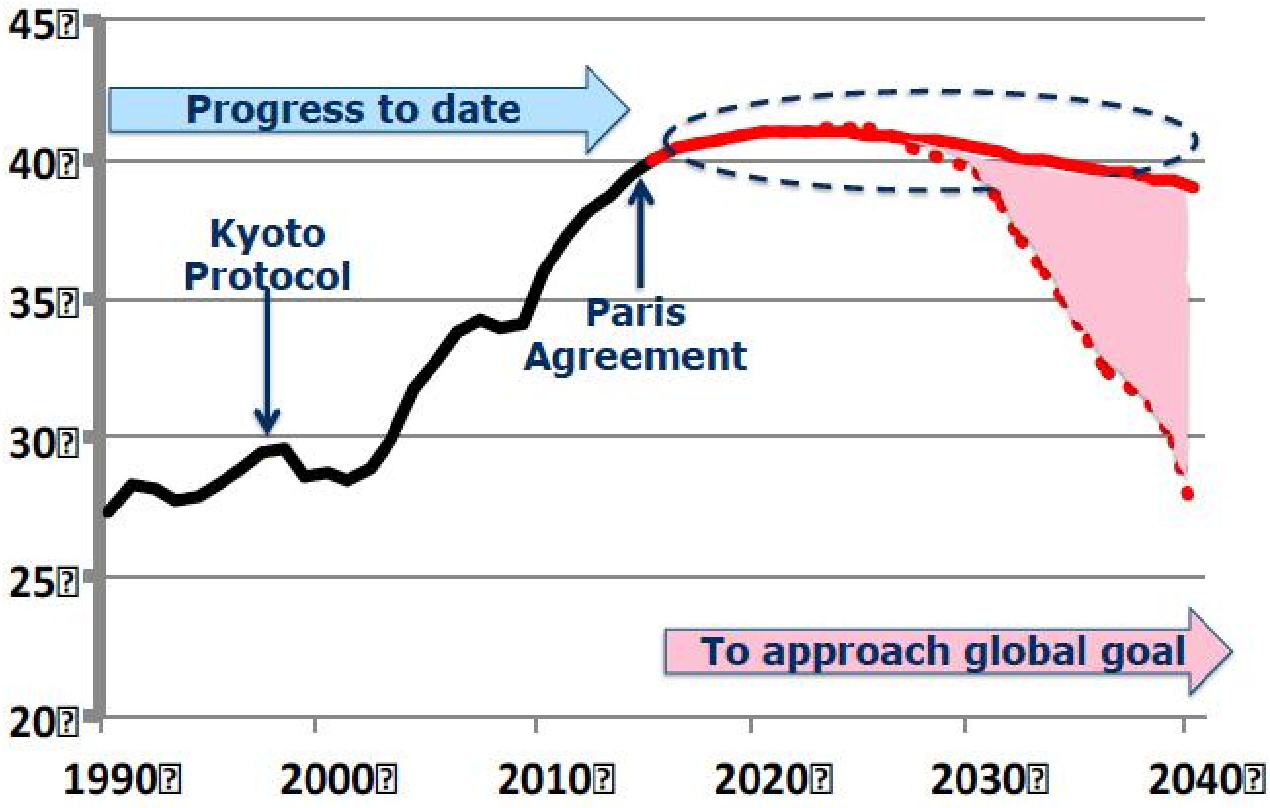
Characterizing the Uncertainty of Climate Change Projections for Africa: Impacts on Investments, Adaptation and Policy for Food, Water and Energy System

Kenneth Strzepek
Amy Dale
Susan Solomon
Brent Boehlert

EAPS Earth, Atmospheric and Planetary Sciences
MIT JOINT PROGRAM ON THE SCIENCE AND POLICY of GLOBAL CHANGE
IEc INDUSTRIAL ECONOMICS, INCORPORATED

