Stochastic decadal simulation: Utility for water resource planning

Arthur M. Greene, Lisa Goddard,
Molly Hellmuth, Paula Gonzalez

International Research Institute for Climate and Society (IRI)

Columbia University, New York, NY USA

Trevor Lumsden

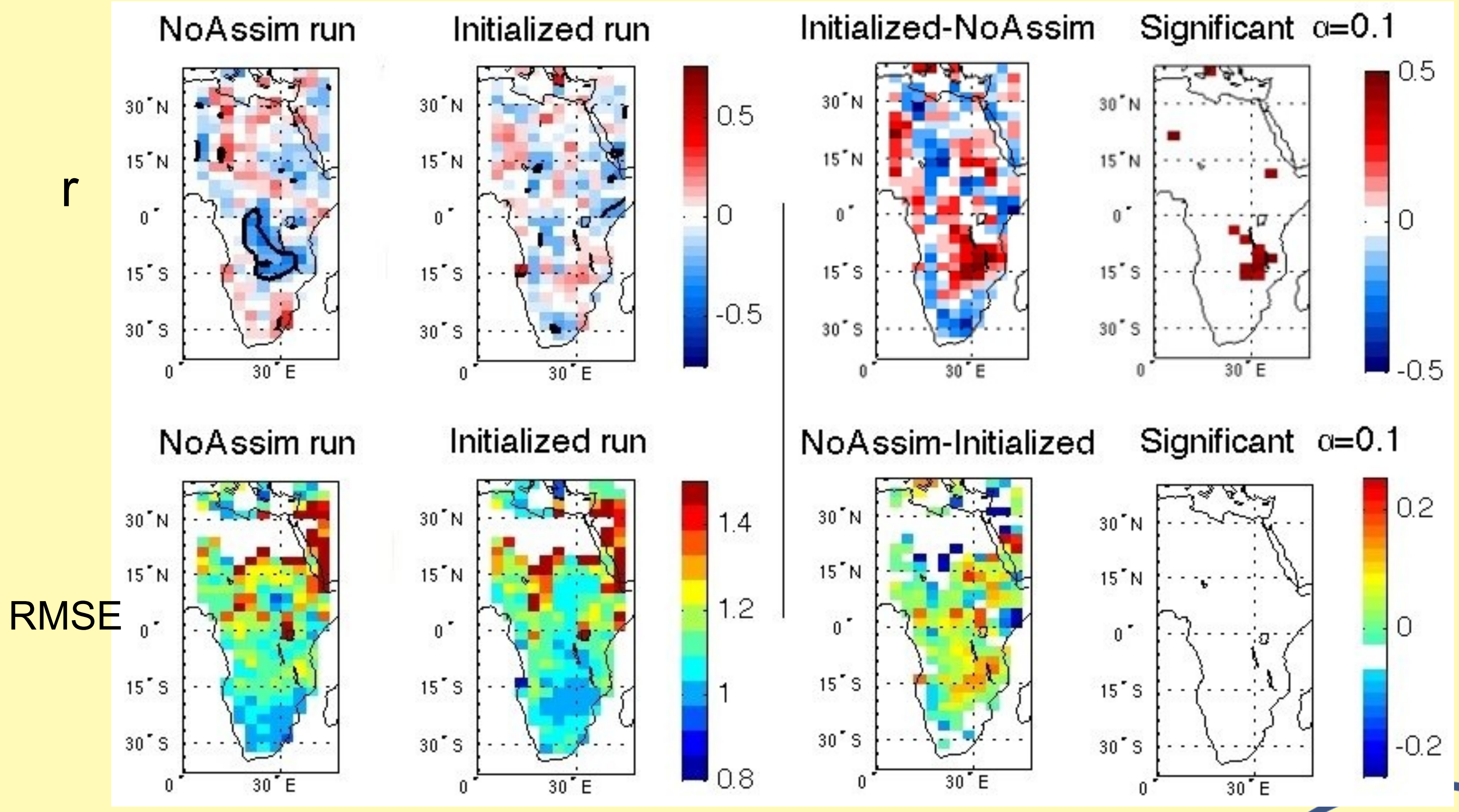
University of KwaZulu-Natal, South Africa

36th CDPW, Fort Worth, October 2011

In a nutshell…

- Skillful decadal forecasts over land, particularly at regional scales, remain to be demonstrated.
- A potentially useful alternative: Synthetic data sequences, conditioned by observations and including a regional climate change component.
- Practical example: The Berg and Breede Water Management Areas, Western Cape, South Africa.

