Water-Food-Climate: How can Africa adapt to climate risk?

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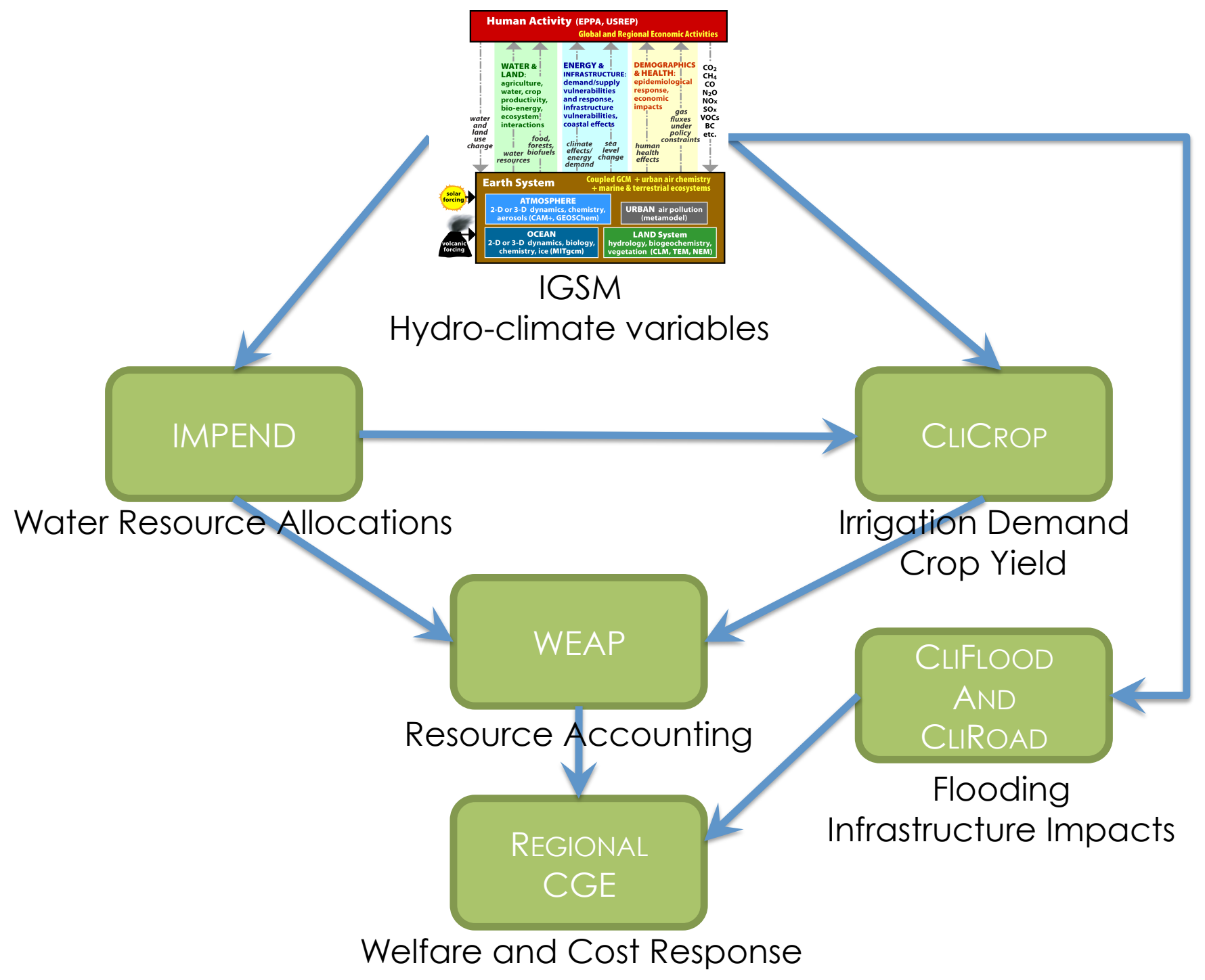
MOTIVATION AND DESCRIPTION

Our global water resources include energy, agricultural and environmental systems - linked together as well as to climate via the water cycle. As such, watersheds and river basins are directly impacted by local and regional climate variations and change, and in turn, these managed systems provide direct inputs to the global economy that serve and promote public health, agricultural and energy production, ecosystem surfaces and infrastructure. With the prospect of potential climate change and associated shifts in hydrologic variation and extremes (i.e. non-stationarity in the hydro- climate system), the MIT Integrated Global Systems Model (IGSM) framework (Sokolov et al., 2005) has enhanced its capabilities to model regional impacts on the managed water-resource systems and infrastructure to quantify the risks to economic growth and development.