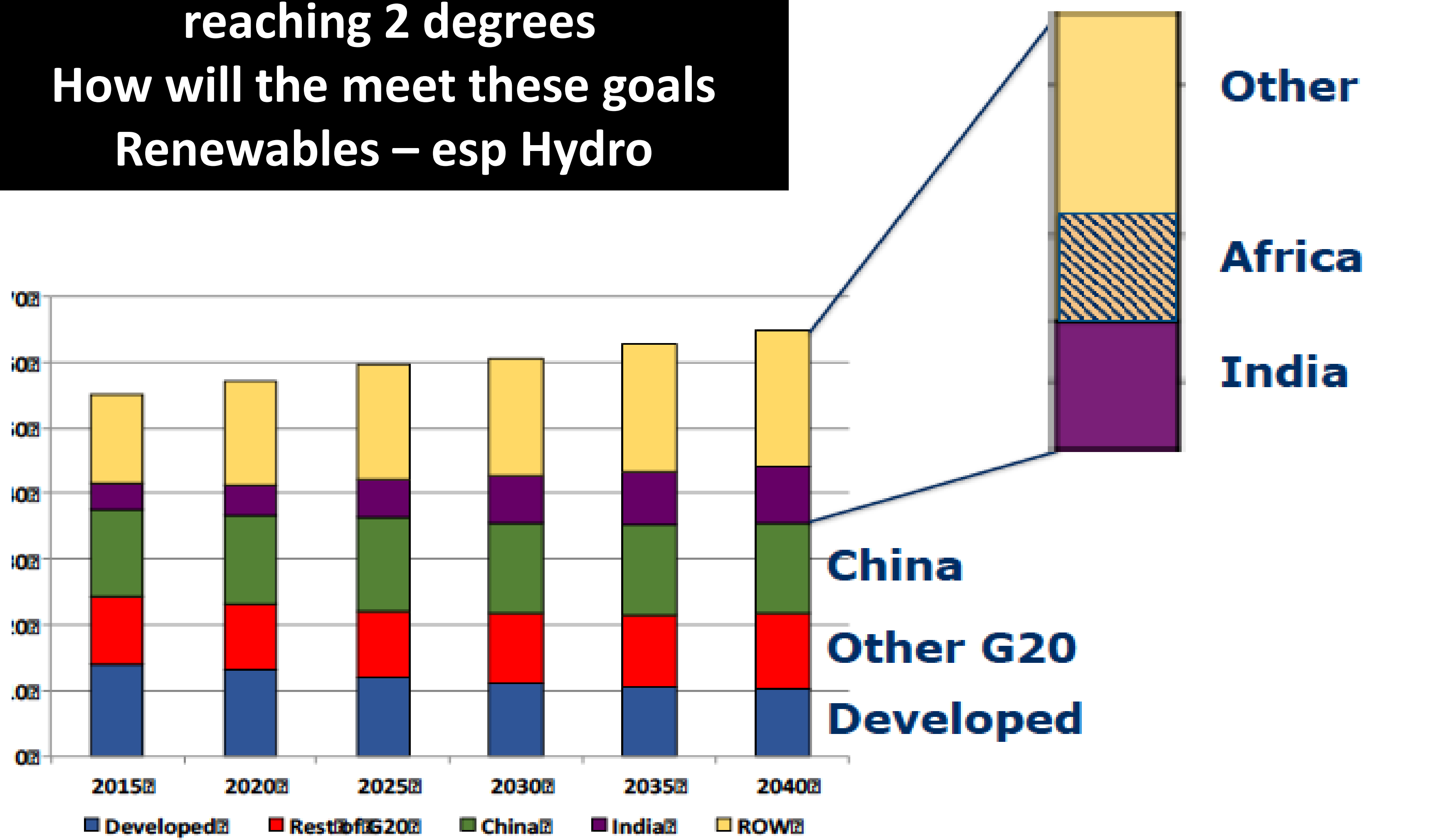
Grappling with Uncertainty

The Threat of Environment: Emission Mitigatoin

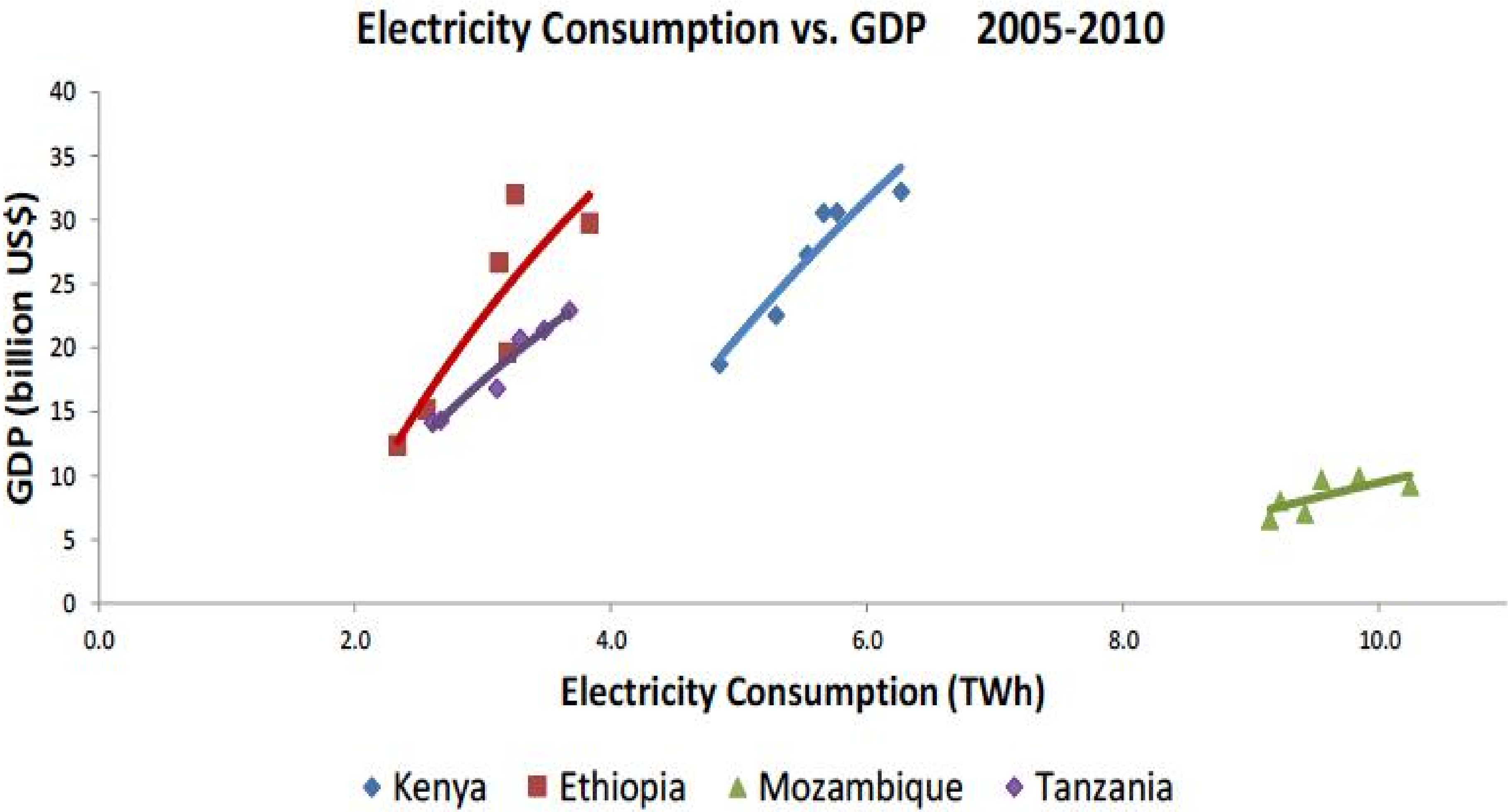


PARIS – AGREEMENT Headed to 3.5 Degrees
How do we get to 2.0 Degrees? – 2nd Cycle

AFRICA & INDIA are key players in reaching 2 degrees
How will the meet these goals
Renewables – esp Hydro



Electricity and Economic Development



Sources: GDP - World Bank; TWh - International Energy Agency

The Threat of
ENERGY POLICY

AFRICA GREEN ENERGY CORRIDOR 2063

The Realities

- There is no road to "development" that does not greatly improve access to energy services.

The Realities

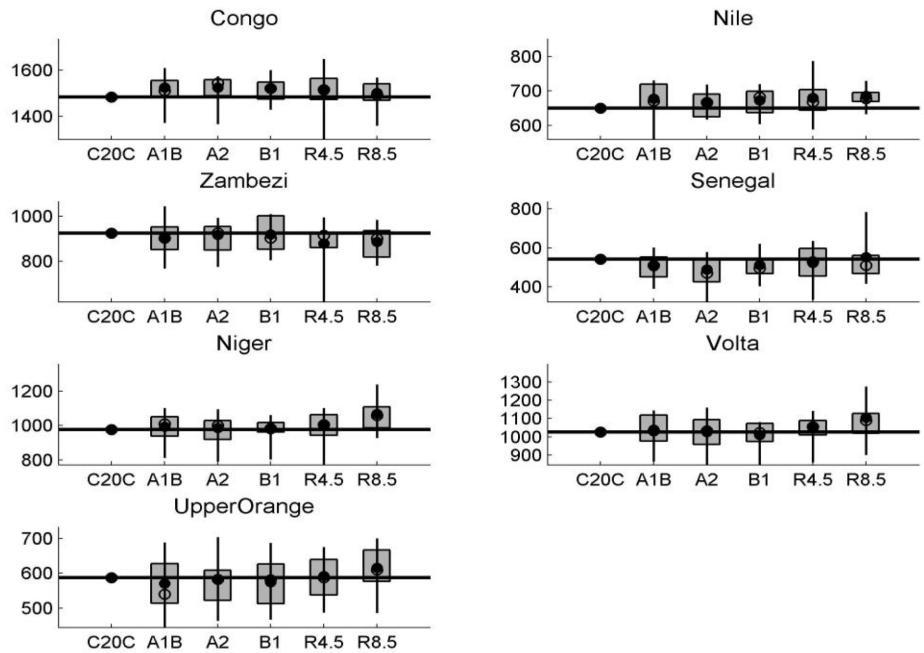
- **Renewable Scenario for Africa projects that the share of renewables in Africa can increase from 17% in 2009 to 50% in 2030, and nearly 75% by 2050.**
- **Total installed renewable capacity would grow from 28 GW in 2010 to around 800 GW in 2050 with hydropower accounting for 20% . An increase of 146 GW**

those that were taken by already wealthy or relatively wealthy, members of what we will call the global consuming class”

