifications

This is a measure of discrimination. Do the forecasts recognize events and non-events? If the forecast probability of an event is higher one year, is the event really more likely?

Decadal Characterization using statistical methods

STOCHASTIC SIMULATIONS: 2 Ensemble Members

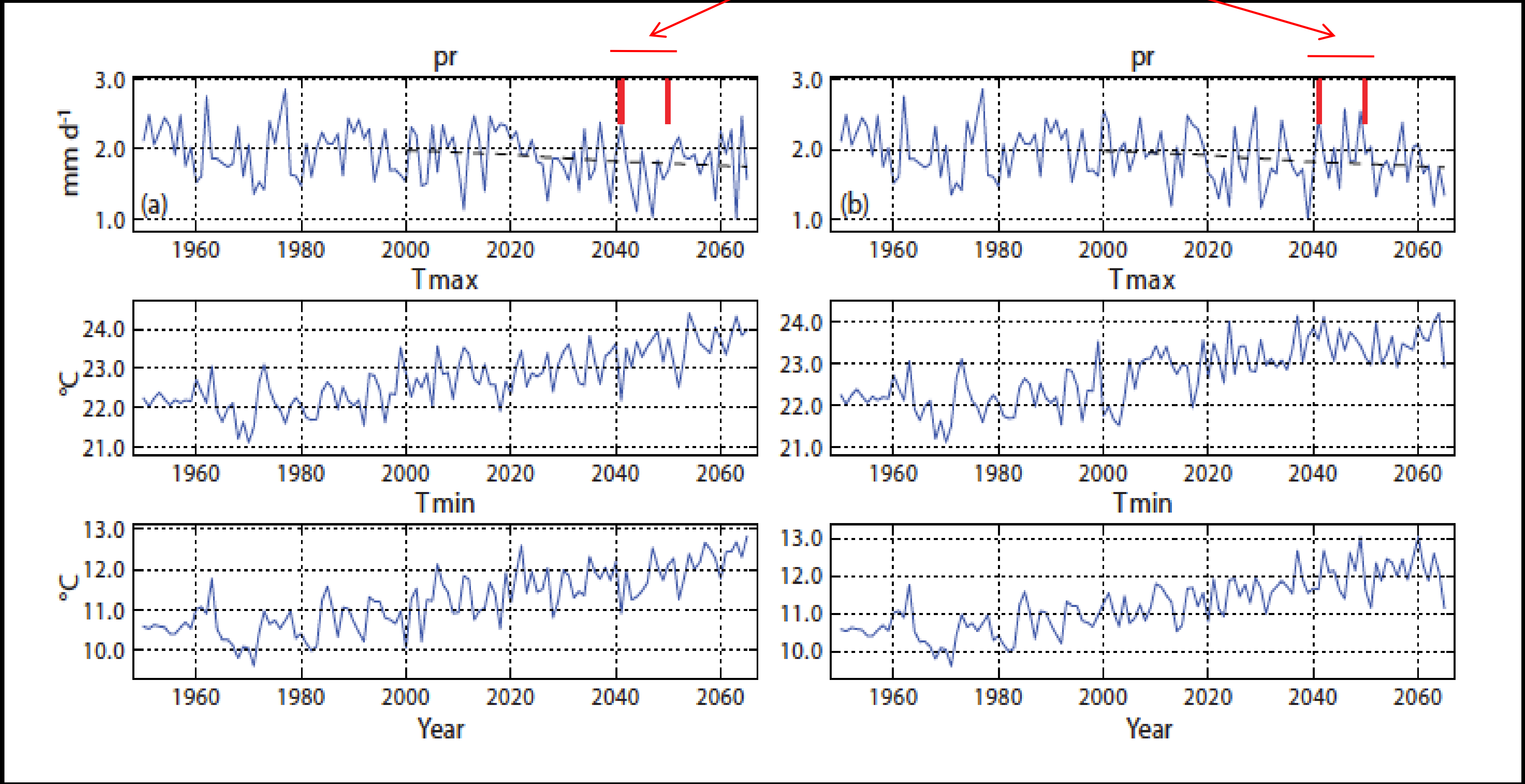
(Greene, et al. 2012)