METHOD

As depicted in **Figure 1**, a chain of impact models are linked with the IGSM. Calculated inflows are passed to an adapted version of IMPEND (Investment Model for Planning Ethiopian and Nile Development) where storage capacity and irrigation flows are optimized to maximize net benefits. Outputs from IMPEND as well as irrigation demands from CliCrop are passed to the Water Evaluation and Planning System (WEAP). Water storage, hydropower potential and irrigation supply are optimized based on climate and municipal/industrial water demands of the river basins – this includes interaction between hydropower and irrigation impacts for adaptation. CliFlood takes hydrologic information from the IGSM to determine flood flow and frequency, and then provides an estimate of annual damage to crops and agricultural capital based on flood design standards. Similarly CliRoads (Chinowsky et al, 2011) takes the flood frequency to determine damage to the existing road infrastructure based on paved and unpaved design standards. It also estimates temperature damage to road surfaces, as well as adaptation costs and/or savings by changing road-design standards. Finally, all information is passed into a regional computable general equilibrium (CGE) model of Mozambique to assess economic impacts. Using this linked model framework, we consider how changes in the regional hydro-climate over southern Africa, in particular the greater Zambezi river basin (**Figure 2**) pose a risk to growth and development. All this is cast under a probabilistic description of regional climate change that is constructed under the IGSM framework.



IGSM
Hydro-climate variables

IMPEND
Water Resource Allocations

CLICROP
Irrigation Demand
Crop Yield

WEAP
Resource Accounting

CLIFLOOD AND CLIROAD
Flooding
Infrastructure Impacts

REGIONAL CGE
Welfare and Cost Response

Figure 1: Model framework schematic (see Method section for details). The chain of impact models into a regional computation general equilibrium (CGE) model are applied to the greater Zambezi basin (Figure 2) for this study.