MOTIVATION

POLICY RELAVANT RESEARCH

CRIDF
UK AID FROM THE BRITISH PEOPLE

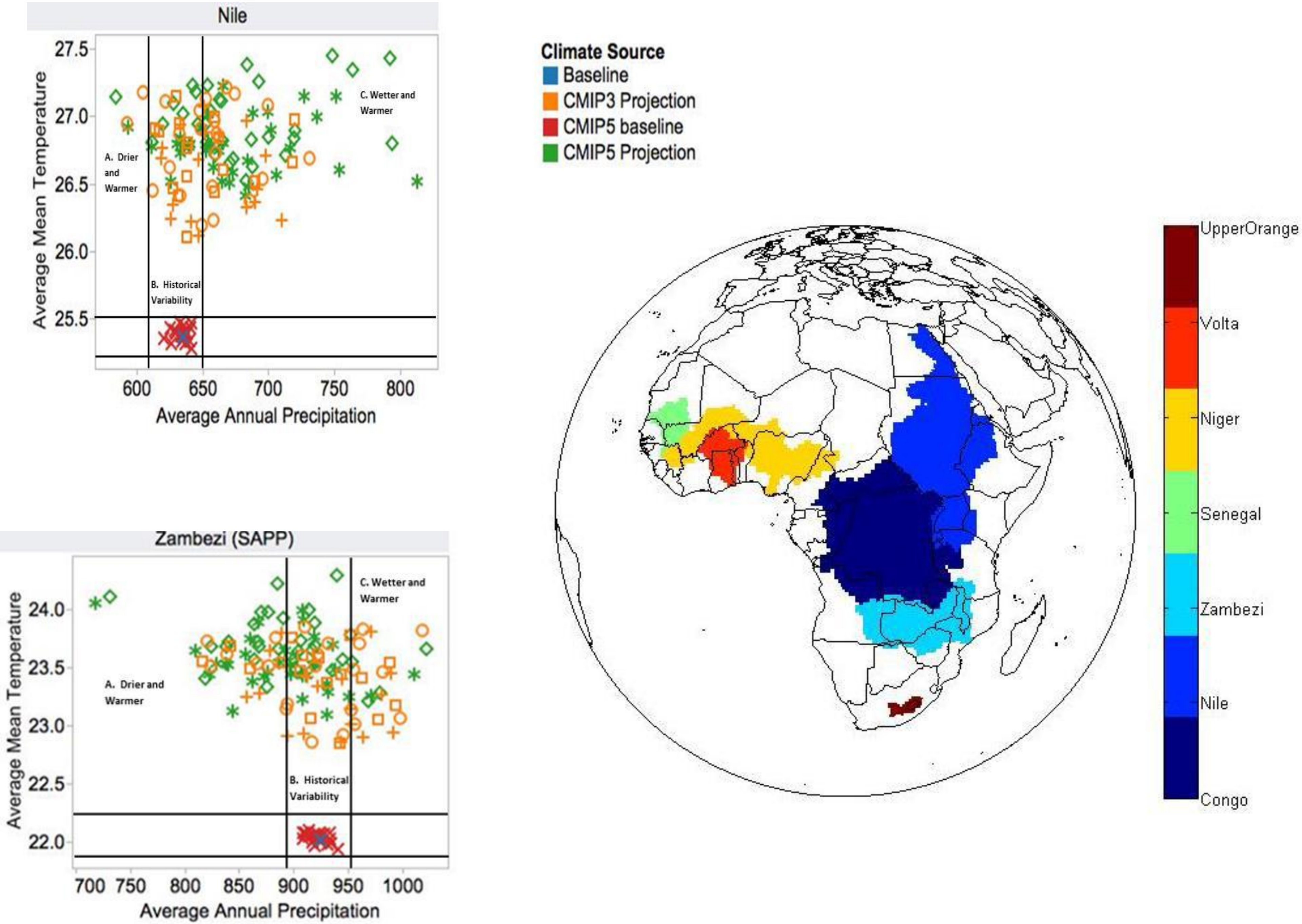


FUTURE CLIMATE FOR AFRICA

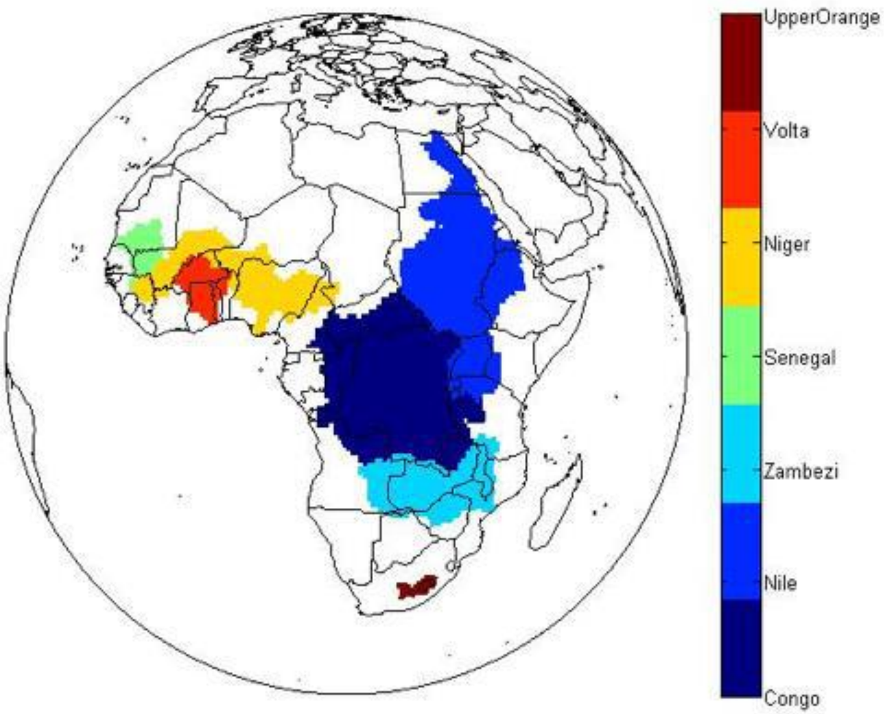
CLIMATE INVESTMENT FUNDS

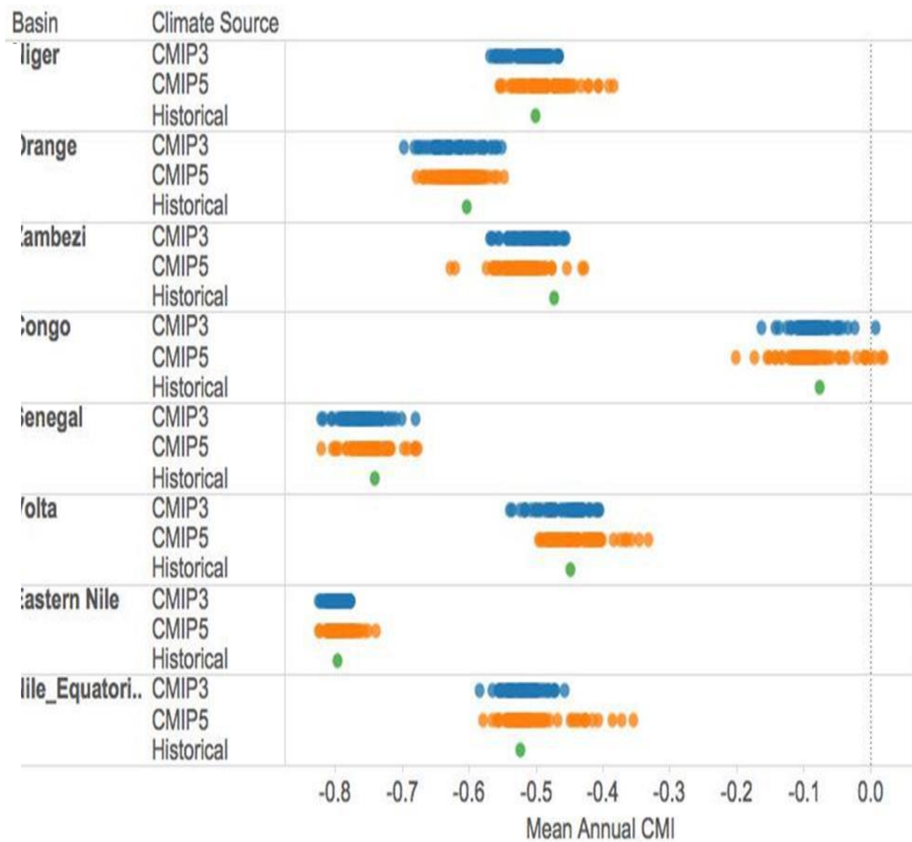
Pilot Program Climate Resilience (PPCR)

Africa Climate Research for Development – CR4D


Nile
Average Mean Temperature
27.5
27.0
26.5
26.0
25.5
600
650
700
750
800
Average Annual Precipitation
A. Drier and Warmer
B. Historical Variability
C. Wetter and Warmer
Climate Source
Baseline
CMIP3 Projection
CMIP5 baseline
CMIP5 Projection
Zambezi (SAPP)
Average Mean Temperature
24.0
23.5
23.0
22.5
22.0
700
750
800
850
900
950
1000
Average Annual Precipitation
A. Drier and Warmer
B. Historical Variability
C. Wetter and Warmer
UpperOrange
Volta
Niger
Senegal
Zambezi
Nile
Congo