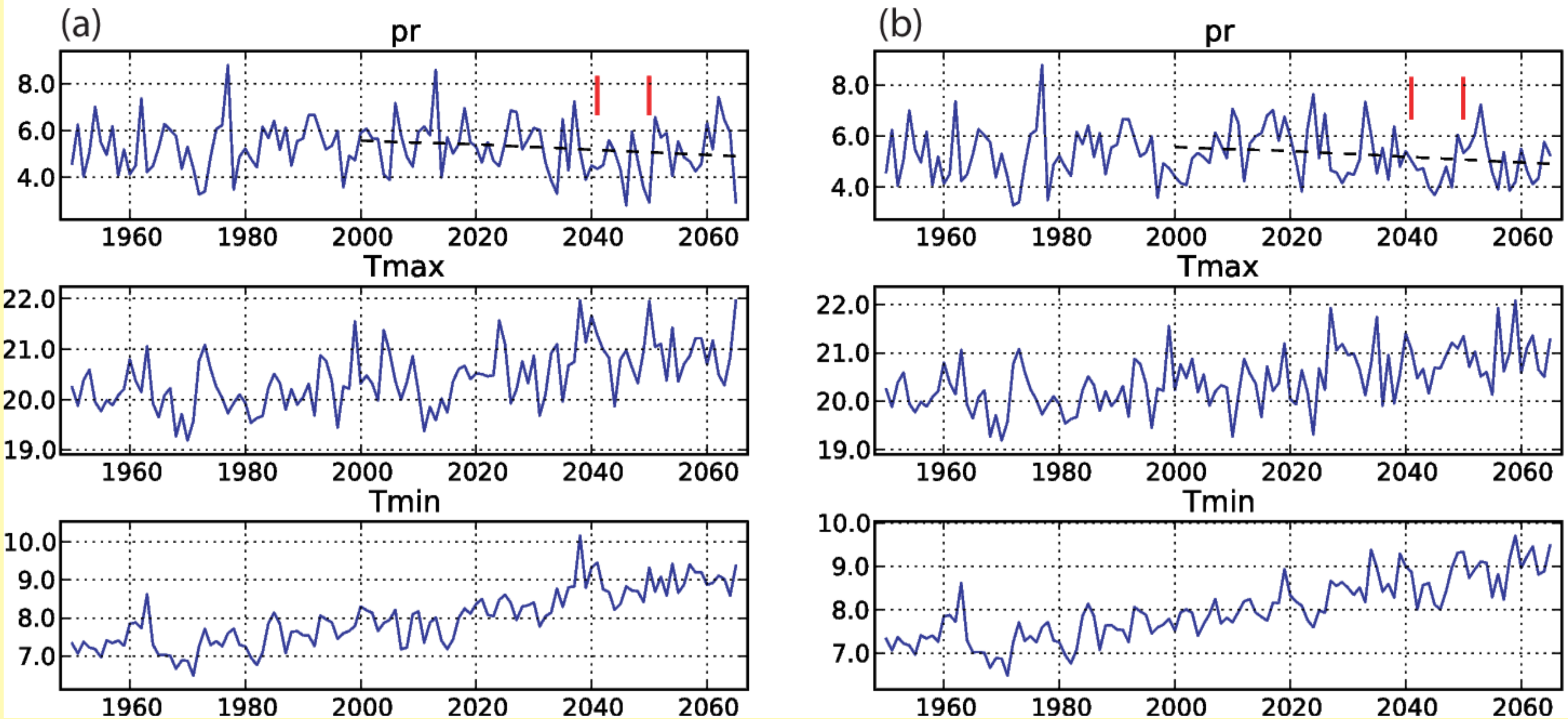
Recent initialized precipitation forecasts - Africa



Data courtesy Doug Smith (see Smith et al., Science 2007)

- Verification: 2-5 yr mean precipitation, using GPCC
- Conclusion: Initialization does not improve forecast skill for (southernmost) Africa at this lead.

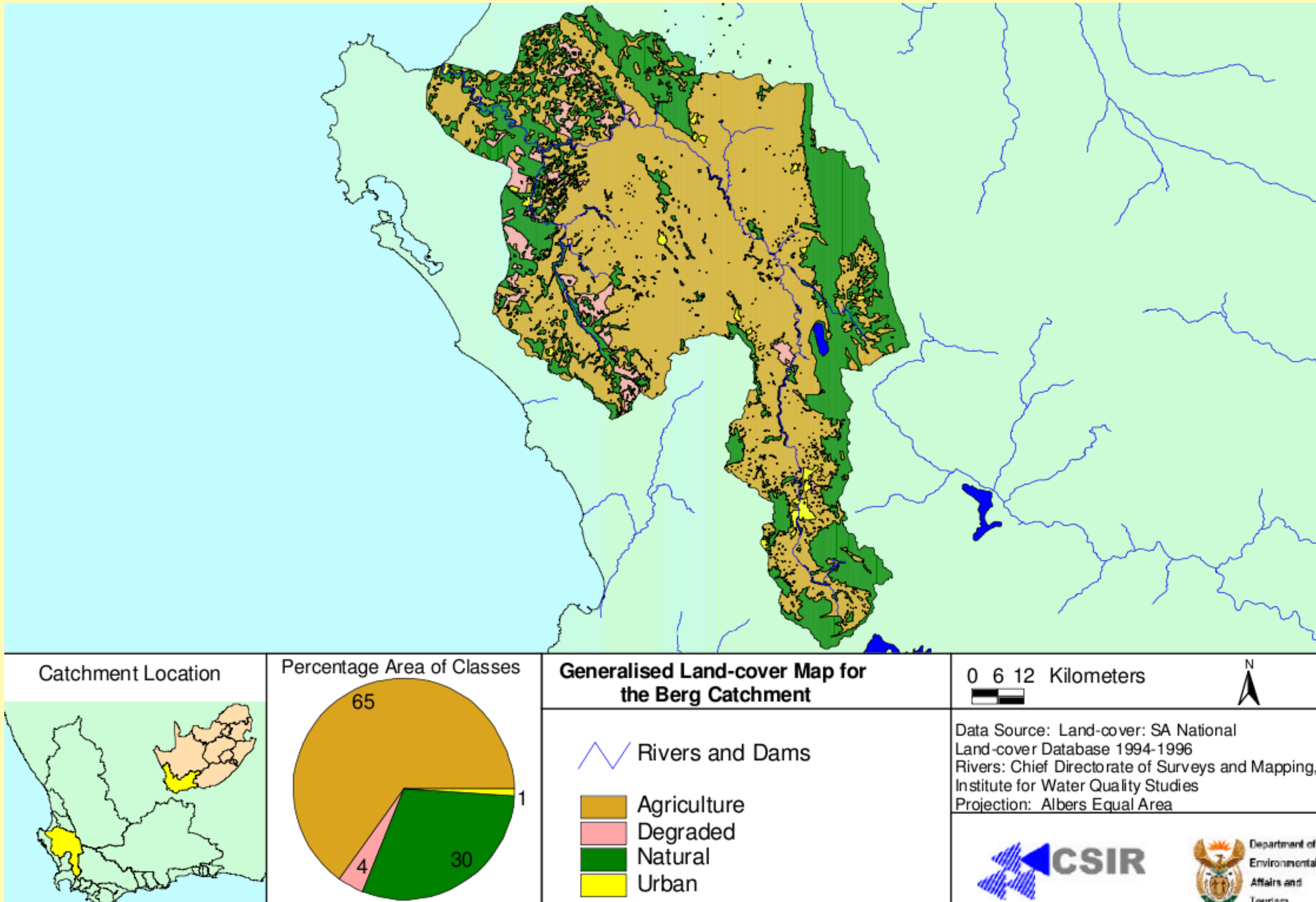
An alternative: Synthetic approach can help to delimit uncertainty



