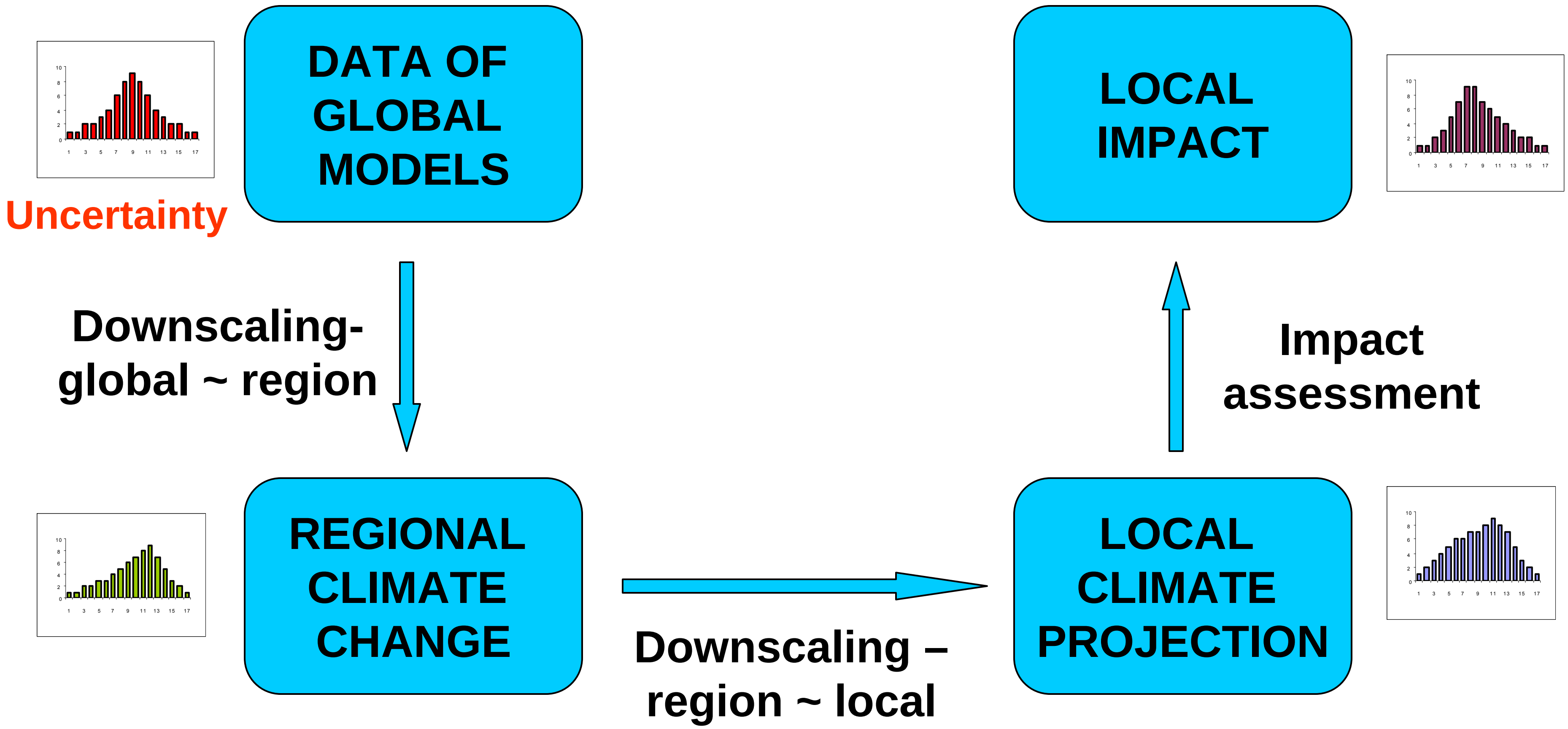
Impact of Climate Change on Crop Yield - A Case Study of Rainfed Corn in Central Illinois

Ximing Cai, Dingbao Wang, Romain Laurent

Ven Te Chow Hydrosystems Laboratory
Department of Civil and Environmental Engineering
University of Illinois at Urbana-Champaign

The procedures



Uncertainties in Climate Change Projections

- Emission scenarios:
  - Which greenhouse gases are emitted into the atmosphere? Where? When?
  - Demographic, economic, technological, environmental…
  - SRES (2000) : 6 illustrative scenarios (A1FI, A1B, A1T, A2, B1, B2)

▪ Uncertainty with climate sensitivity

The increase in the equilibrium global-mean surface air temperature due to a doubling of atmospheric CO2 concentration

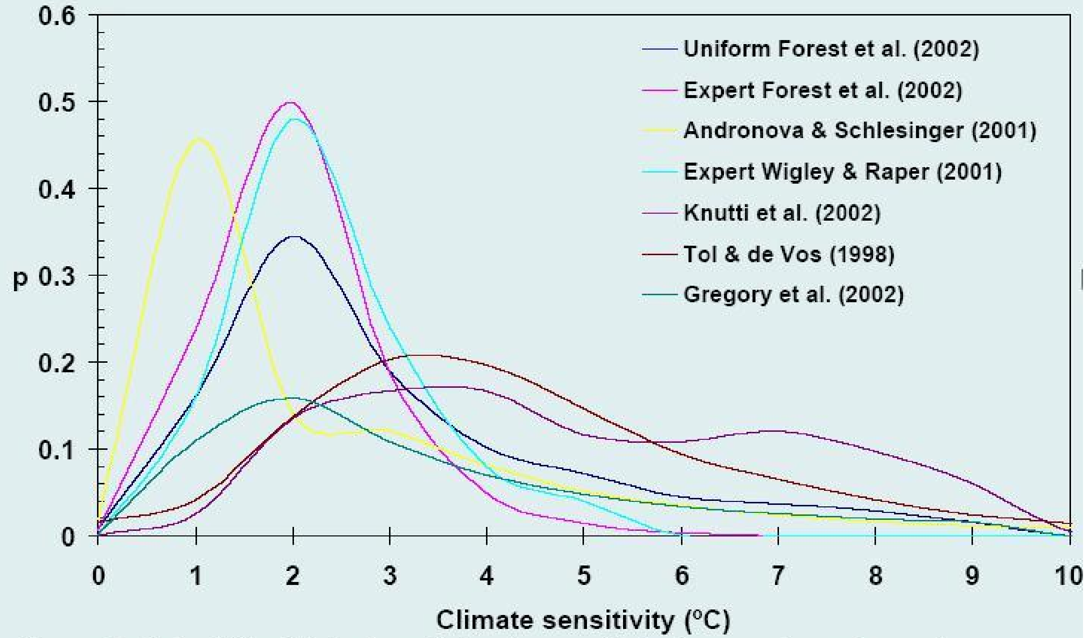
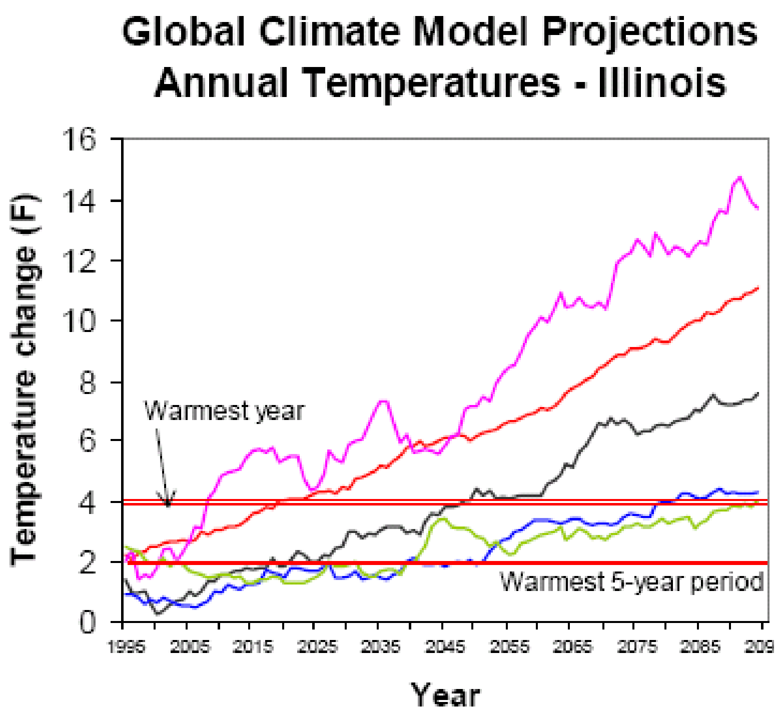