Uncertain Runoff Impacts Africa's Major River Basin

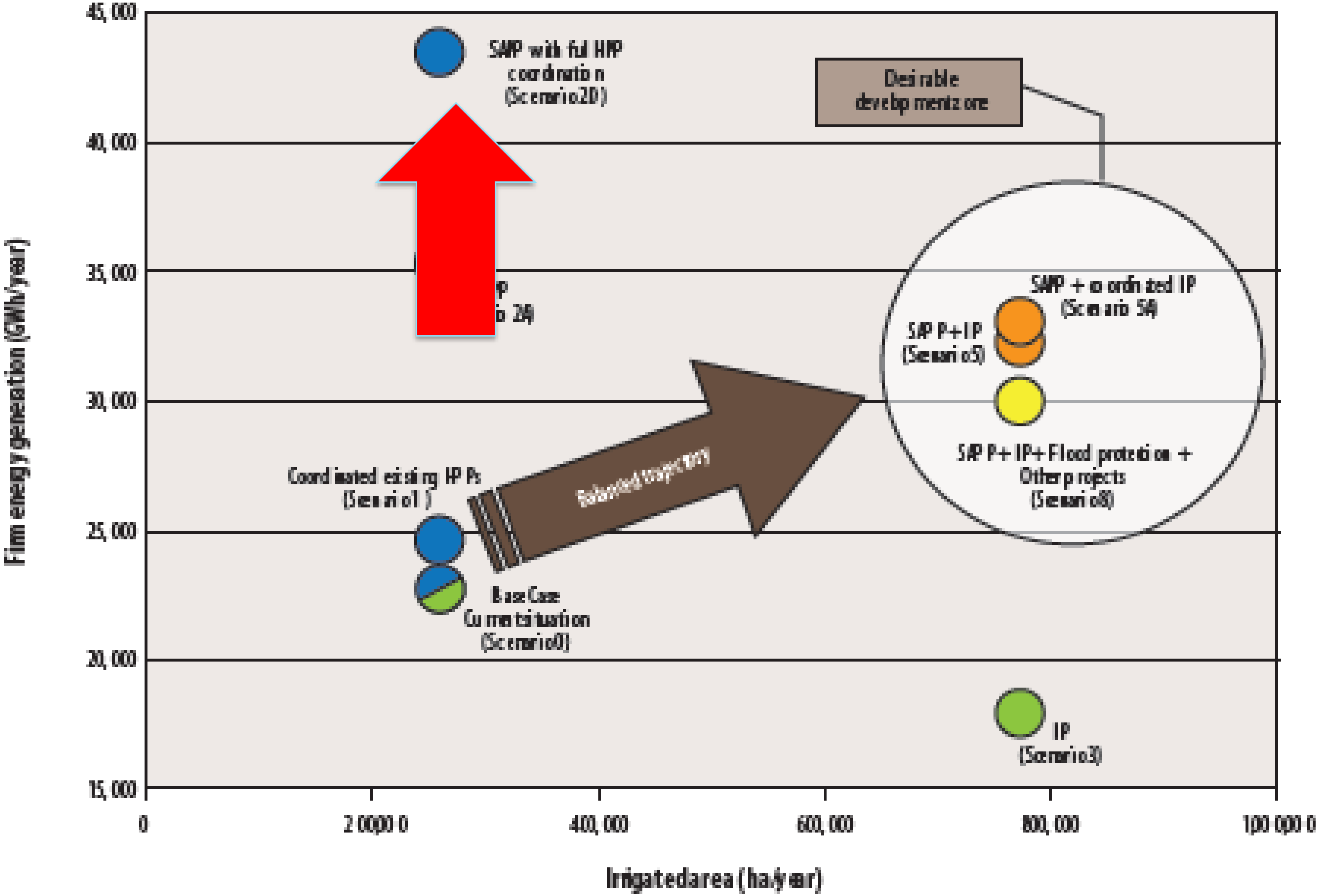




Zambezi Strategic Plan Objectives

Theme	ZSP Objective
Cooperation and good neighborliness	To promote and facilitate regional cooperation and good neighborliness.
Development and utilization for economic growth and prosperity	To promote and facilitate equitable, safe and optimal development and utilization of the resources of the Zambezi watercourse for economic growth and prosperity.
Sustainable and ecologically sound development and utilization	To promote and facilitate sustainable and ecologically sound development and utilization of the resources of the Zambezi watercourse
Climate resilience	To promote and facilitate climate resilient infrastructure and development to manage and reduce (in-vestment and societal) risk and promote economic growth and prosperity.
Public access for basic needs and livelihoods	To promote and facilitate public access to sufficient and safe water supplies, and related essential services, for basic needs and livelihoods
Capital mobilisation and investment finance	To promote and facilitate capital mobilization and in-vestment finance.

Energy- Food Security Trade off



Africa Climate Resilient Investment Facility (AFRI-RES) [NDF C91]

Bridge construction. Often the life time of a bridge will be 50 years or more.

29.03.2017

The AFRI-RES initiative aims to strengthen the capacity of African institutions (including national governments, river basin organisations, regional economic communities, power pools, and others) and private sector to plan, design, and implement investments in selected sectors, so as to increase their resilience to climate change.

Regional Africa
Africa Climate Resilient Investment Facility (AFRI-RES)
Ref: NDF C91

NDF Grant: EUR 5,000,000
Project Period: 2017–2020
Partner Agency: World Bank
Implementing Agency: African Climate Policy Centre (ACPC) and the World Bank

Objective

The overall objective of the initiative is to strengthen the capacity of African institutions (including national governments, river basin organisations, regional economic communities, power pools and others) and private sector to plan, design and implement

AGU PUBLICATIONS

Earth's Future

RESEARCH ARTICLE

10.1002/2017EF000539

Climate model uncertainty in impact assessments for agriculture: A multi-ensemble case study on maize in sub-Saharan Africa

Amy Dale[1,2], **Charles Fant**[1], **Kenneth Strzepek**[1], **Megan Lickley**[2], **and Susan Solomon**[1,2]

[1]Joint Program on the Science and Policy of Global Change, Massachusetts Institute of Technology, Cambridge, Massachusetts, USA, [2]Department of Earth, Atmospheric and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, Massachusetts, USA

Key Points:

- We estimate the influence of global climate model uncertainty on projected maize yield changes in sub-Saharan Africa due to climate change
- Five different GCM ensembles all project yield losses in the Sahel region and Southern Africa and sub-regional increases in East Africa
- Irreducible internal variability is a major cause of uncertainty in crop model projections even out to 2090

Supporting Information:

- Supporting Information S1
- Data Set S1

Corresponding author:
A. Dale, amydale@mit.edu

Citation:
Dale, A., C. Fant, K. Strzepek, M. Lickley, and S. Solomon (2017), Climate model uncertainty in impact assessments for agriculture: A multi-ensemble case study on maize in sub-Saharan Africa, *Earth's Future*, *5*, 337–353, doi:10.1002/2017EF000539.