- Two realizations from a stochastic model, for an individual station within an economically significant watershed. (data are trivariate).
- Decadal-mean precip for 2041-2050 falls at the fifth percentile for both, but within-decade variations differ.
- Detailed statistics are conditioned by obs; long-term trends by IPCC

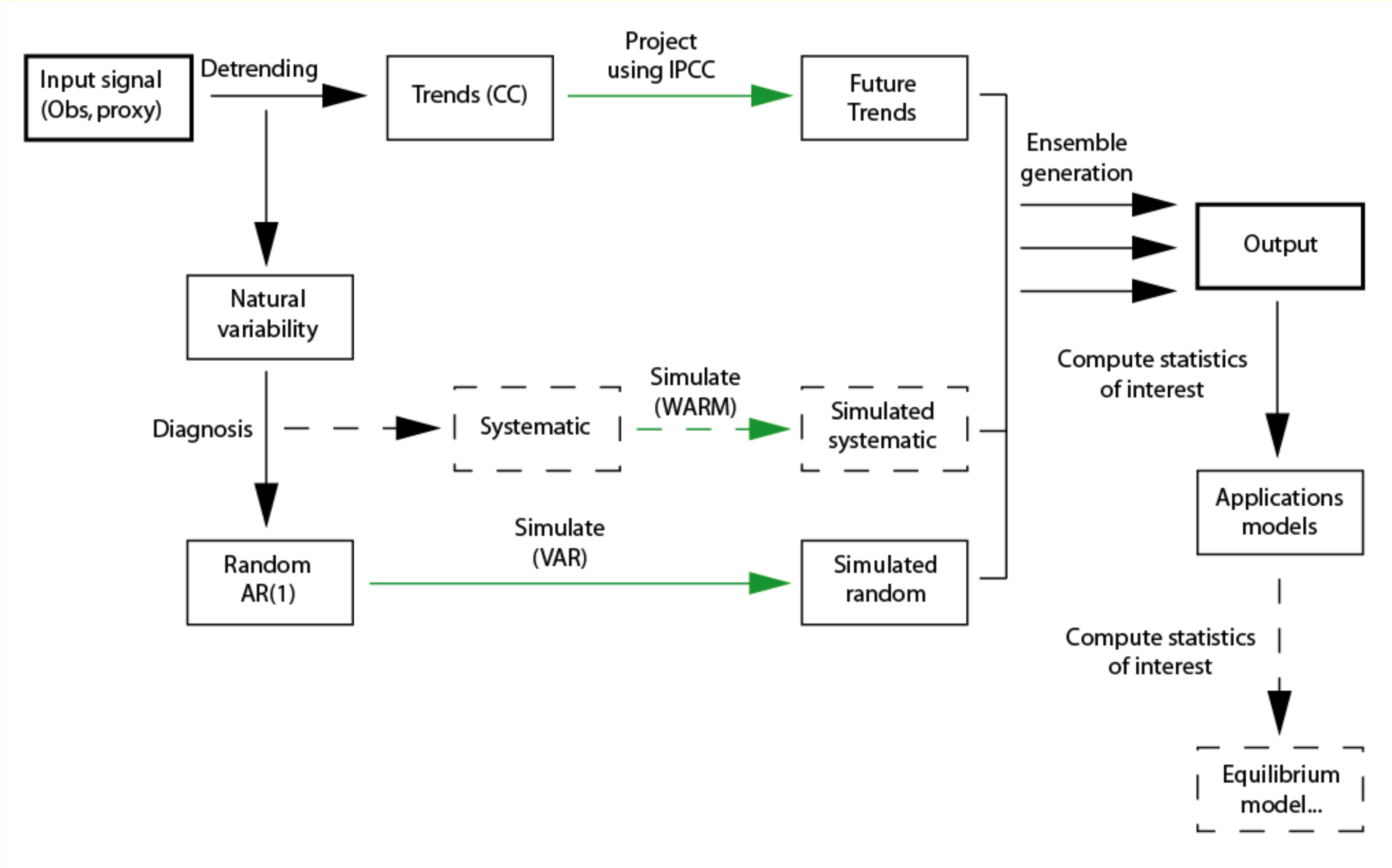
Study area (in part): Berg river watershed

- Length: ~300km
- Area: 7715 km^2
- Headwaters in Drakenstein mountains, ~1000 m.a.s.l.
- Precipitation, temperature gradients with elevation
- Principal H_2O source for Cape Town, including commercial, industrial
- Economically significant agricultural resource
- Extant data, hydrology and economic models make for an excellent "testbed."