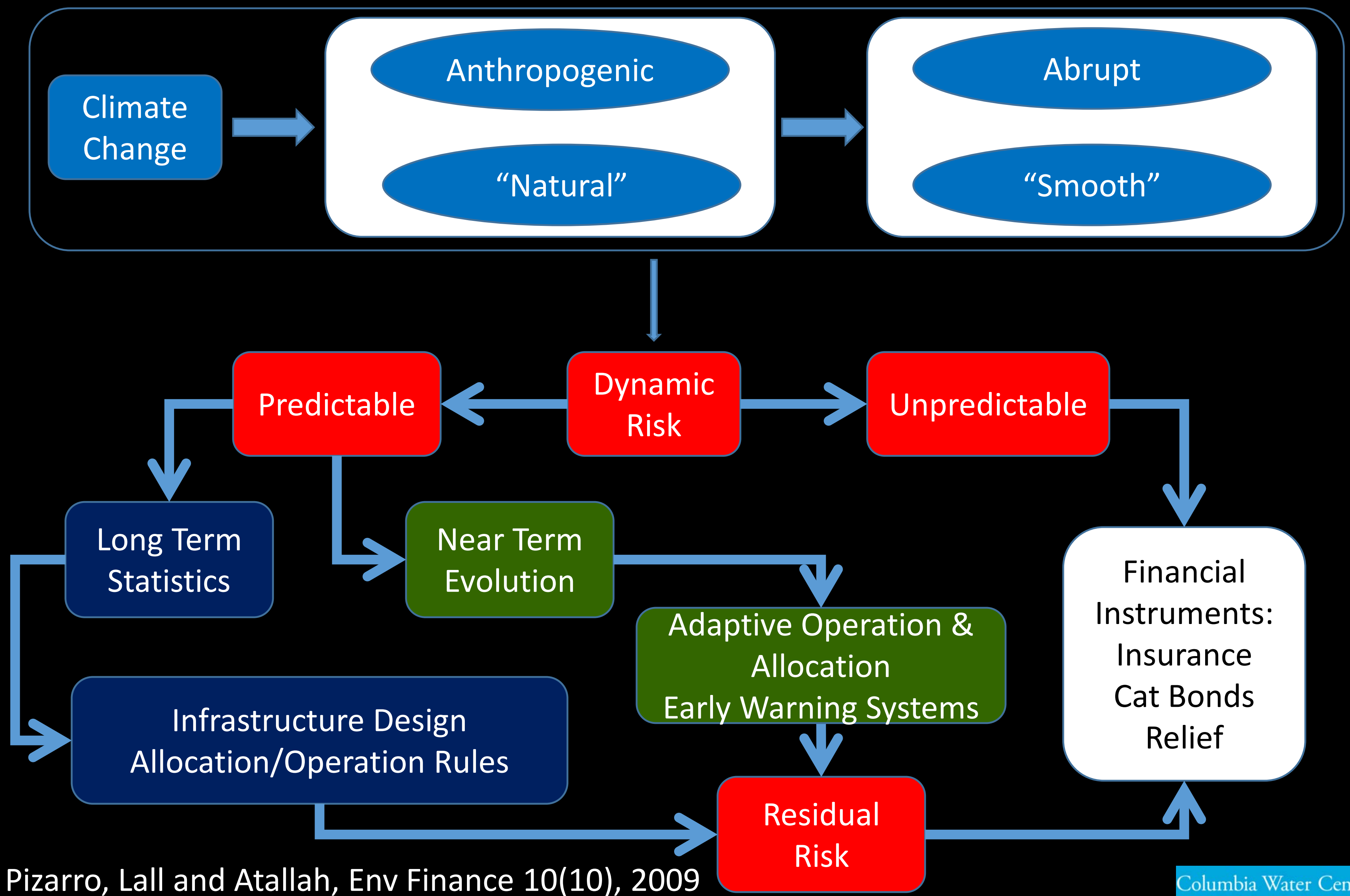
Decadal Characterization using statistical methods

STOCHASTIC SIMULATIONS: 2 Ensemble Members – (Example for South Africa)

Decadal Variability



Building Resilience to Climate Risk:



Pizarro, Lall and Atallah, Env Finance 10(10), 2009

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Summary

- Integrated approach to the design and optimization of climate risk management tools for energy systems
  - Climate Science → Simulations and Prediction
  - Modern, Stochastic/Machine Learning Models → Simulations
  - Comprehensive consideration of Instruments
    - Financial Instruments
    - Reservoir Management
    - Demand Management
  - Global Optimization
  - Client Participation: Discussion, Review, Implementation, Feedback, Practical constraints