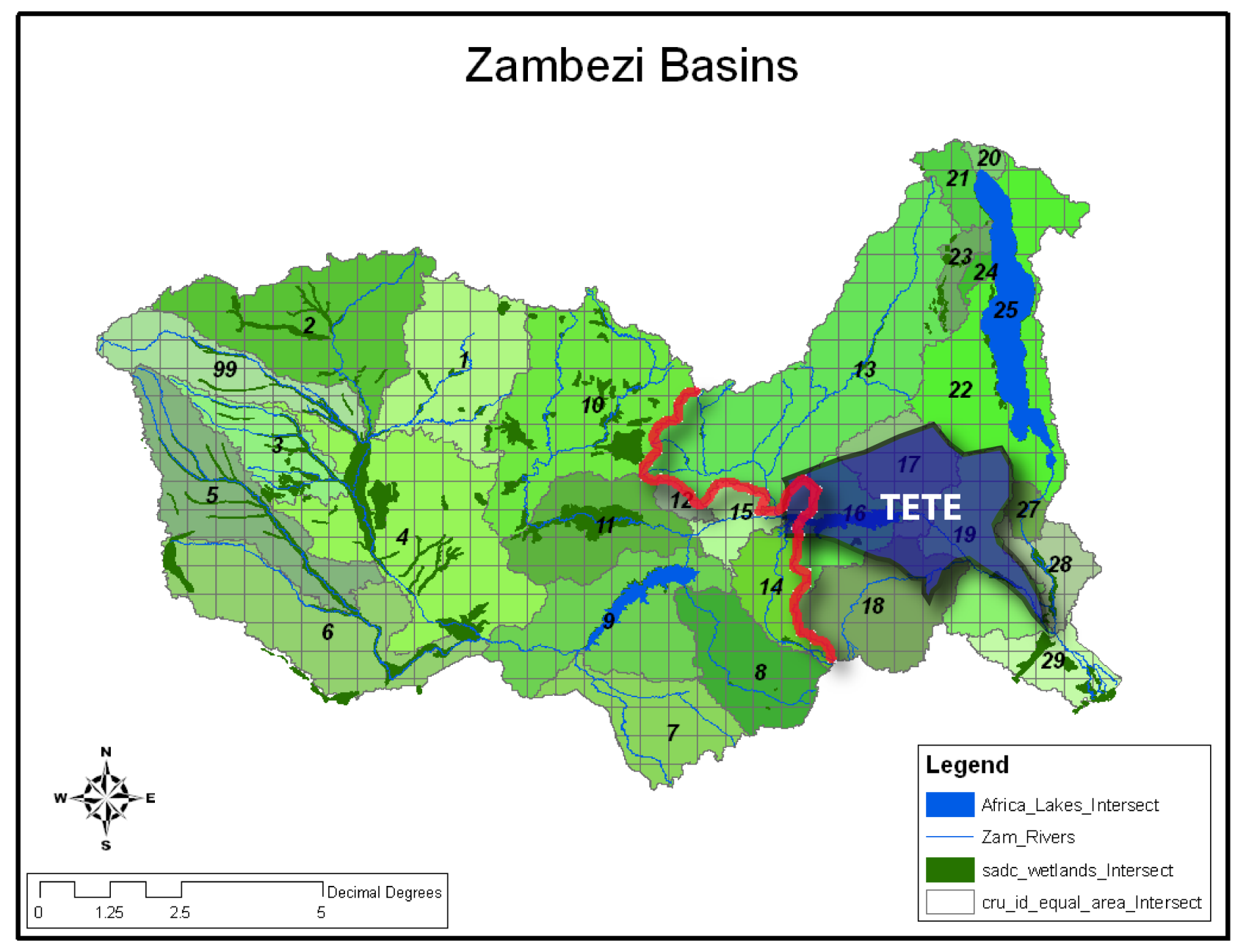


Figure 2: The greater Zambezi river basin considered for this focused study. The eastern and western basins are delineated by the red line. The Tete province (results in Fig. 6 shown for) is indicated by the dark blue domain.