IRI

Simulation schematic



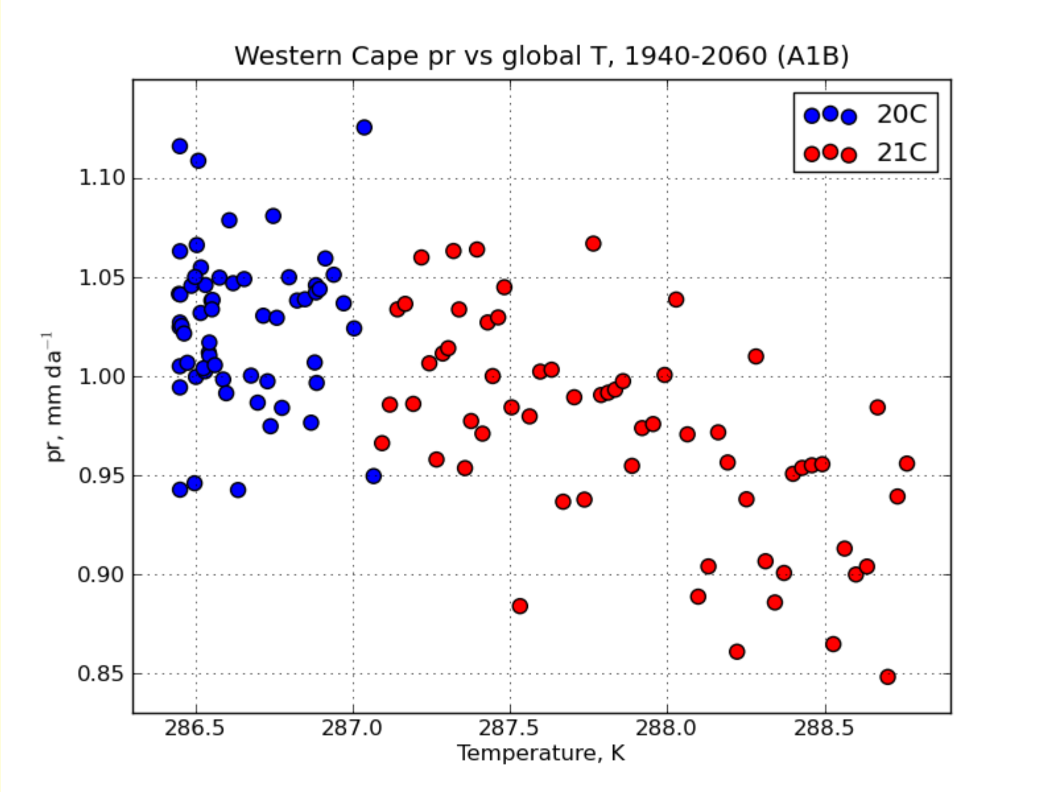
Green arrows: Subjective judgment required

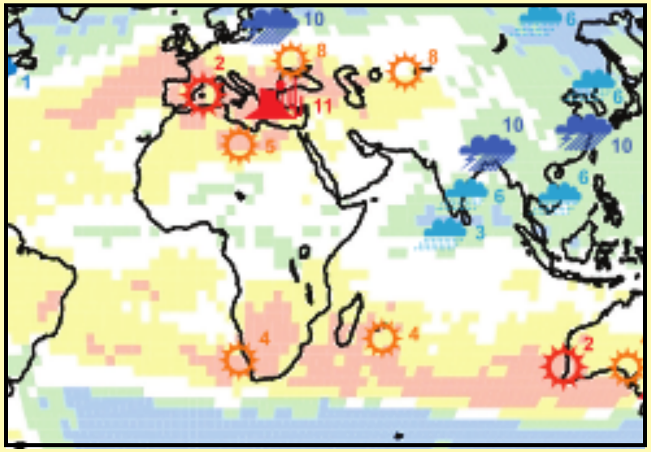
Simulation design issues

- Projection of regional forced signal
  - Estimation of regional response
  - Implicit role for IPCC models
- Identification of systematic signal components
  - Here, meaning “significantly different from AR(1)”
  - A key decision: How to represent? One option: “WARM”
- Stationarity assumptions
  - Second moments
  - Serial autocorrelation (→ AR(1) variability)
  - Seasonal cycle, daily statistics
  - Local/regional covariation – spatial scale of decadal “footprint”
- Description of uncertainty
  - Arises at many levels: intermodel, scenario, estimation…
  - Not solely a matter of amplitude, but also temporal behavior
- Multivariate model
  - May be required by downstream modeling framework
  - Best if training data conforms…

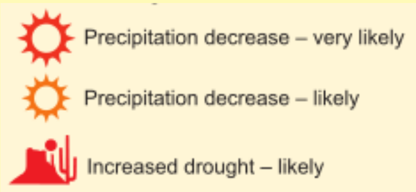
Climate change trends: Which century to trust?