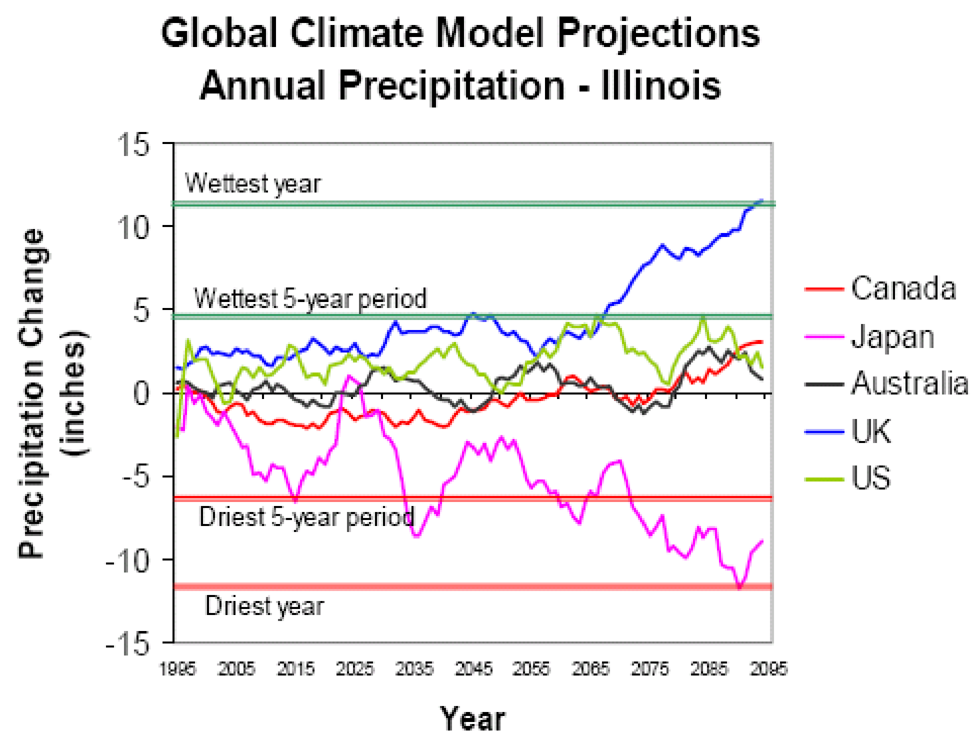
Figure 3. Probability distribution of climate sensitivity for a number of recent studies. Bins of 1 °C.

Dessai, S., X. Lu, and M. Hulme, 2003: Development of a simple probabilistic climate scenario generator for impact and adaptation assessments. *Geophysical Research Abstracts*, 5(12547).

Regional variability

Occurring between models as different regional responses, and within models through chaotic behaviors and modes of climate variability, especially multi-decadal variability





(After Winstanley, 2004 Illinois Water Conference)