CLIMATE PROJECTIONS

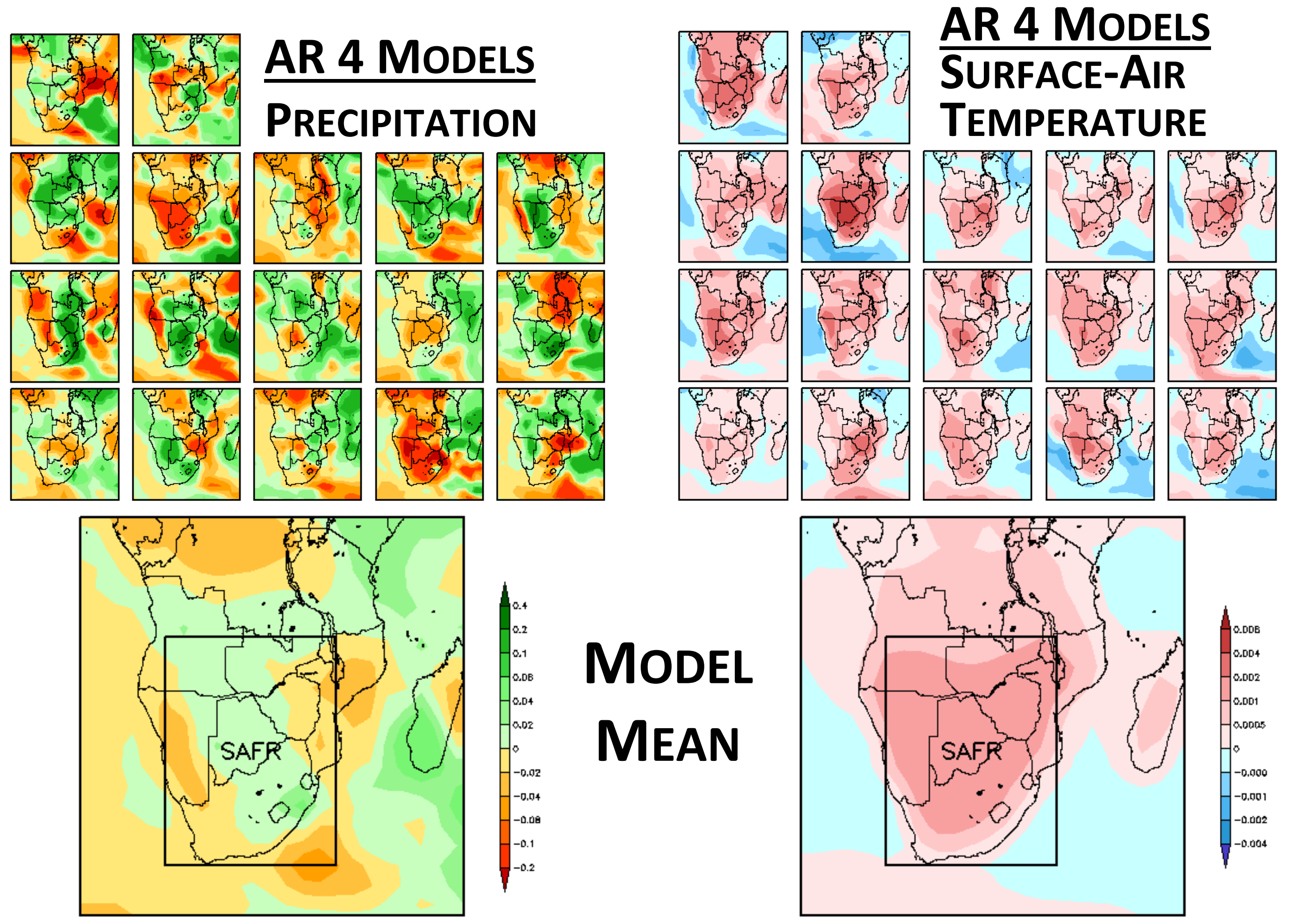


Figure 3: Climate-change pattern kernels from the IPCC AR4 climate models – and used to construct hybrid climate-change distributions from the IGSM (Fig. 1). Shown are the relative changes in DJF precipitation (left panels) and temperature (right panels) in response to a unit global temperature increase as a result of anthropogenic greenhouse emissions.