- Regional pr response to global mean temperature change: Weak in 20c, decidedly negative in 21c.
- Because (a) consensus among the IPCC models is strong, and (b) region lies at the poleward margin of the dry subtropics, 21c sensitivity is utilized.
- Consequence: Simulated precipitation decreases by about 10% by mid-century (annual mean).

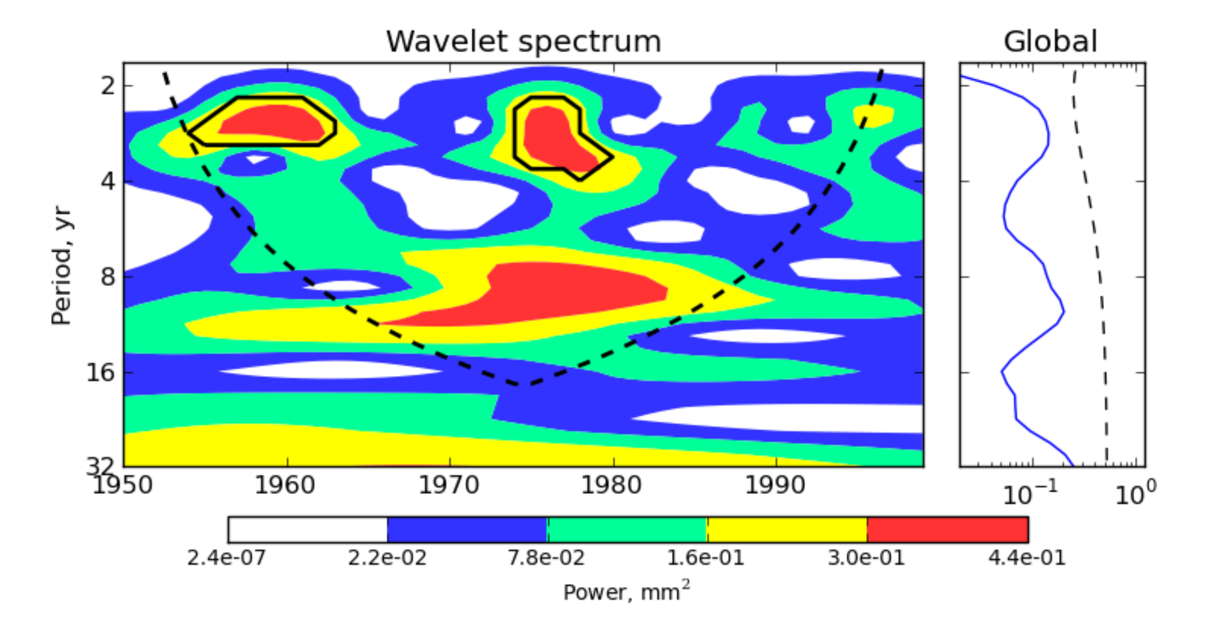




IPCC, 2007



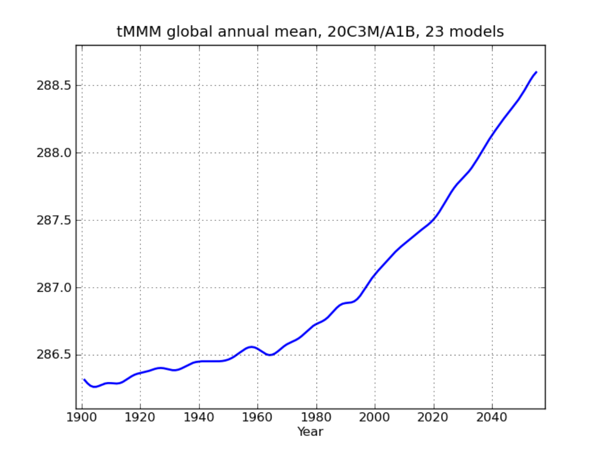
What's the frequency, Kenneth?



- A regular oscillation with 18-yr period has been reported for Southern Africa precip. This was not detected by a wavelet analysis (figure).
- Spectra for Tmax, Tmin show no evidence for systematic processes, i.e., different than AR(1).
- Annual-decadal simulation component then requires just two elements: Climatic trend and stochastic variations.

Berg and Breede WMAs: Simulation detail

- Multivariate setting: pr, Tmax, Tmin
- Observations: 50 yr of daily data (1950-1999) for 171 quinary catchments in the Berg (mostly) and Breede WMAs.
- Forced trends from IPCC (A1B)
- - For Tmax, Tmin, via 20C regression
- - For pr, via 21C regression
- Because there is no evidence for systematic low-frequency variations, only trend and stochastic components are modeled.



- Annual–multidecadal variability simulated with VAR(1) model.
- Subannual variations generated by block resampling observations.

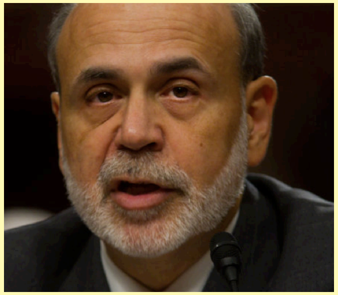
Vector autoregressive (VAR) model in brief

Formally, $\mathbf{y}_t = \mathbf{A}\mathbf{y}_{t-1} + \boldsymbol{\varepsilon}_t$, where

$\mathbf{y}_t$ is a three-component vector (pr, Tmax, Tmin) at time t,

$\mathbf{A}$ is a 3 x 3 matrix of coefficients, and

$\boldsymbol{\varepsilon}_t$ is a noise process that is white in time, not necessarily in (parameter) space.