Abstract We present maize production in sub-Saharan Africa as a case study in the exploration of how uncertainties in global climate change, as reflected in projections from a range of climate model ensembles, influence climate impact assessments for agriculture. The crop model AquaCrop-OS (Food and Agriculture Organization of the United Nations) was modified to run on a 2° × 2° grid and coupled to 122 climate model projections from multi-model ensembles for three emission scenarios (Coupled Model Intercomparison Project Phase 3 [CMIP3] SRES A1B and CMIP5 Representative Concentration Pathway [RCP] scenarios 4.5 and 8.5) as well as two "within-model" ensembles (NCAR CCSM3 and ECHAM5/MPI-OM) designed to capture internal variability (i.e., uncertainty due to chaos in the climate system). In spite of high uncertainty, most notably in the high-producing semi-arid zones, we observed robust regional and sub-regional trends across all ensembles. In agreement with previous work, we project widespread yield losses in the Sahel region and Southern Africa, resilience in Central Africa, and sub-regional increases in East Africa and at the southern tip of the continent. Spatial patterns of yield losses corresponded with spatial patterns of aridity increases, which were explicitly evaluated. Internal variability was a major source of uncertainty in both within-model and between-model ensembles and explained the majority of the spatial distribution of uncertainty in yield projections. Projected climate change impacts on maize production in different regions and nations ranged from near-zero or positive (upper quartile estimates) to substantially negative (lower quartile estimates), highlighting a need for risk management strategies that are adaptive and robust to uncertainty.

MOTIVATION

MAIZE & WATER IN SUB-SAHARAN AFRICA (SSA) UNDER CLIMATE CHANGE

Almost a quarter of the world's malnourished population lives in SSA

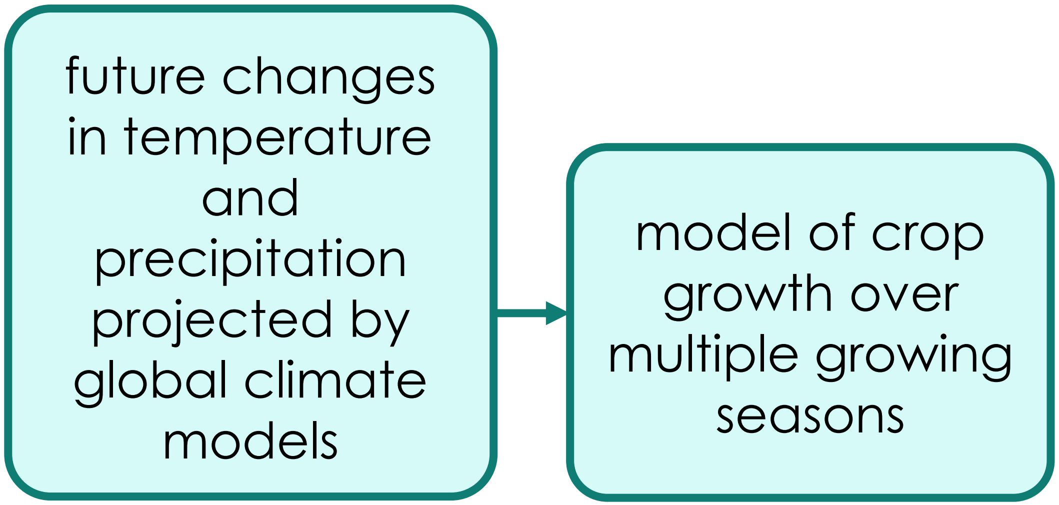
Maize (corn) is the most calorically important crop in SSA and the most widely produced crop by harvested area. It is also drought-sensitive.

high reliance on rainfall rather than irrigation → high sensitivity to future changes in precipitation

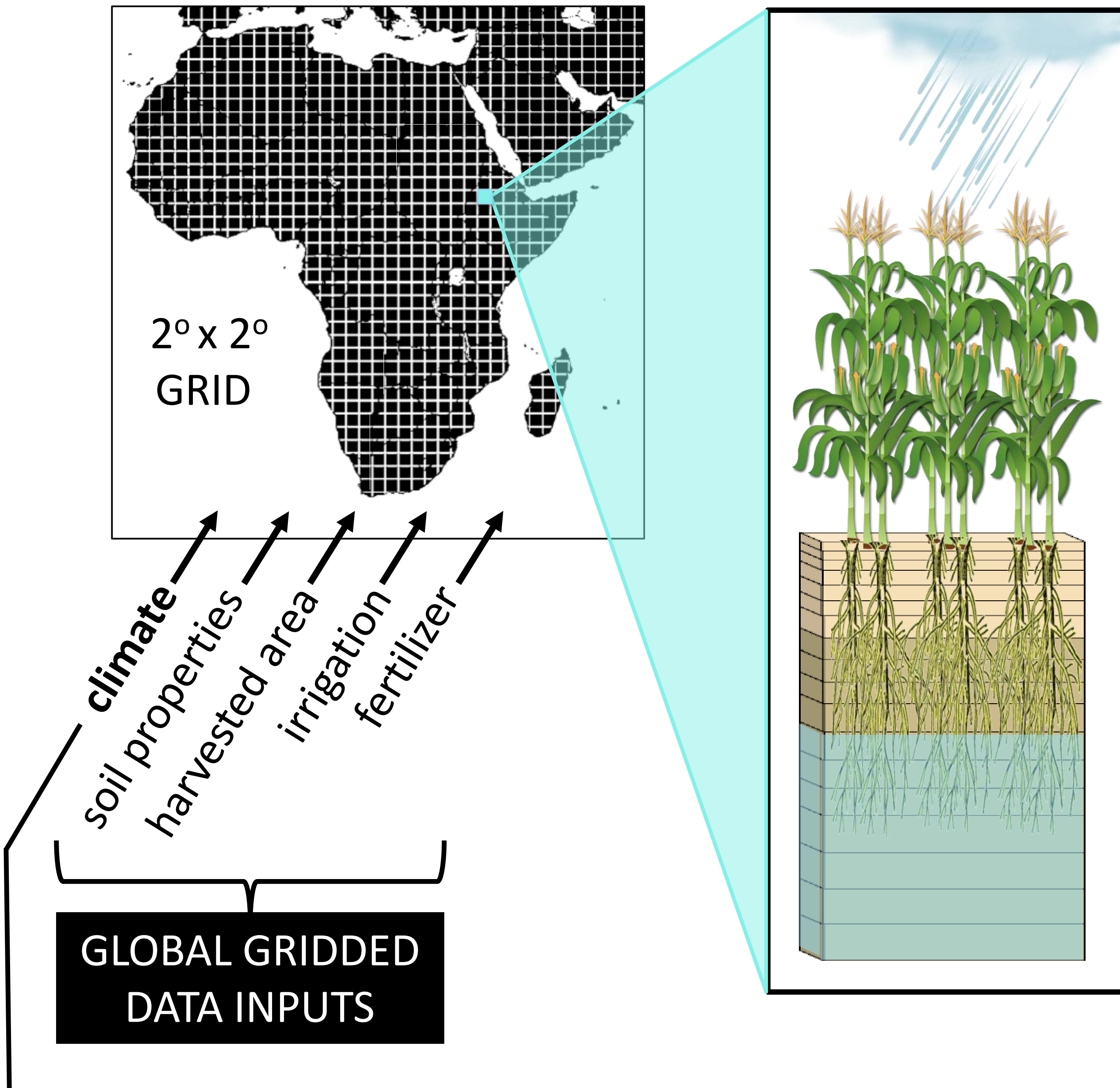
OBJECTIVE

(1) Predict regional and national trends in maize yields in sub-Saharan Africa under climate change

(2) Identify the sources of uncertainty in global climate models that drive uncertainty in predicted climate change impacts