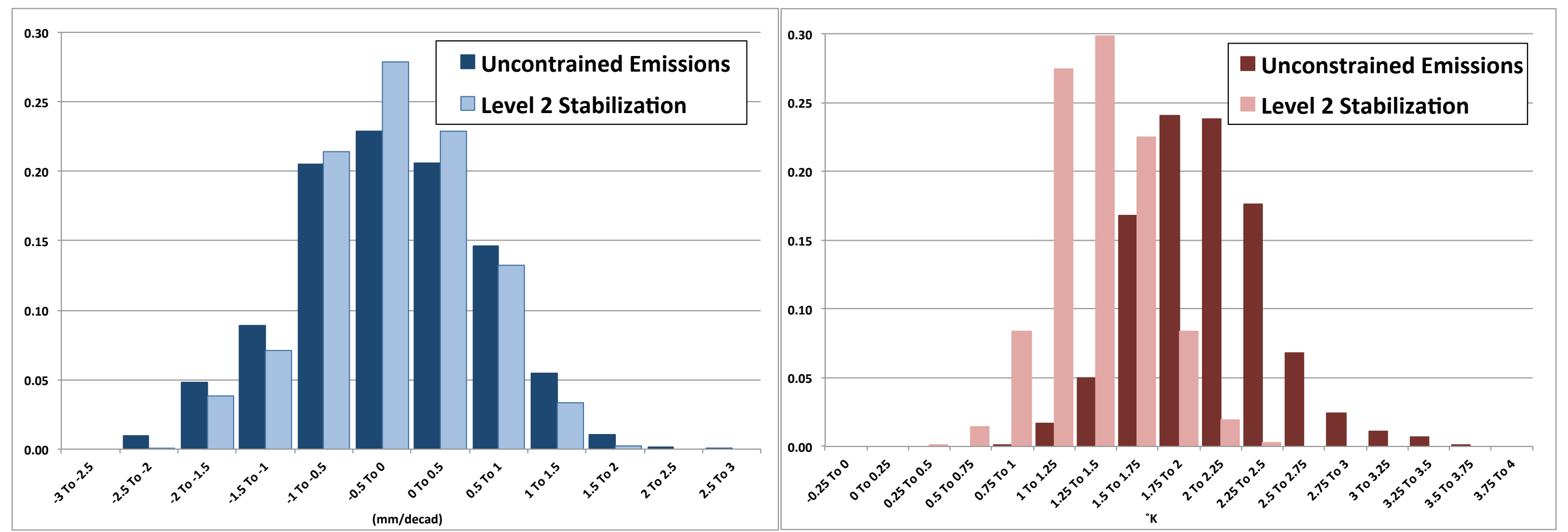


Figure 4: Hybrid Frequency Distributions (HFDs, Schlosser et al., 2011) of decadal averaged precipitation (left panel) and temperature (right panel) changes (2050-2000) over Southern Africa (SAFR of Fig.1). Results shown for an unconstrained-emission and modest greenhouse gas stabilization policies (650 ppm CO_2-eq by 2100, Webster et al., 2011).

HYDROLOGIC BASIN PROJECTION

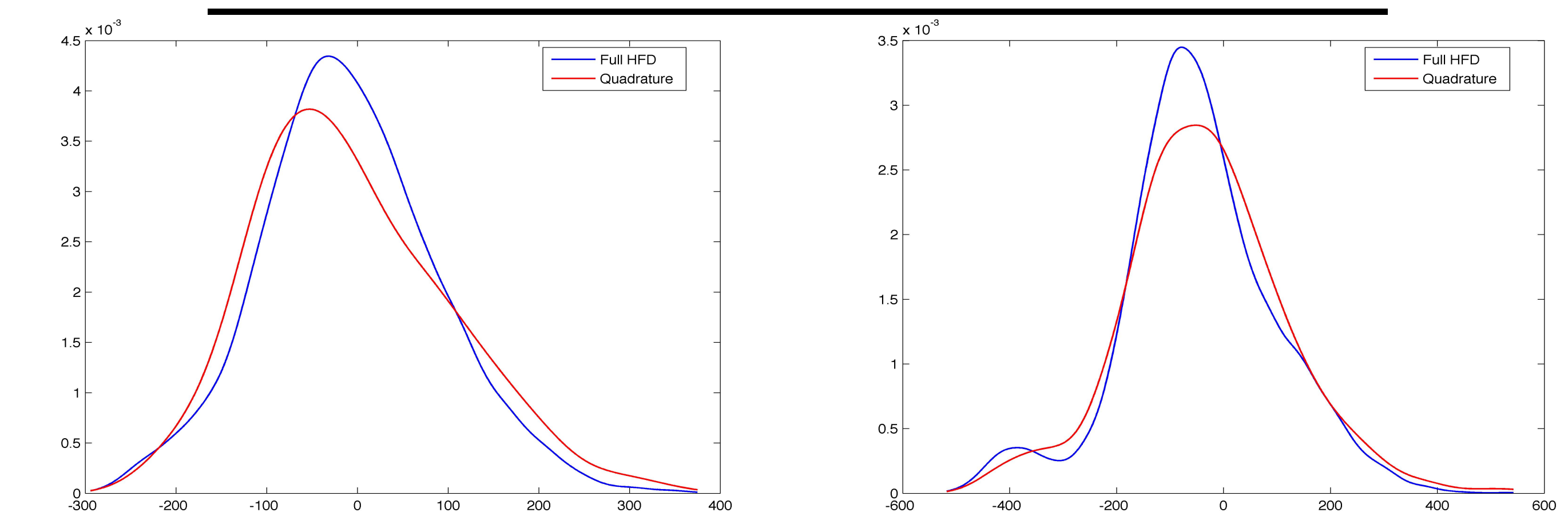


Figure 5: Frequency distributions of decadal averaged changes (2050-2000) in runoff for the eastern (left panel) and western (right panel) Zambezi basins. Results shown for unconstrained-emission pathway. The blue curve is the result of the full HFD ensemble, the red curve shows the result from the reduce sampling of the Gaussian quadrature reduction (see text for details).