- Historically, VAR models are associated more with econometrics than with climate, but structurally, a VAR model of order 1 is essentially a linear inverse model.
- For simulation purposes, two data characteristics are of primary concern: Intervariable correlation and serial autocorrelation in the individual variables.

VAR fit: Observed, simulated statistics

Intervariable correlation

Observations

	pr	Tmax	Tmin
pr	1.000		
Tmax	-0.447	1.000	
Tmin	0.068	0.733	1.000

Simulation

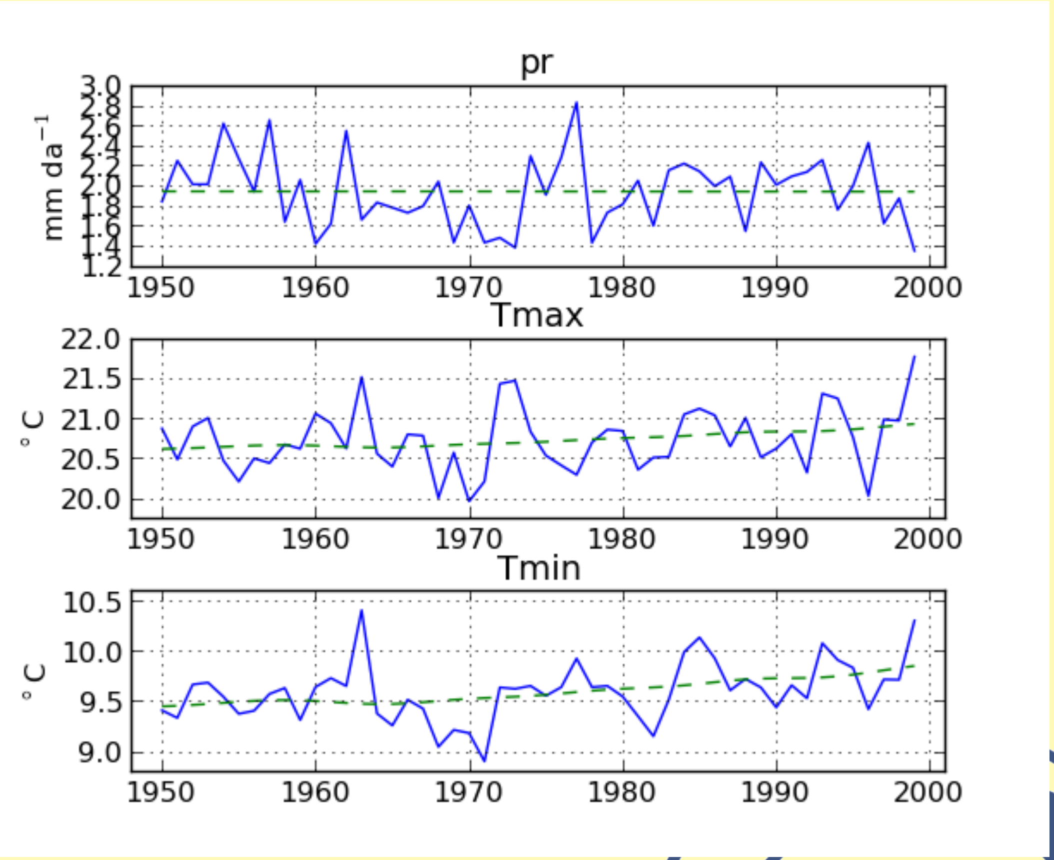
	pr	Tmax	Tmin
pr	1.000		
Tmax	-0.445	1.000	
Tmin	0.068	0.733	1.000

Serial autocorrelation

	pr	Tmax	Tmin
Obs	0.004	0.168	0.297
Sim	-0.008	0.176	0.303

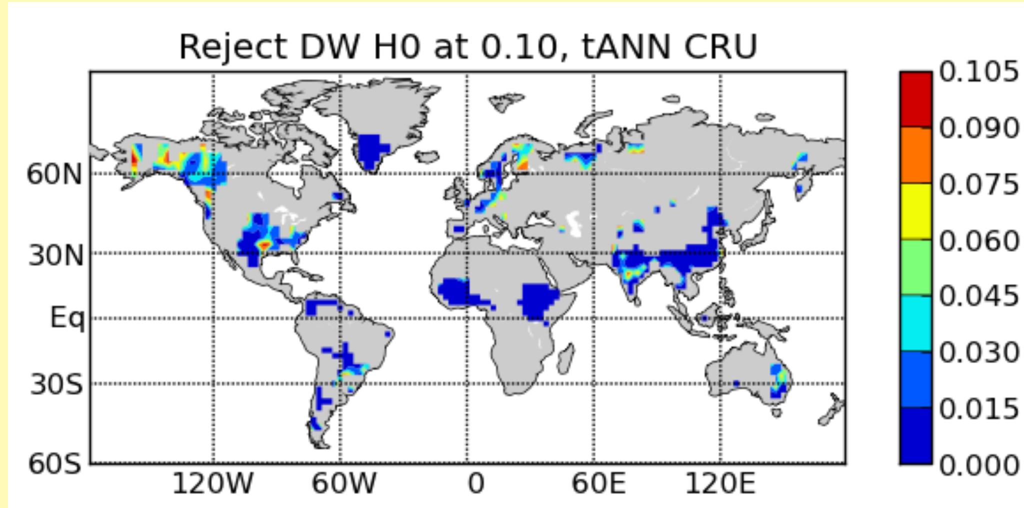
Tmin significant at 0.05,
Tmax not quite…