CONCEPTUAL MODEL



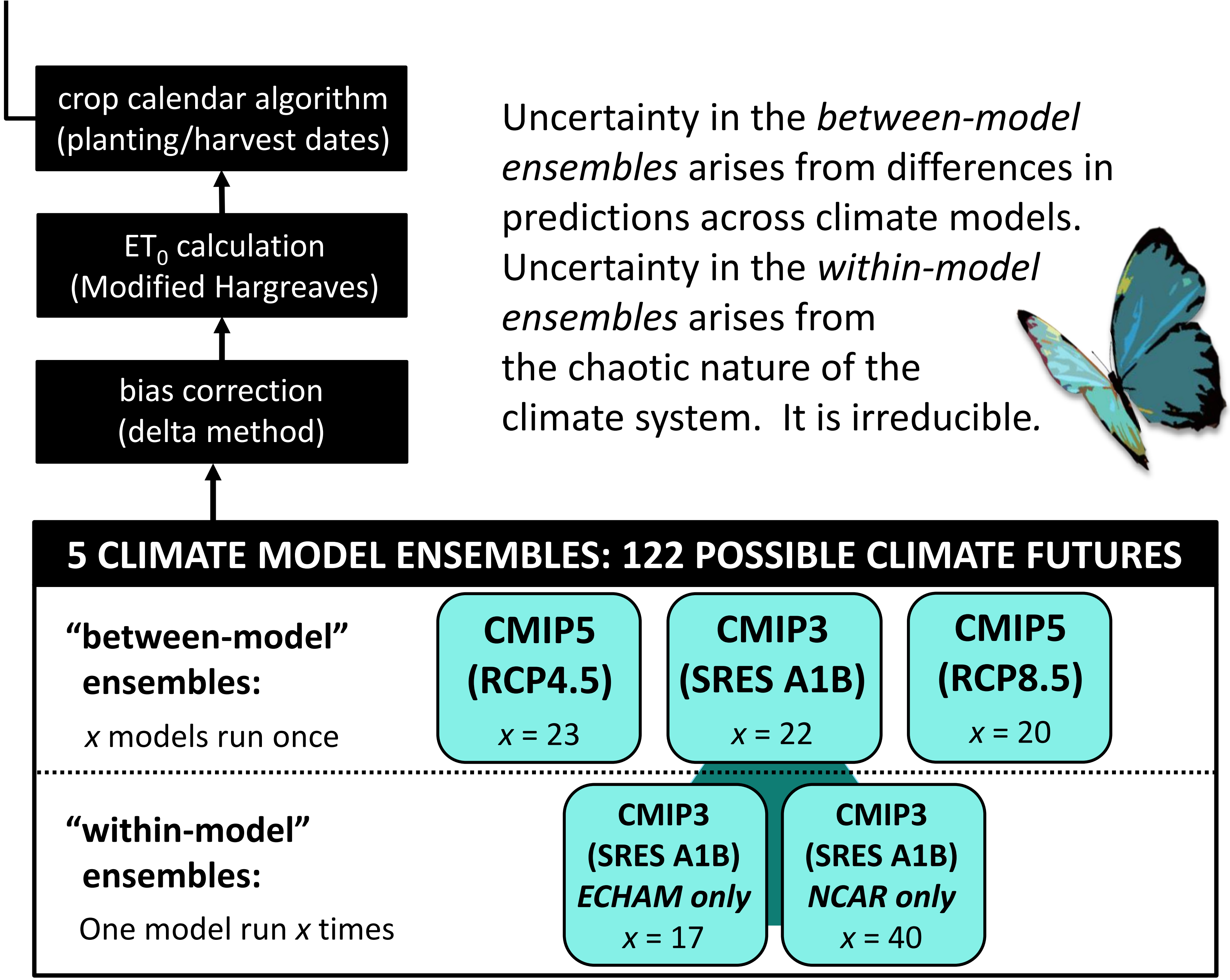
FAO AquaCrop-OS

coupled model of soil water balance and crop growth, transpiration, and senescence

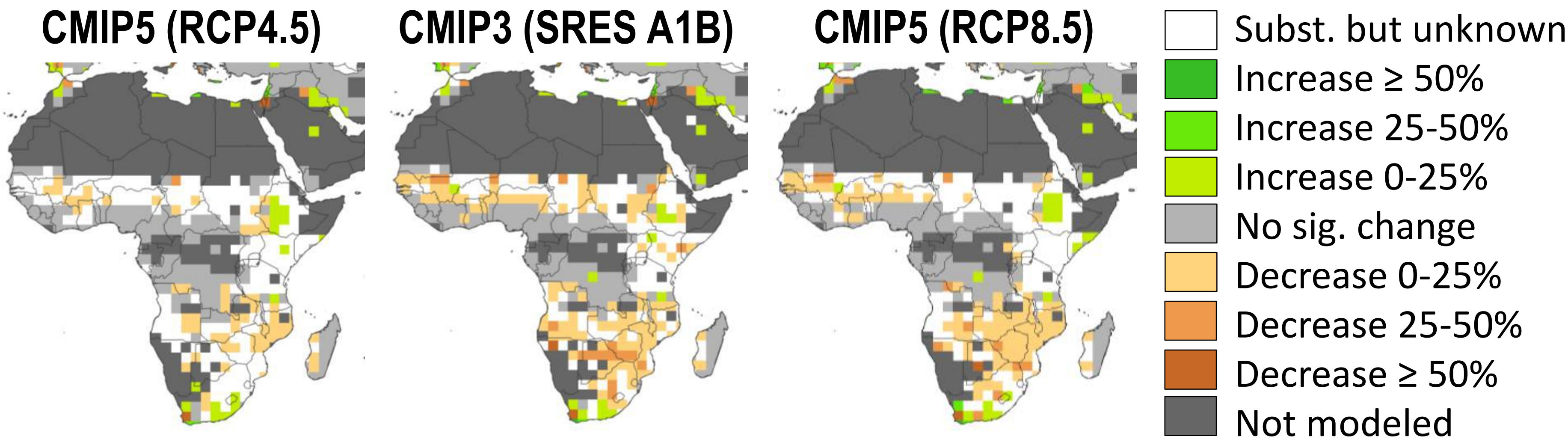
daily time step

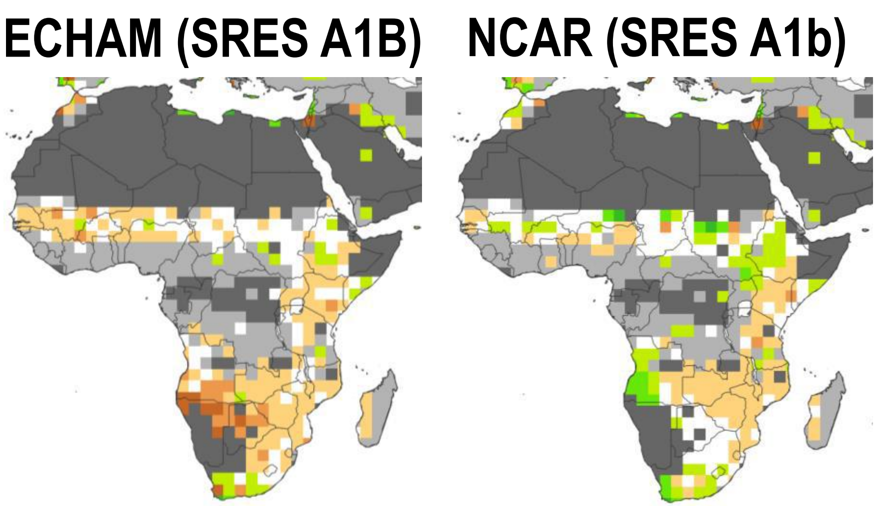
Plant stressors:

- water scarcity
- waterlogging
- heat/cold
- soil infertility


crop calendar algorithm
(planting/harvest dates)
ET0 calculation
(Modified Hargreaves)
bias correction
(delta method)
Uncertainty in the *between-model ensembles* arises from differences in predictions across climate models.
Uncertainty in the *within-model ensembles* arises from the chaotic nature of the climate system. It is irreducible.
5 CLIMATE MODEL ENSEMBLES: 122 POSSIBLE CLIMATE FUTURES
“between-model” ensembles:
x models run once
CMIP5 (RCP4.5) x = 23
CMIP3 (SRES A1B) x = 22
CMIP5 (RCP8.5) x = 20
“within-model” ensembles:
One model run x times
CMIP3 (SRES A1B) ECHAM only x = 17
CMIP3 (SRES A1B) NCAR only x = 40