IRRIGATION DEMAND

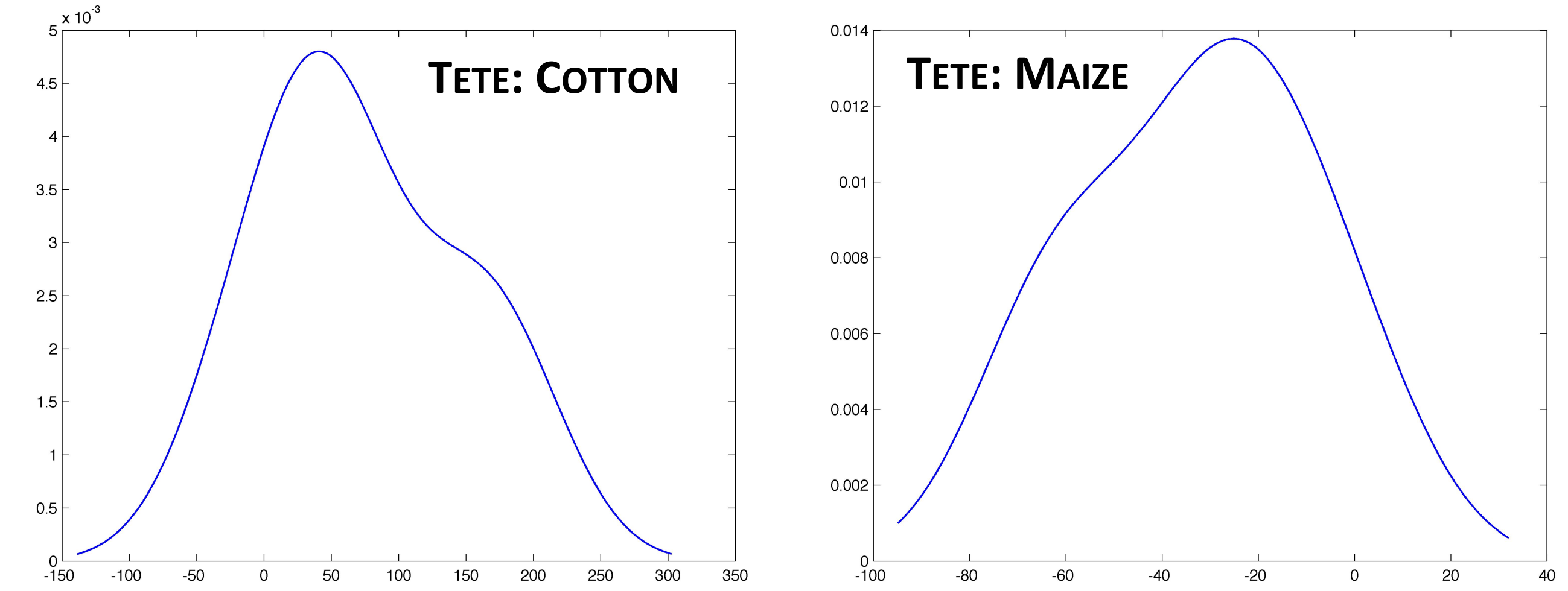


Figure 6: Frequency distributions of decadal averaged changes (2050-2000) in irrigation demand for a selected province (Tete, Fig. 2) and crops. The results are based on a Gaussian Quadrature sampling of the HFDs (Fig. 3) for the unconstrained emission IGSM scenario (Sokolov et al., 2009).

GAUSSIAN QUADRATURE REDUCTION

The hybridization of IGSM ensembles with the AR4 climate-pattern kernels (**Figure 3**) leads to 6800 possible climate outcomes for HFDs (**Figure 4**). For the biophysical and economic impact modeling, this poses a computational burden. We reduce this number to 426 climates using an approach from Arndt et al.(2006). Specifically, twelve summary climate variables for the Zambezi river basin were identified. We then select 100 separate quadratures (climates and associated weights) that match all moments of the summary variables up to order three. If the summary climate variables are good predictors of the outcomes of interest, then the quadratures should outperform random sampling. The approach is evaluated (**Figure 5**) using runoff where the "true" distribution is obtained by running all climates through the CliRun runoff model. The quadratures outperform random samples for both the mean and the variance of annual runoff (dividing the Zambezi basin into East and West quadrants). We then select one quadrature from the 100 using a minimum variance criteria. All subsequent biophysical (**Figure 6**) and economic modeling (**Figure 7**) then use the 426 climates and associated weights.