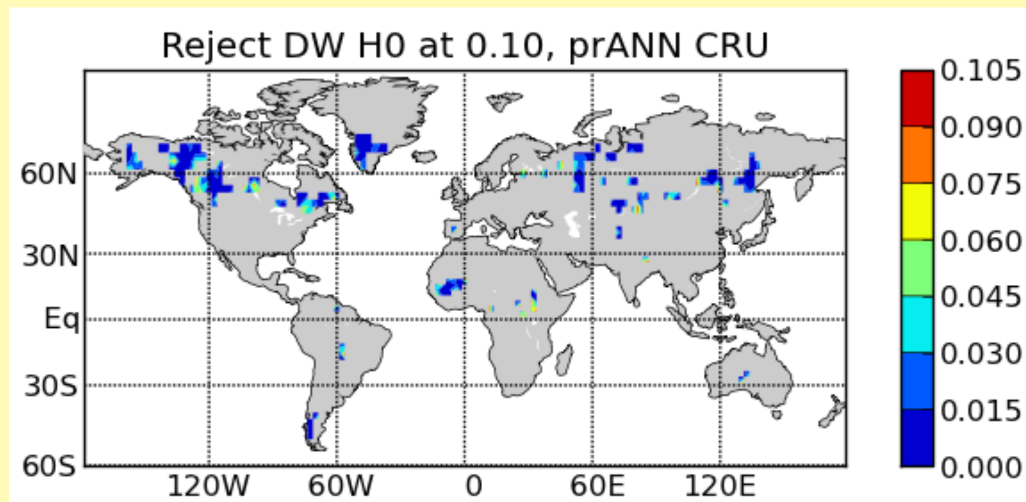
Annualized data (171-station means)



Where is redness?

- p-value for rejecting H0: Residuals are not lag-1 autocorrelated.
- Regression is on the MMM global mean temperature.
- Annual mean temperature (top), precip (below).
- Screened for filled data – removes many gridpoints from consideration.

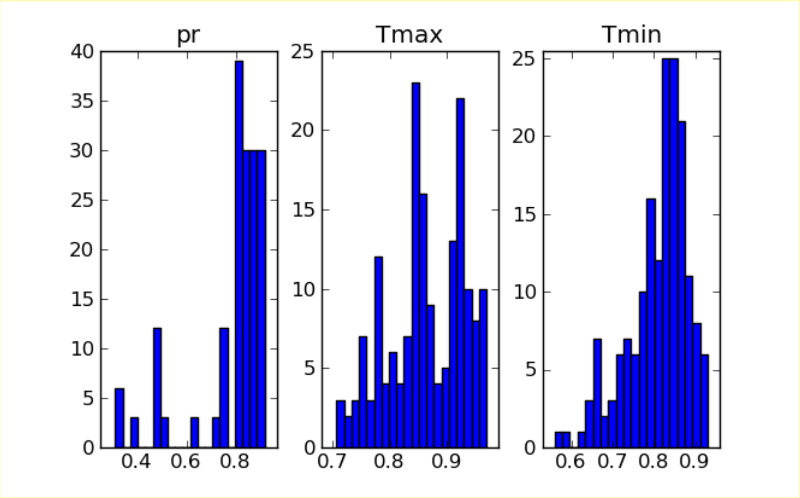




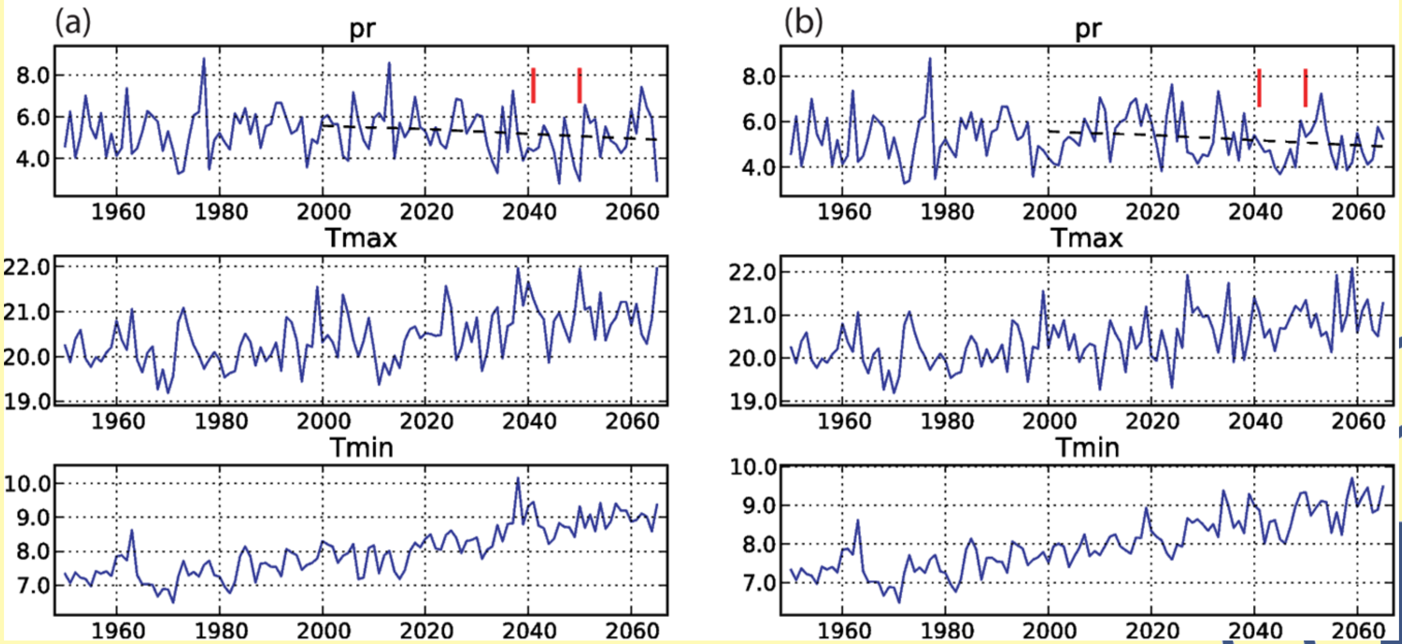
Propagation of simulations to the local level, daily time scale