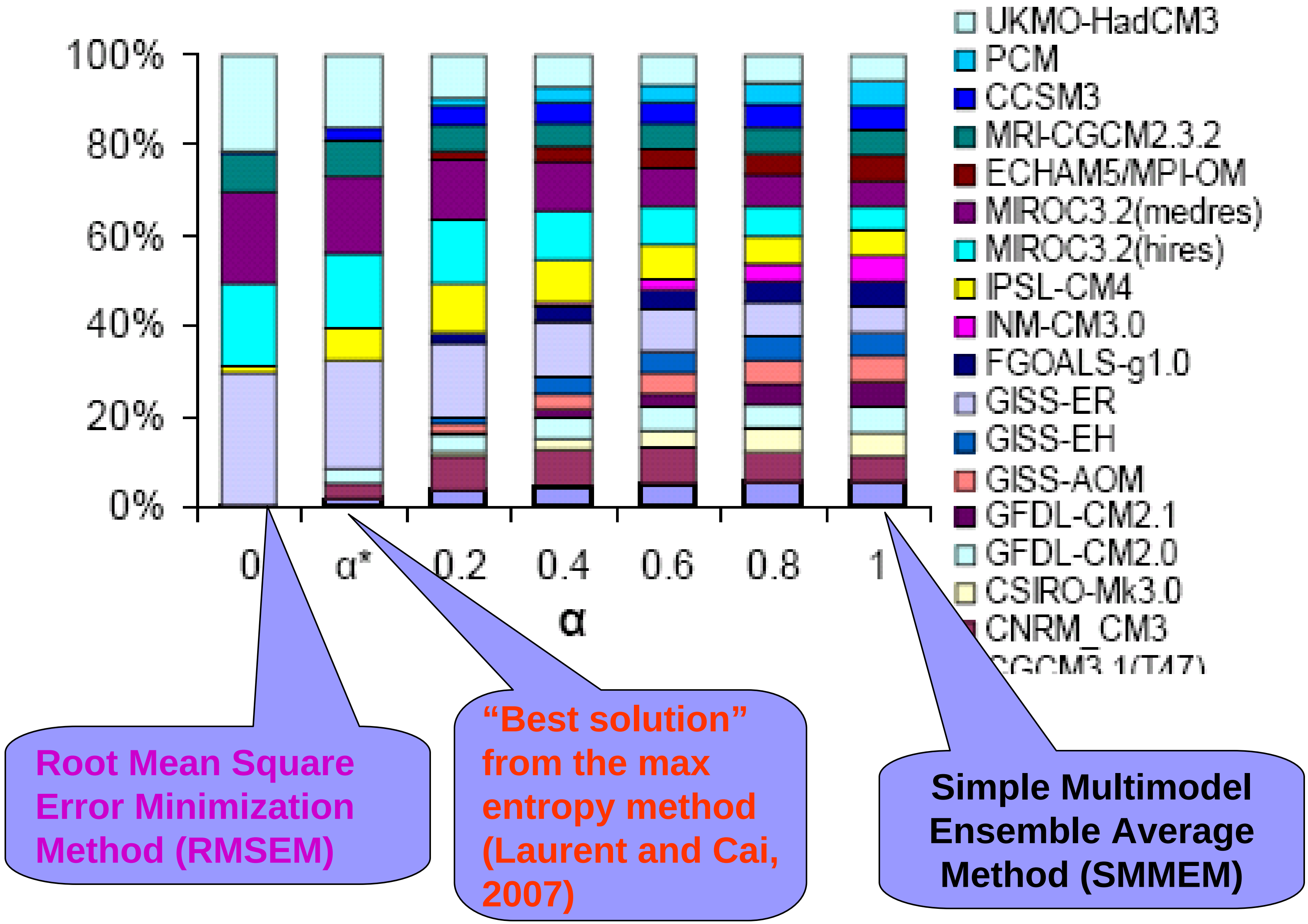
Model Uncertainty Quantification

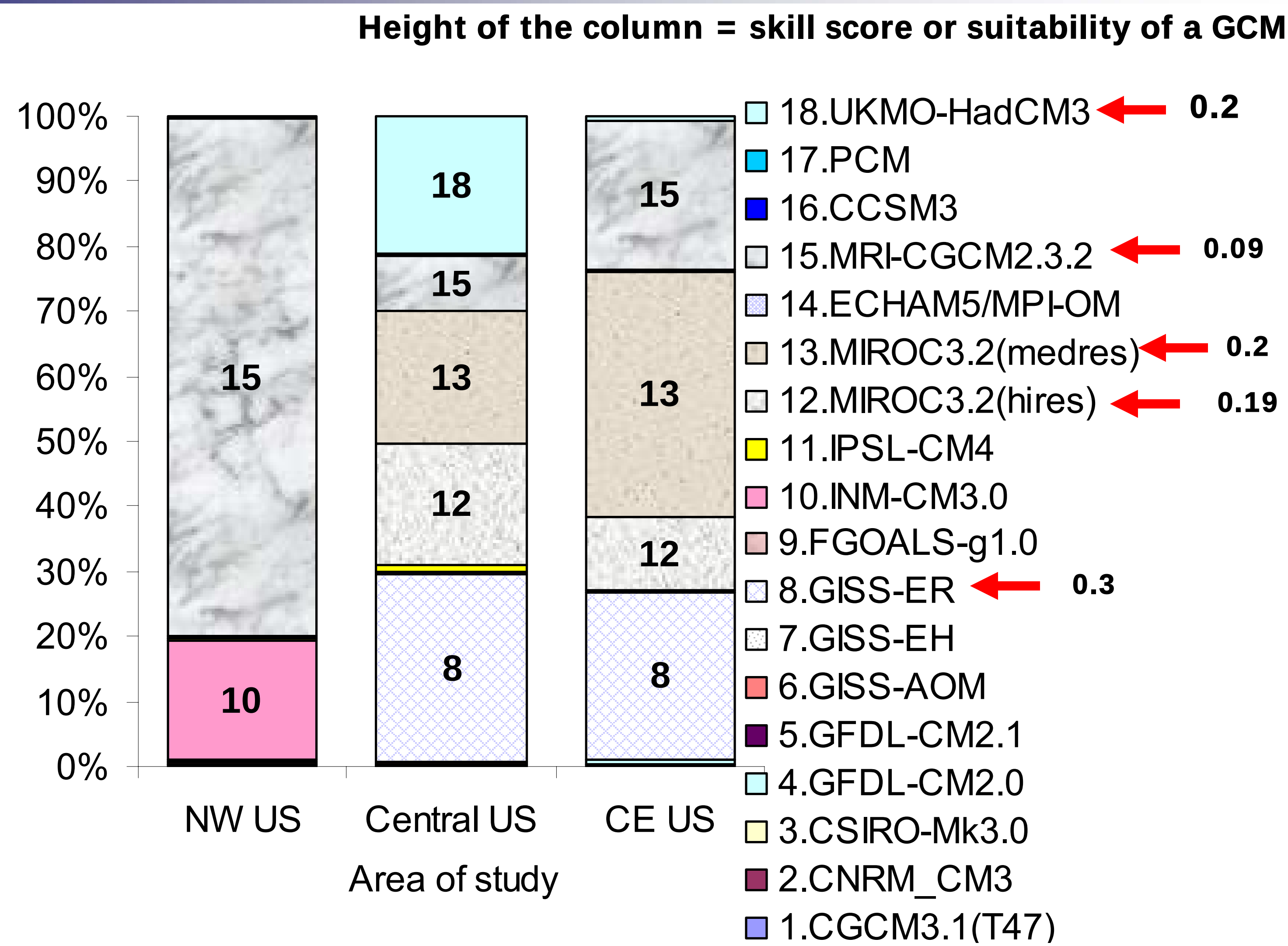
• Output from a single GCM

• Average of the outputs from a set of GCMs (equal trust for all GCMs)

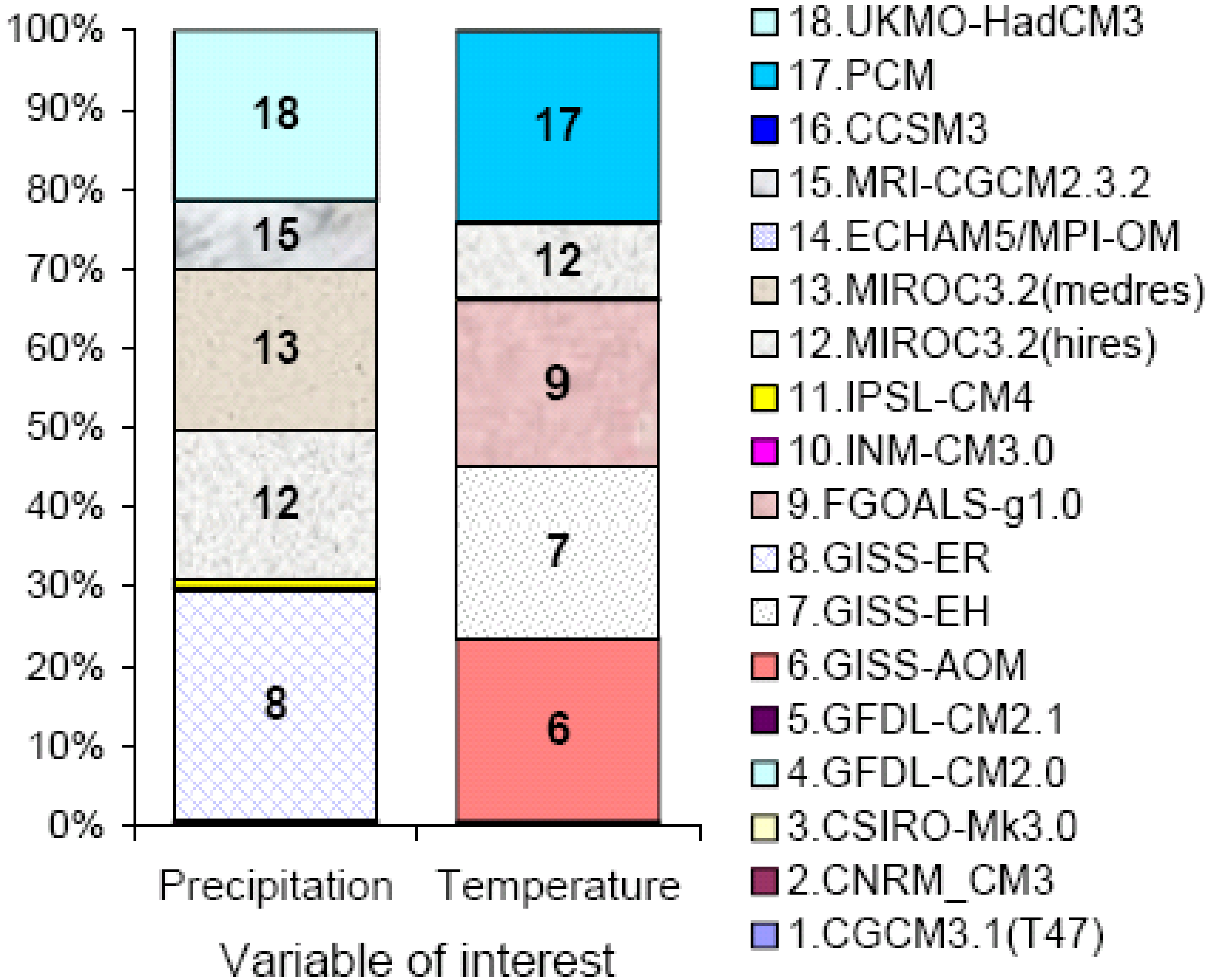
• Probability-weighted multimodel ensemble average, $T = \sum_{i=1..N} p_i \cdot T_i$ (higher trust is assigned to the GCMs which have **better performance with historical data**

Premise : Models being able to reasonably reproduce past climate also perform well at predicting future climate


100%
80%
60%
40%
20%
0%
0
α*
0.2
0.4
0.6
0.8
1
α
UKMO-HadCM3
PCM
CCSM3
MRI-CGCM2.3.2
ECHAM5/MPI-OM
MIROC3.2(medres)
MIROC3.2(hires)
IPSL-CM4
INM-CM3.0
FGOALS-g1.0
GISS-ER
GISS-EH
GISS-AOM
GFDL-CM2.1
GFDL-CM2.0
CSIRO-Mk3.0
CNRM_CM3
Root Mean Square Error Minimization Method (RMSEM)
“Best solution” from the max entropy method (Laurent and Cai, 2007)
Simple Multimodel Ensemble Average Method (SMMEM)