MEDIAN PERCENT CHANGE IN CROP YIELD, 2010-2050

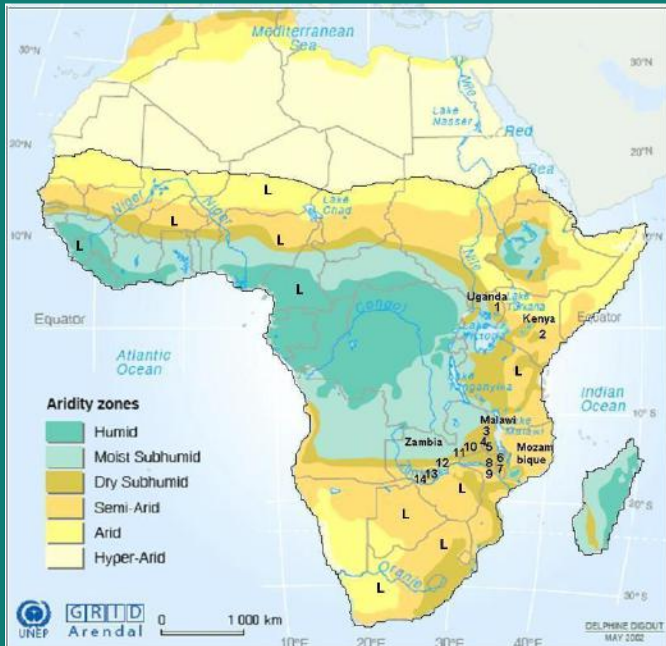


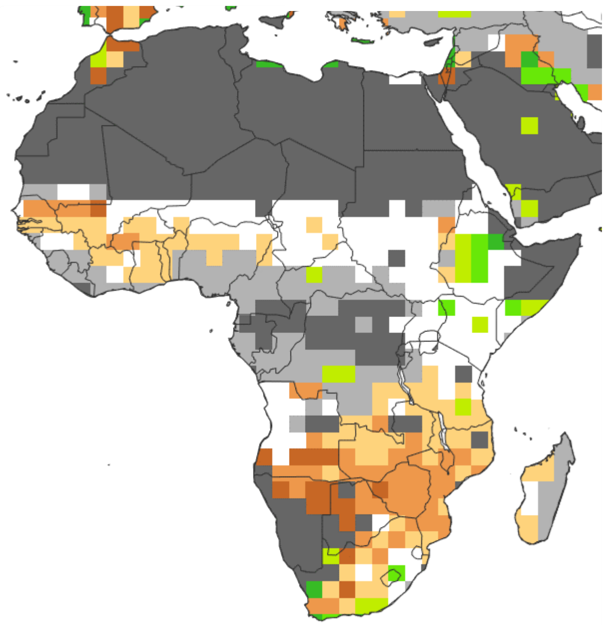


- Many spatial trends were robust across all five ensembles (next slide)
- Internal variability (chaos) was a major source of uncertainty

MEDIAN PERCENT CHANGE IN CROP YIELD, 2010-2090

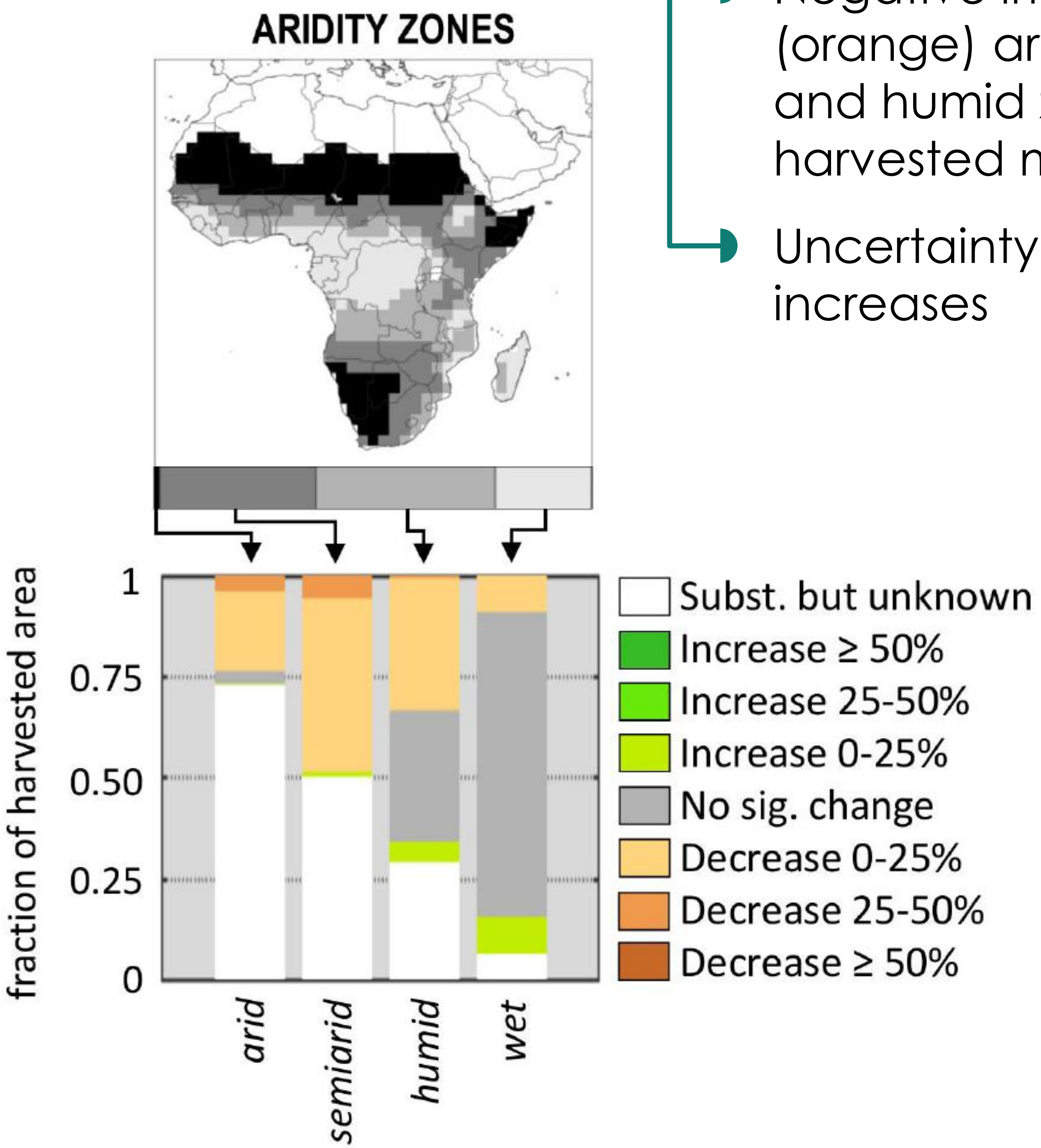
CMIP5 (RCP8.5)





Spatial patterns were related to aridity zones

MEDIAN PERCENT CHANGE IN CROP YIELD, 2010-2050

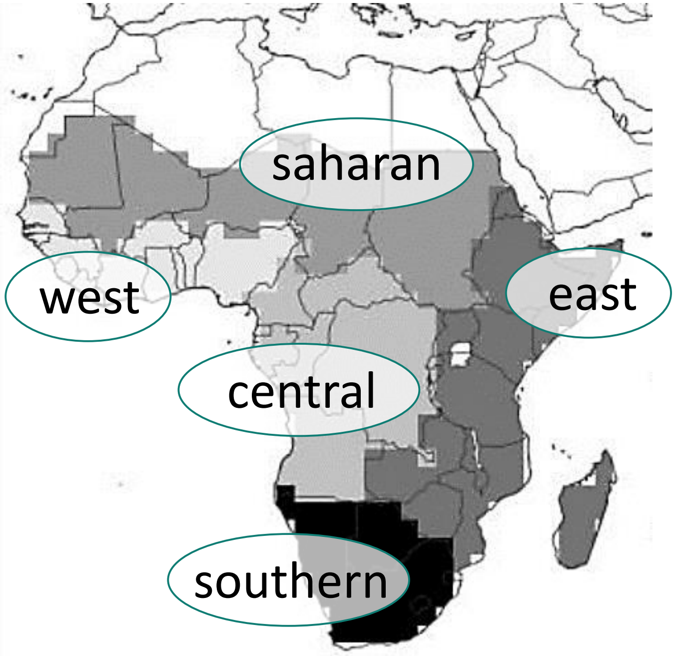


- Negative impacts on maize yields (orange) are highest in the semiarid and humid zones (~80% of current harvested maize area)
- Uncertainty (white) increases as aridity increases