ECONOMIC IMPACTS

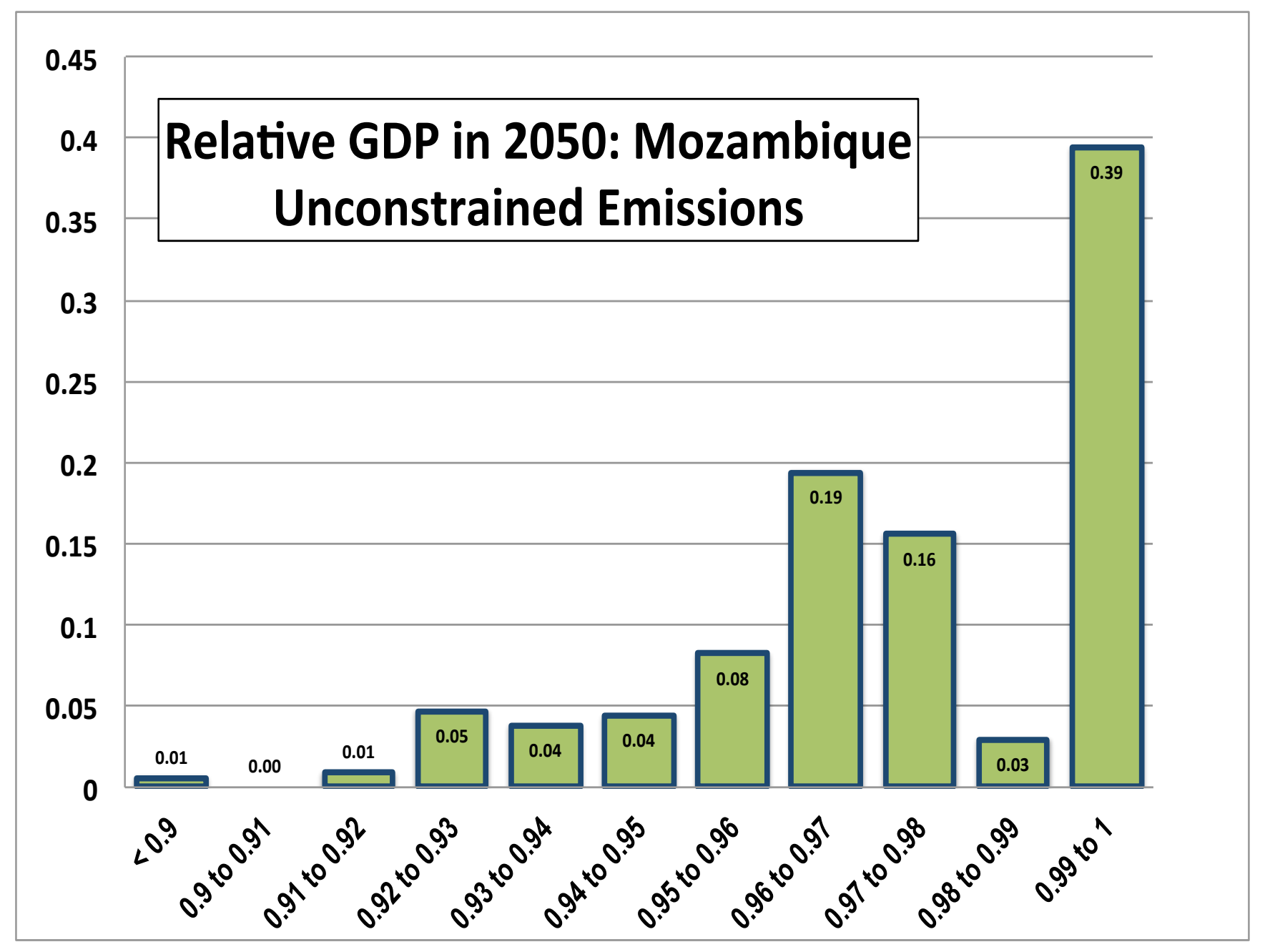


Figure 7: Frequency distribution of GDP in 2050 for Mozambique relative to a scenario with no climate and weather variability. The results are based on a Gaussian Quadrature sampling of the HFDs (Figs. 5 and 6) for the unconstrained emission IGSM scenario (Sokolov et al., 2009).

Most economic outcomes (**Figure 7**) result on the more favorable end of the distribution with some outcomes close to the level that would be attained with no climate and weather variability at all. Nevertheless, the left tail of the distribution is long and thus pointing to the potential for some decidedly unfavorable outcomes. More detailed analysis of the characteristics and likelihood of these outcomes is merited.

References:

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