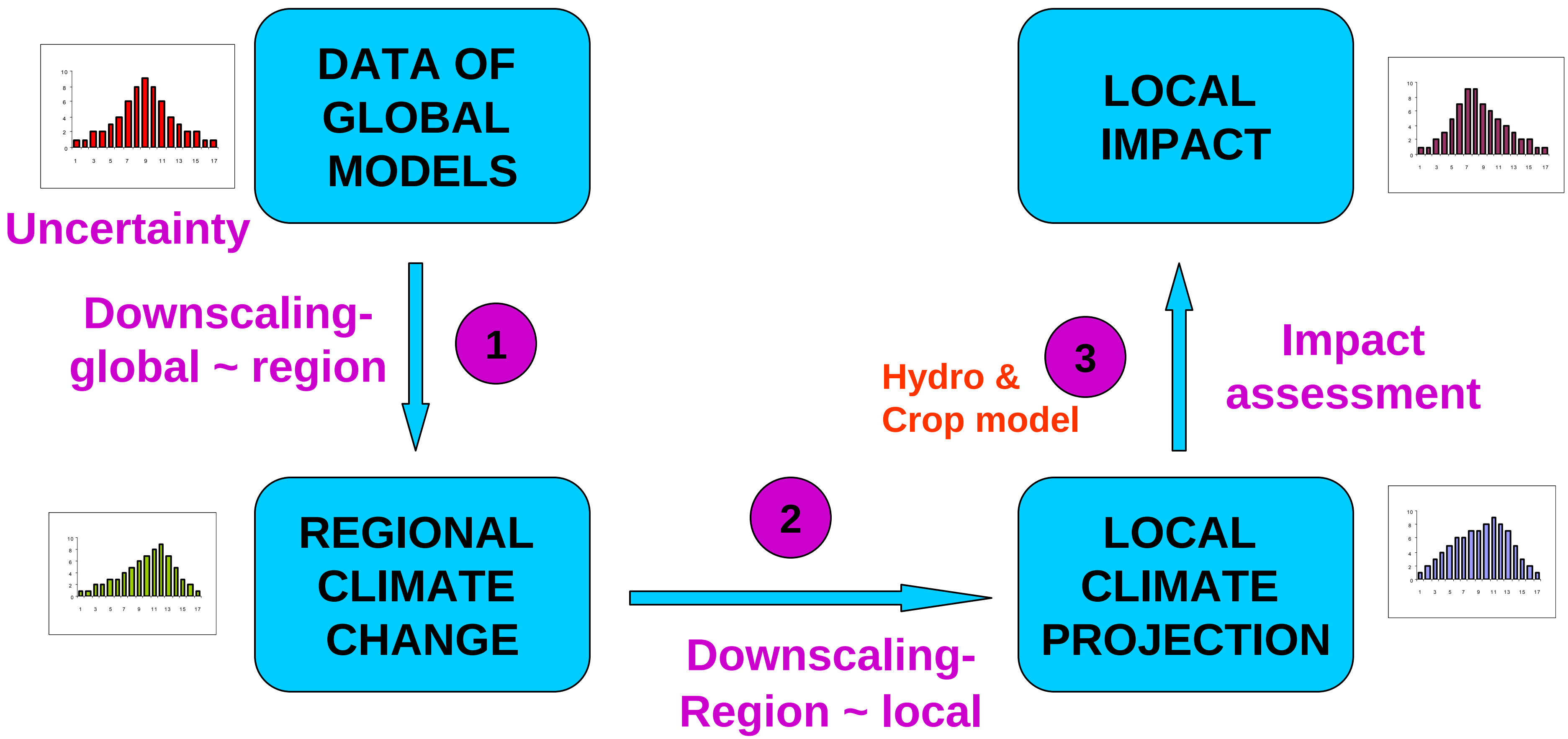


GCM skill score (suitability) in terms of precipitation for three regions



100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
18
15
13
12
8
17
12
9
7
6
Precipitation
Temperature
Variable of interest
18.UKMO-HadCM3
17.PCM
16.CCSM3
15.MRI-CGCM2.3.2
14.ECHAM5/MPI-OM
13.MIROC3.2(medres)
12.MIROC3.2(hires)
11.IPSL-CM4
10.INM-CM3.0
9.FGOALS-g1.0
8.GISS-ER
7.GISS-EH
6.GISS-AOM
5.GFDL-CM2.1
4.GFDL-CM2.0
3.CSIRO-Mk3.0
2.CNRM_CM3
1.CGCM3.1(T47)

The Procedures

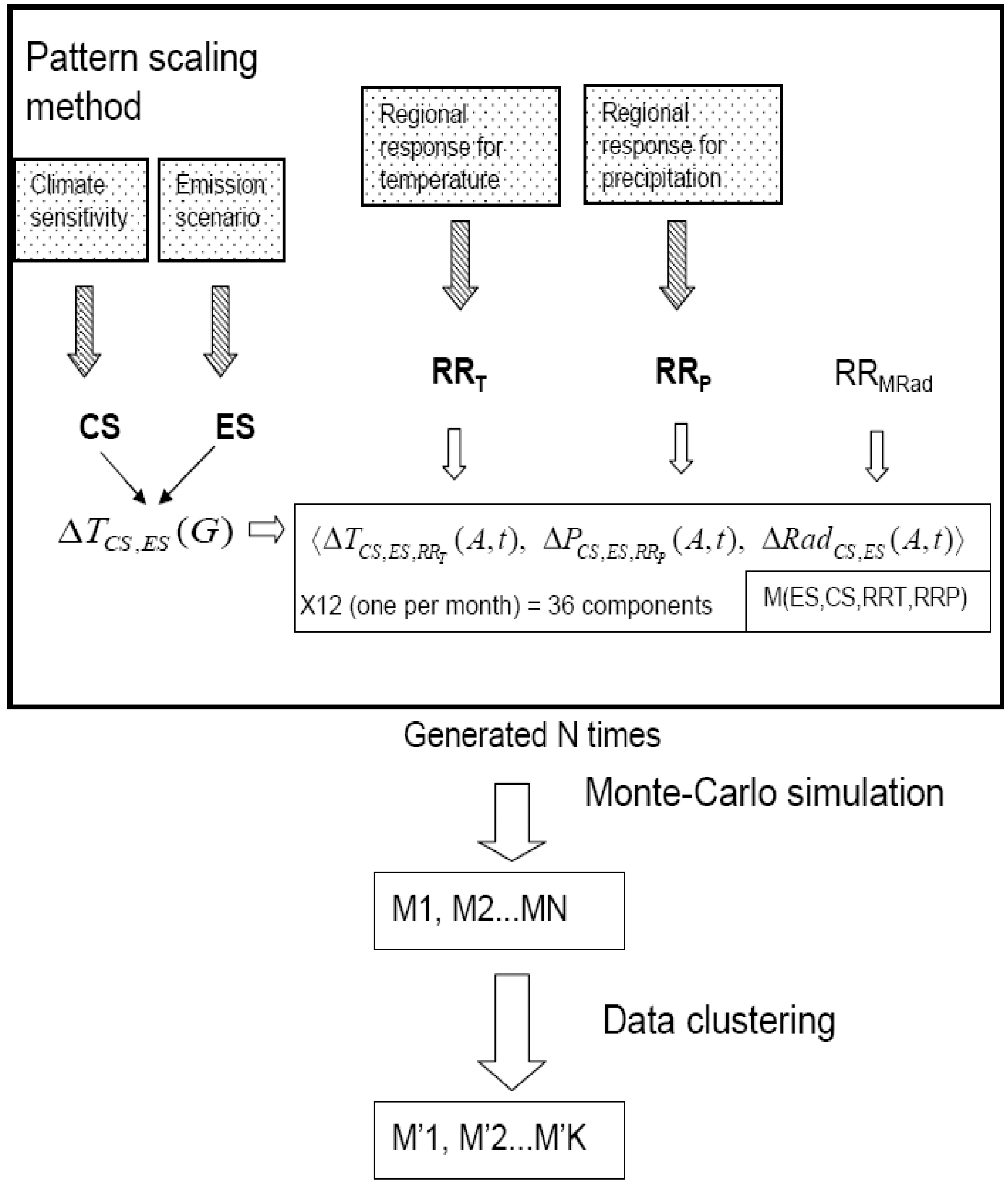


Deriving regional climate change using global climate models

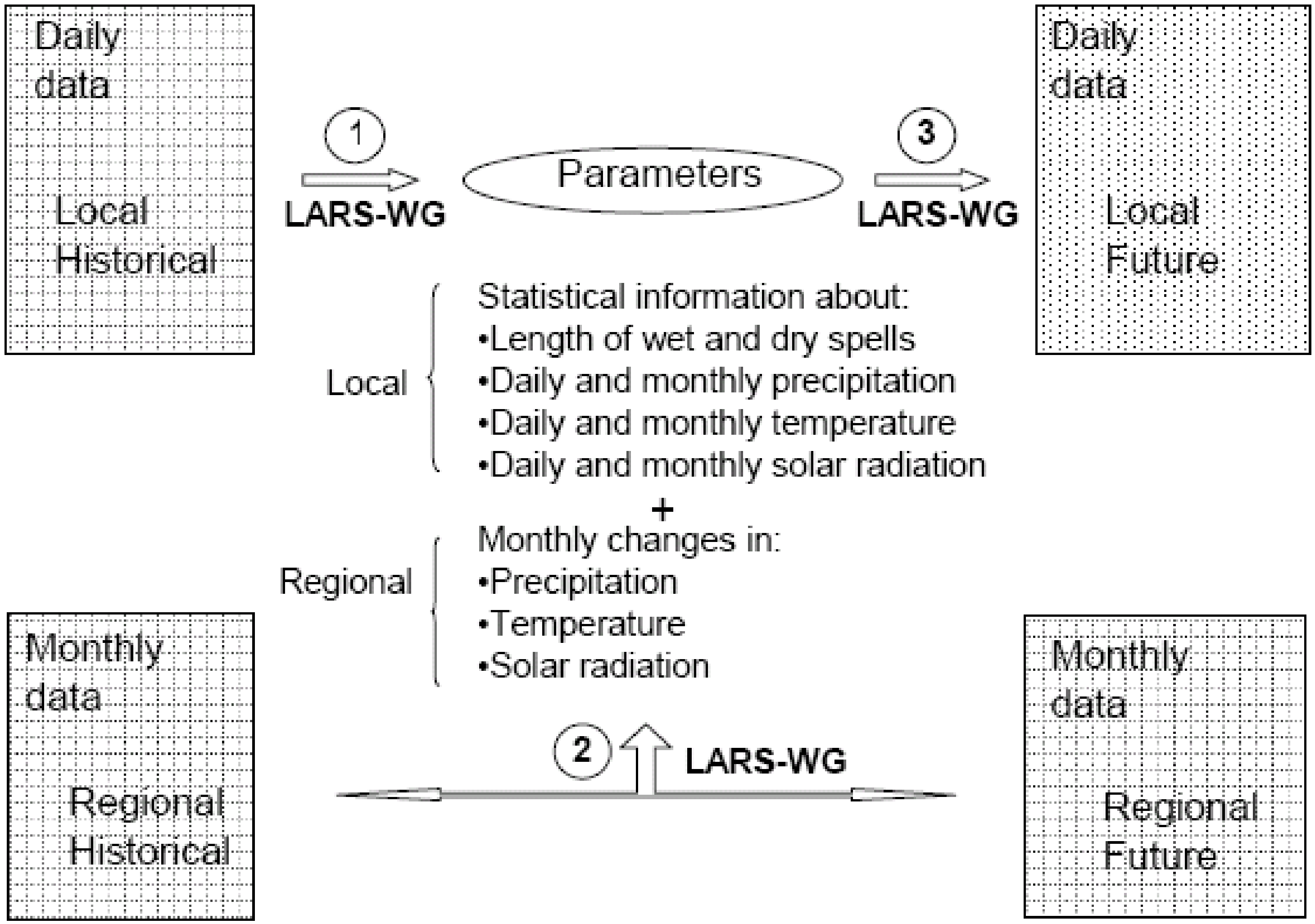
Pattern scaling method: Calculate (ΔP_R, ΔT_R, ΔRad_R) assuming each of these changes at the regional scale is proportional to the global warming through an in-variant scaling factor