- Individual station records are well-correlated with the “regional” signal: Catchment behaves coherently (top).
- “Decadal” signal downscaled to station level via linear regression.
- Subannual variations: block-resampled from observations → spatial coherence.
- Single simulation “instance” propagated to entire catchment, enabling distributed streamflow scenarios.

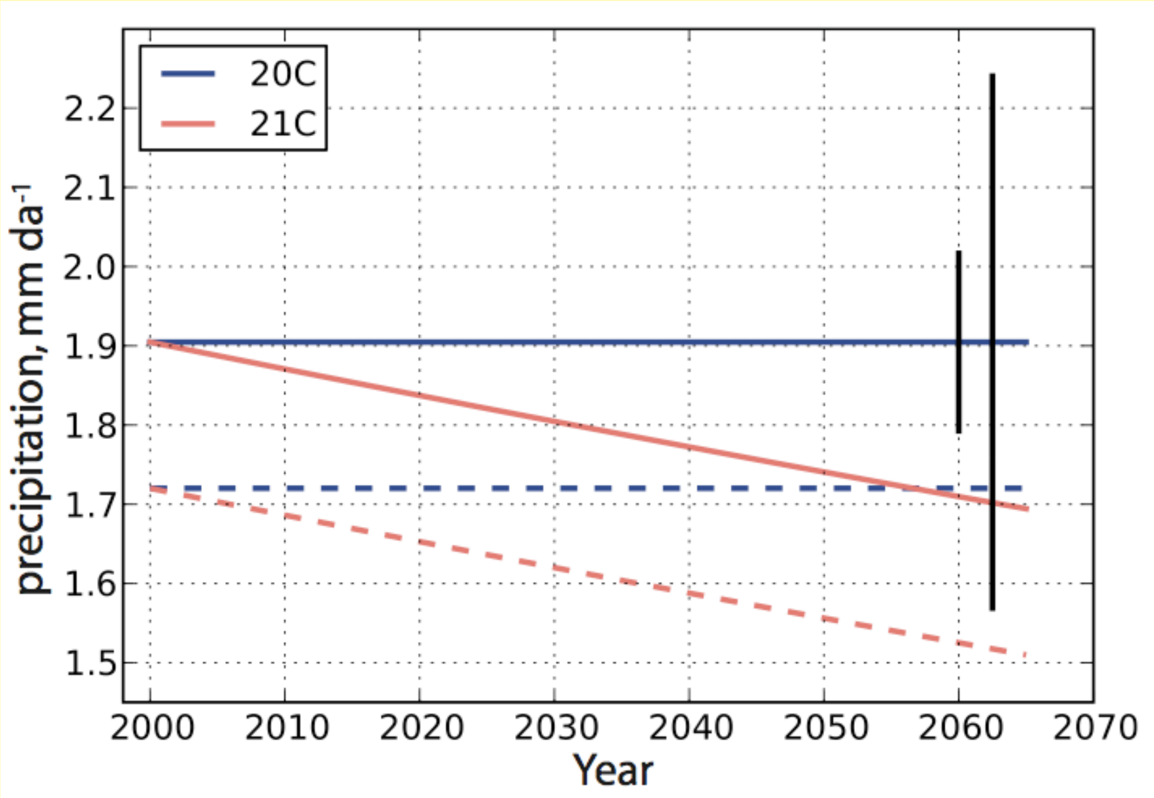
Station correlations with regional signal



Station-level simulation; T trends are local



Projected rainfall shifts in the context of interannual, decadal variability



- By mid-21st century, mean annual precip is projected to lie at about the present fifth percentile for decadal means.
- This shift is less than 1σ for interannual variability.
- Follow-on models will help to “interpret” stochastically simulated variability, in the context of projected demand.

IRI

Some concluding remarks

- Method might be termed a “decadal weather generator,” but some elements assume particular importance in this framework:
  - Mandatory treatment of secular (i.e., climate change) trends
  - Explicit consideration of low-frequency variability
- Changepoints, anthropogenically-induced shifts in variance not evident in the (50-yr) observational record; no provision made for these in simulations.
- Relevant paleodata – if they existed – could possibly play a role.
- Uncertainty in GCM sensitivity to be treated
- Simulations are presently being run in the first “downstream” model: Agricultural Catchments Research Unit (ACRU) agrohydrology model, University of KwaZulu-Natal. Stay tuned!

-~- The End -~-

amg@iri.columbia.edu

IRI