Monte Carlo simulation: Generate a number of sets {ΔP_R, ΔT_R, ΔRad_R}

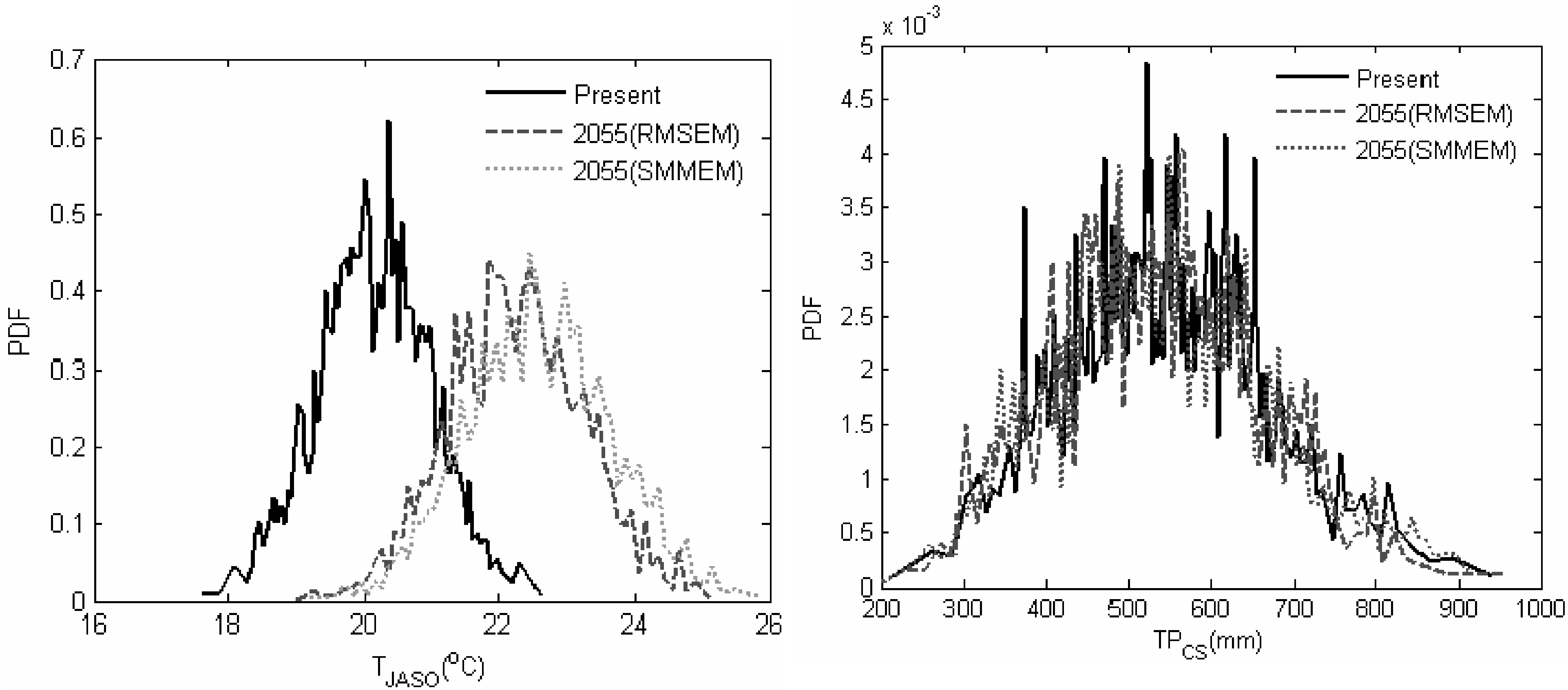
Data clustering: Generate a representative set of climate change scenarios from the Monte Carlo simulation samples



LARS-WG: Incorporating Climate Change with Local Climate Pattern

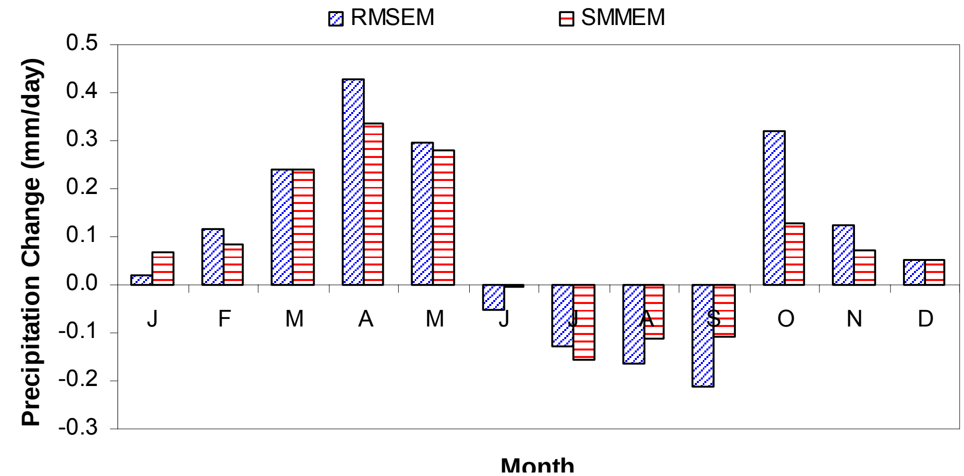


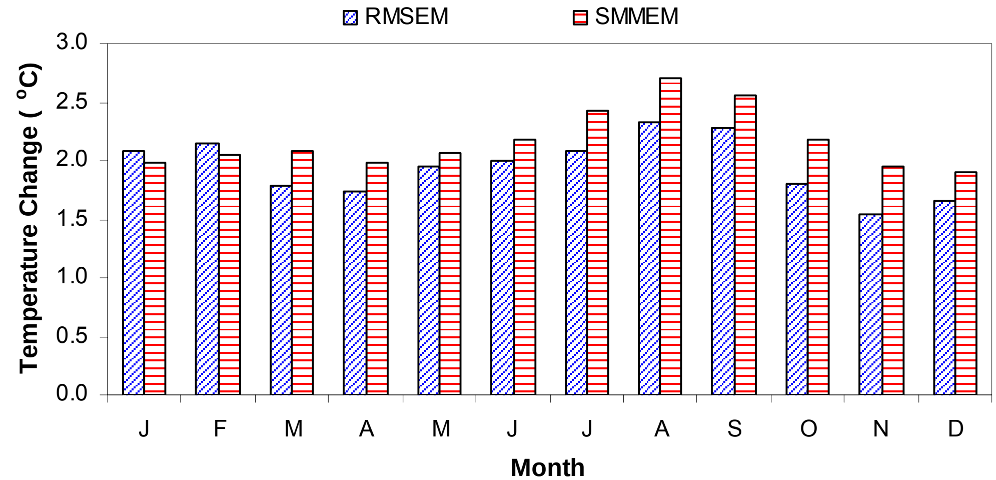
- LARS-WG (Semenov and Barrow, 1997), weather generator, a numerical model which produces synthetic daily time series of a suite of climate variables with certain statistical properties

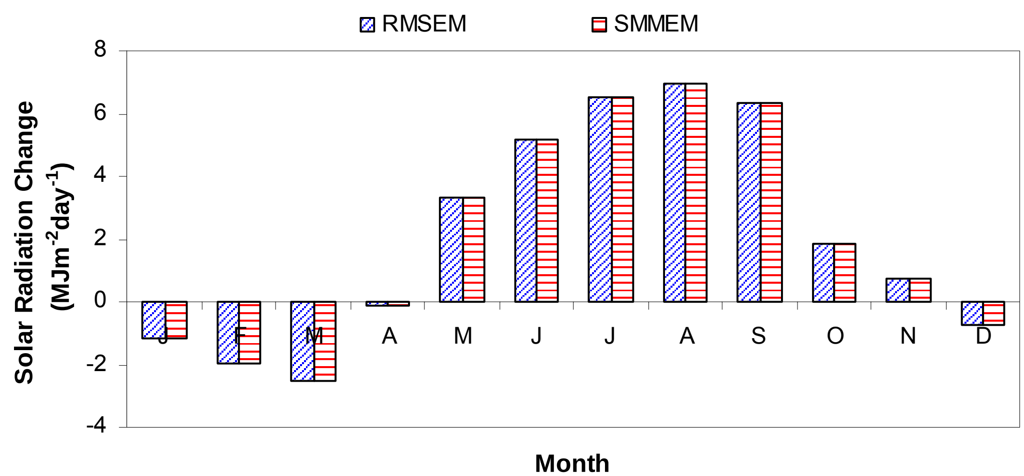


The PDF of the average temperature (T) and total precipitation (TP) between Apr. 15th and Oct. 14th, Central Illinois, present and 2055

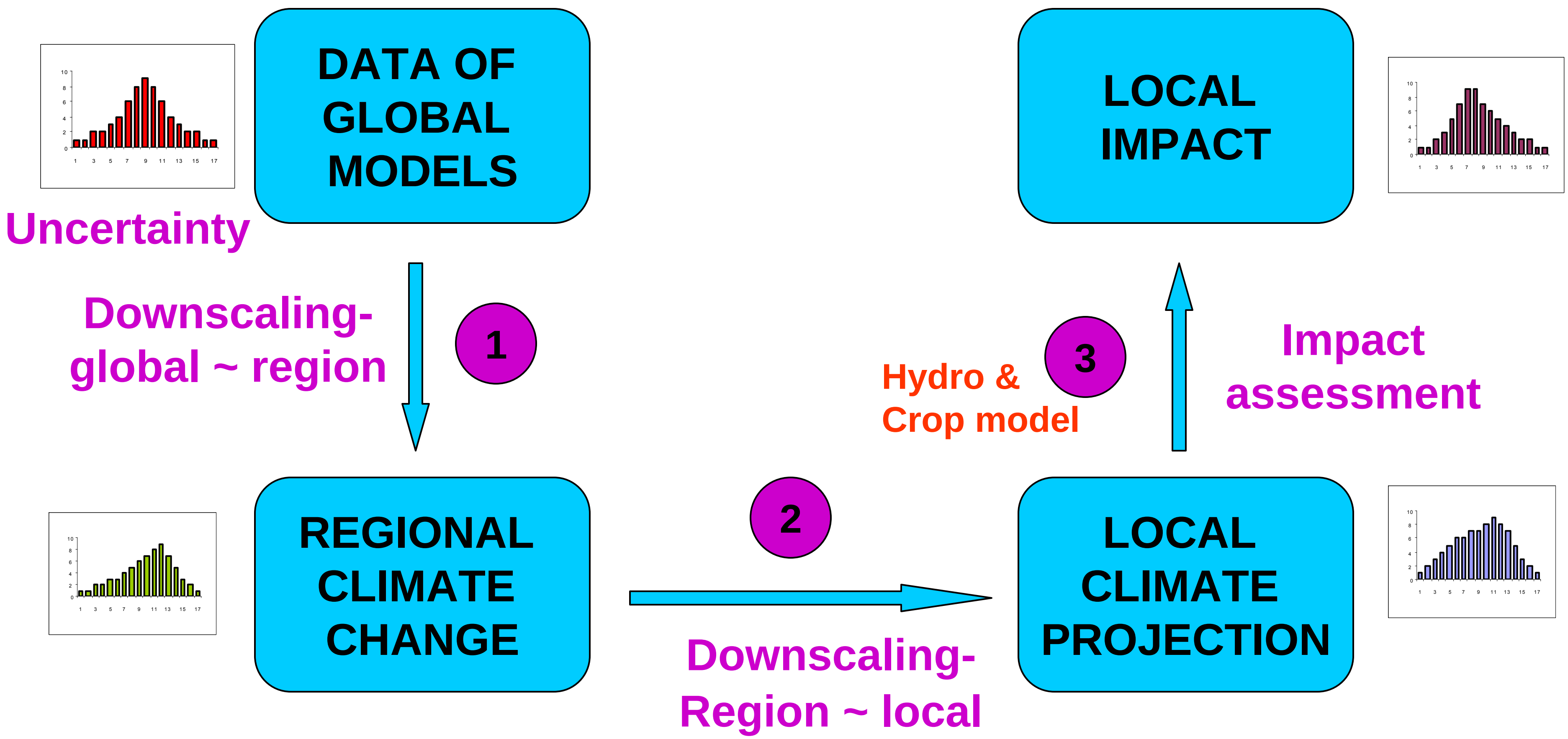
Monthly precipitation, Temperature, and solar radiation change (2055) in Central Illinois -- A drier and hotter summer during the corn growth season and wetter and warmer pre- and post-crop seasons



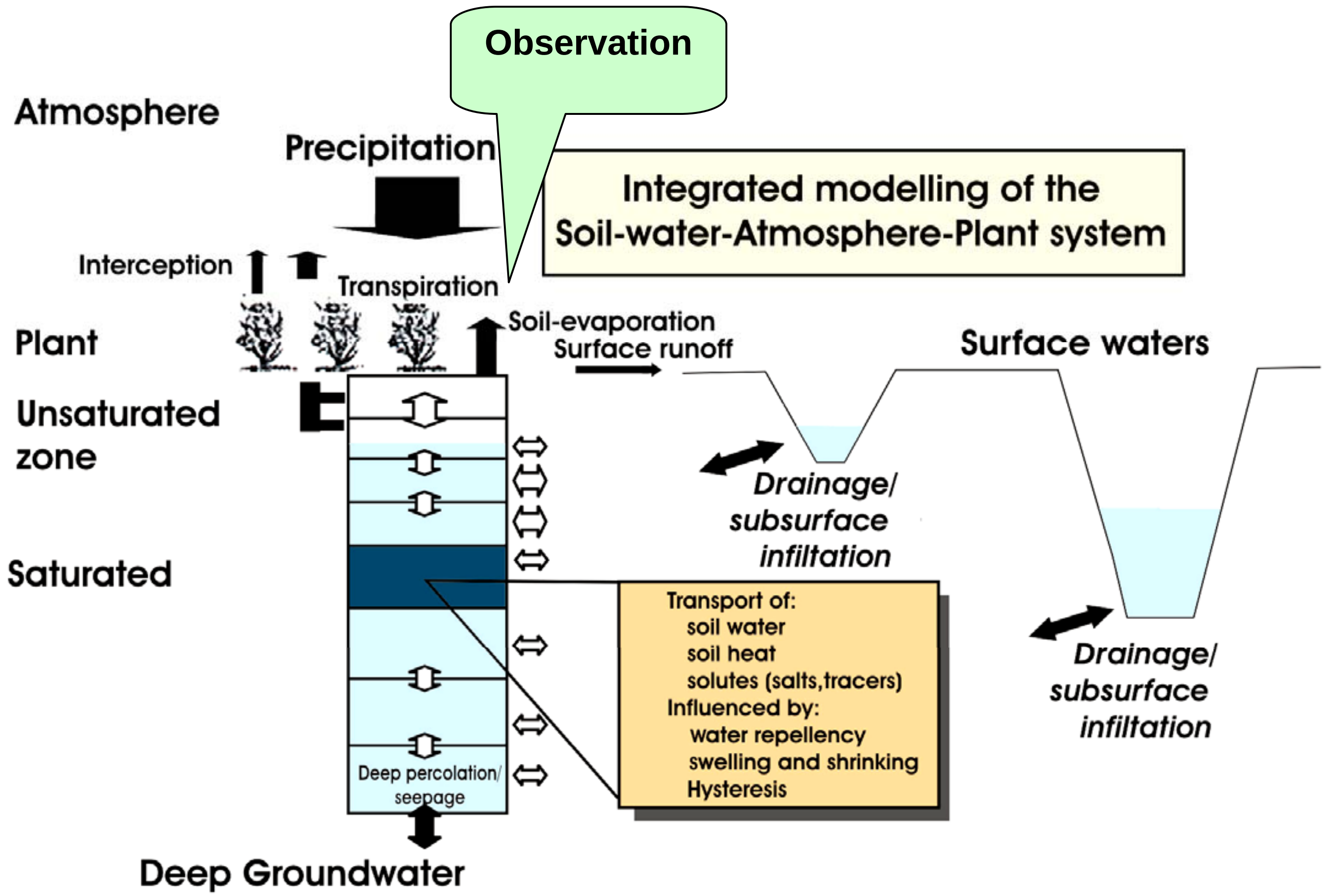




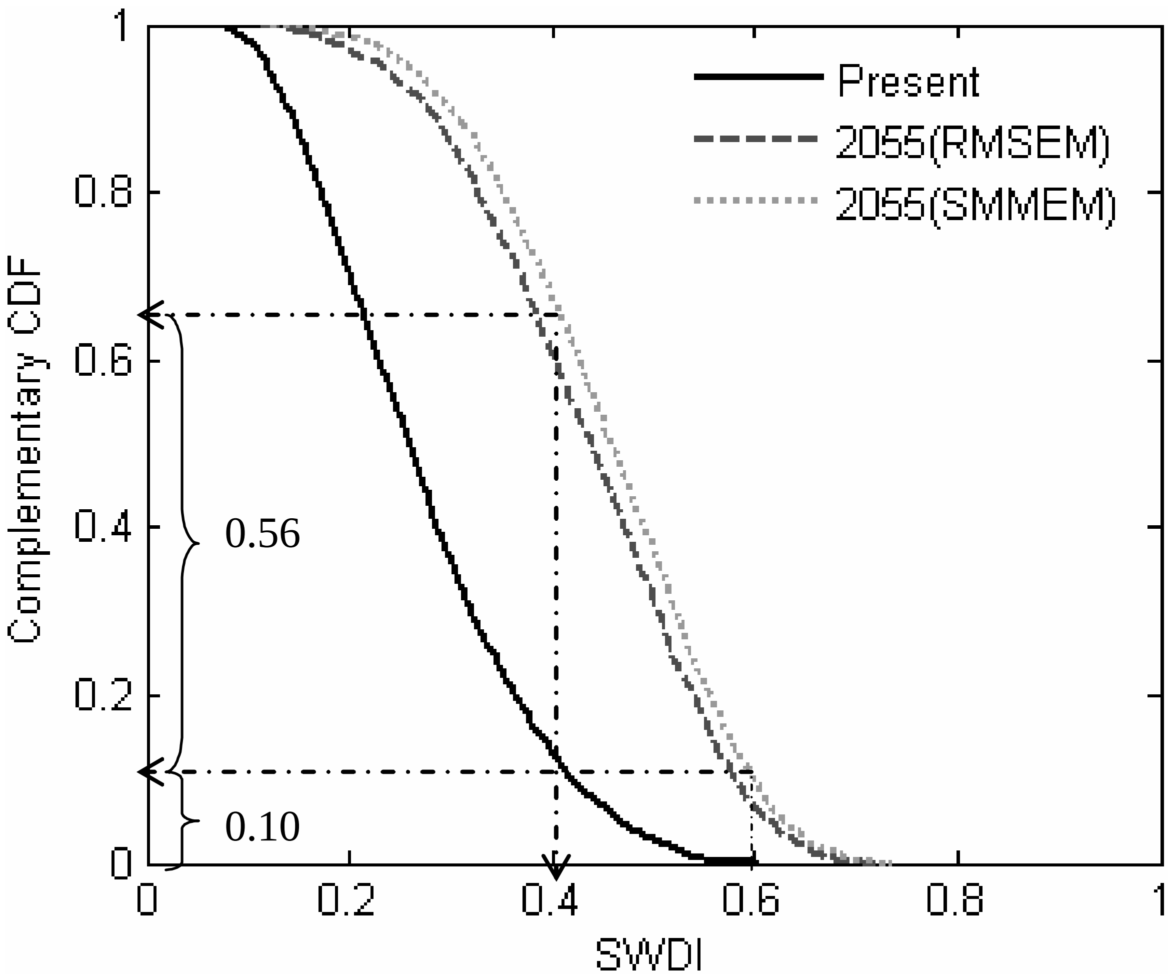
The Procedures



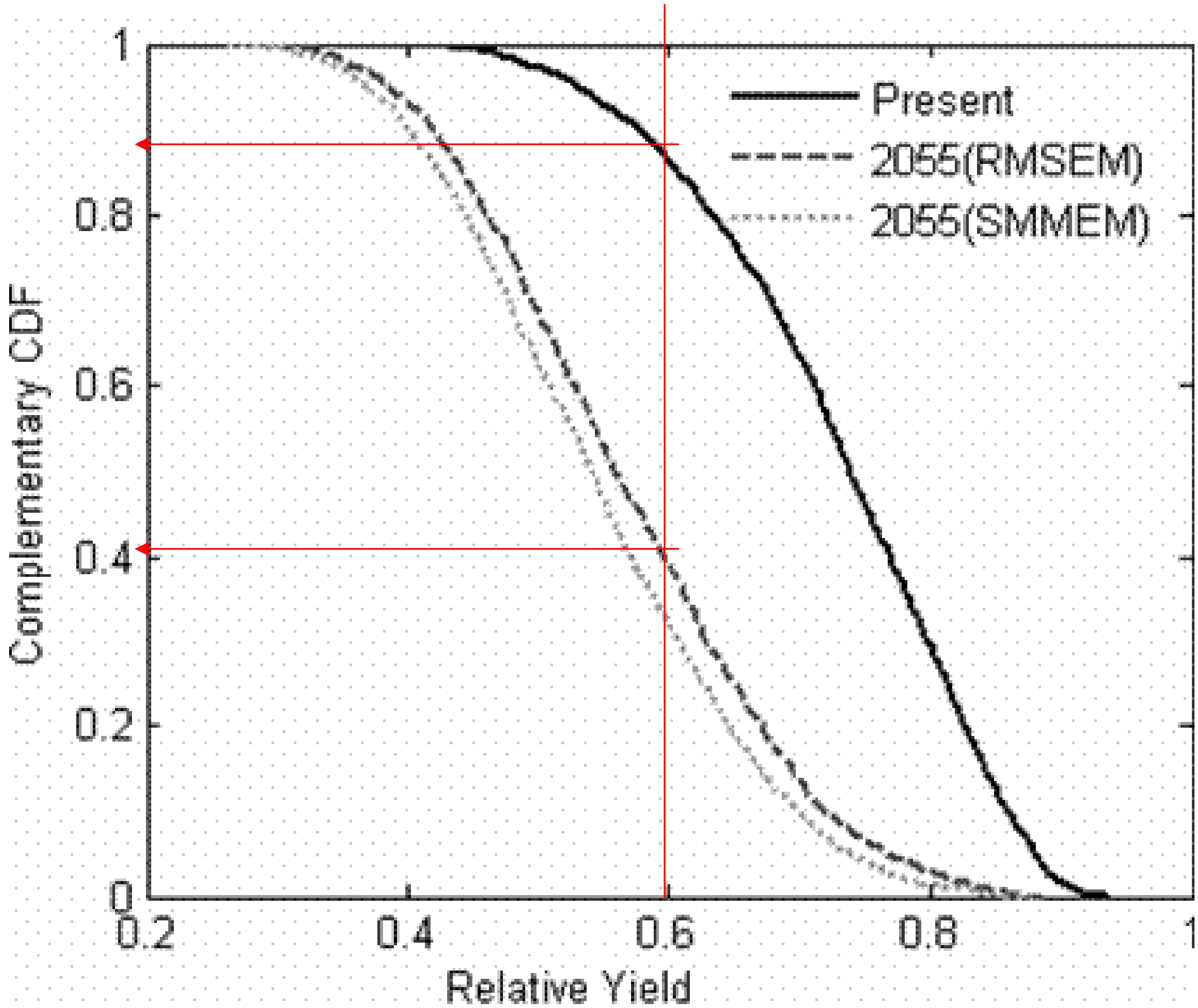
SWAP (Soil Water Atmosphere Plant model)



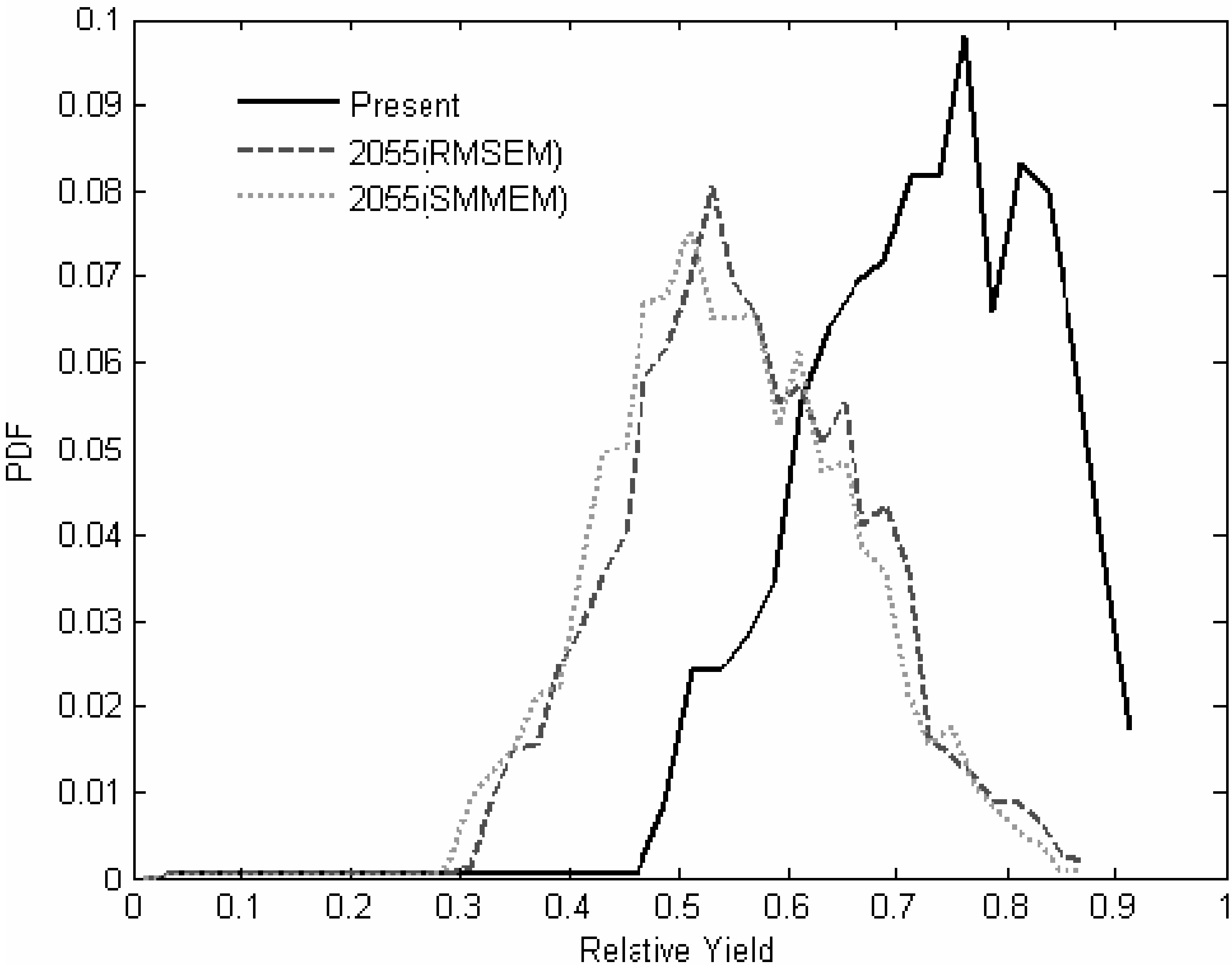
Van Dam et al. (1997)



Complementary CDFs of the average growing season (April 15 – October 14) soil water deficit index (SWDI)

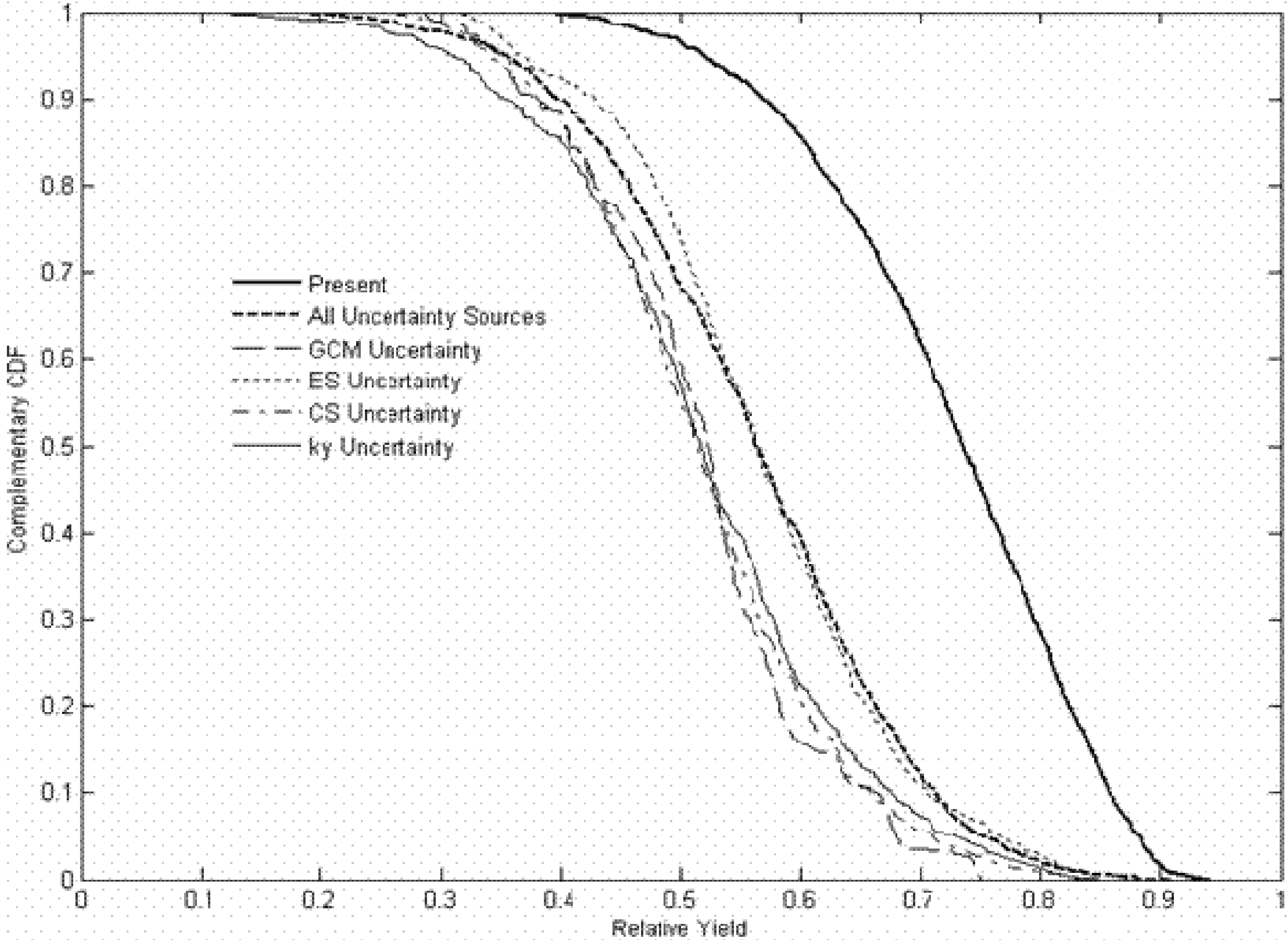


Complementary CDF of relative crop yield



PDF of relative crop yield

Comparing individual uncertainty sources: GCM, emission scenarios, climate sensitivity, and crop response coefficient



The complementary CDF of relative yield for present and 2055 under five scenarios, respectively, and all four uncertainty sources together.

Summary

- A drier and warmer summer and wetter and warmer pre- and post-crop seasons

- Soil water deficit levels may increase in the flowering and yield formation stages, resulting in larger variability and vulnerability in 2055 than at present

- The mean yield of rainfed corn yield in Central Illinois will decline by 23 – 34% and the probability that the yield may not reach 50% of the potential yield ranges from 32 – 70 %, if no adaptation measures are instituted

- Among the multiple uncertainty sources, the GHG emission projections may have the strongest effect on the risk estimate of crop yield reduction