MEDIAN PERCENT CHANGE IN CROP YIELD, 2010-2090

75% of maize production

	current production (Mt)	% change in production, 2010-2090 for RCP8.5: Q1	median	Q3
Southern	15	-	**-14**	+
East	30	-	**-6**	-
Saharan	3	-	**-5**	+
Central	5	-	**-3**	-
West	18	-	**-4**	-
South Africa	14	-	**-23**	+
Nigeria	11	-	**-2**	-
Ethiopia	7	+	**13**	+
Tanzania	7	-	**-2**	+
Kenya	4	-	**-2**	+
Zambia	3	-	**-22**	-
Uganda	3	-	**-1**	+
Ghana	2	-	**-5**	-
SSA, all	69	-	**-8**	-



MEDIAN PERCENT CHANGE IN CROP YIELD, 2010-2090

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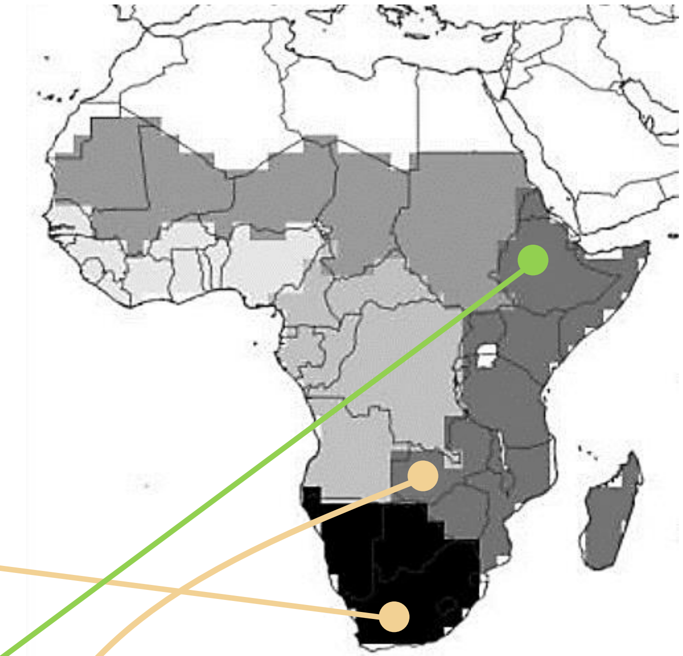
Uganda	3	-	**-1**	+
Ghana	2	-	**-5**	-
SSA, all	69	-	**-8**	-



Impacts are especially large in South Africa and Zambia

Ethiopia may see positive effects

MEDIAN PERCENT CHANGE IN CROP YIELD, 2010-2090

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Zambia	3	-	**-22**	-
Uganda	3	-	**-1**	+
Ghana	2	-	**-5**	-
SSA, all	69	-	**-8**	-

Uncertainty is high

Many regions/countries could experience positive yield changes

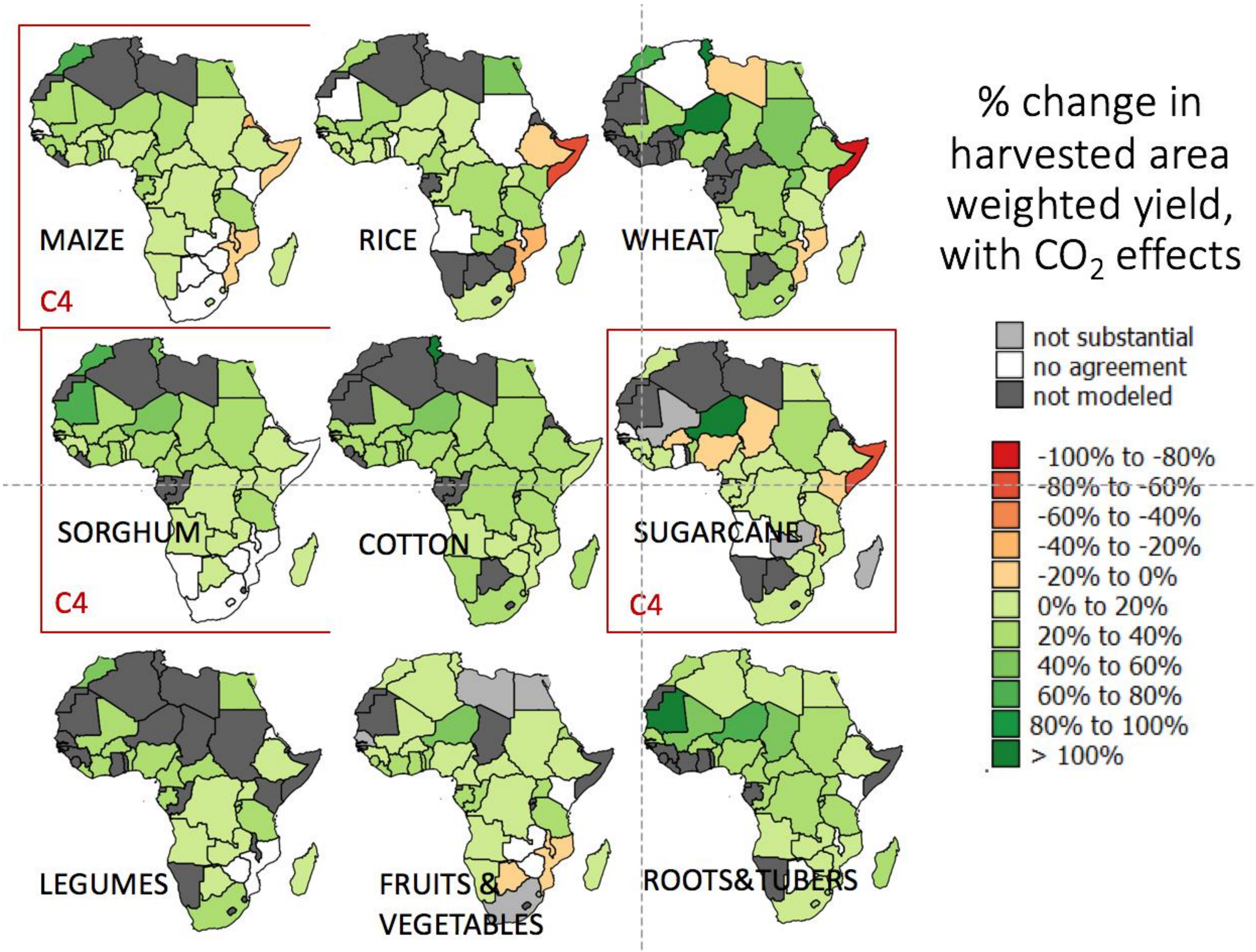
Predicted maize yield changes due to climate change:

- Resilience in Central Africa due to high rainfall
- Widespread yield losses in Southern Africa & Sahel due to aridity increases
- Sub-regional yield gains in East and Southern Africa due to increasing rainfall (Horn of Africa) and increasing temperature (Ethiopian highlands, southern tip)
- Changes in T had a larger overall impact than changes in P (when summed across SSA) because positive and negative regional P impacts cancelled each other out. T effects were negative except in the two sub-regions indicated
- Spatial trends were in qualitative agreement with previous work

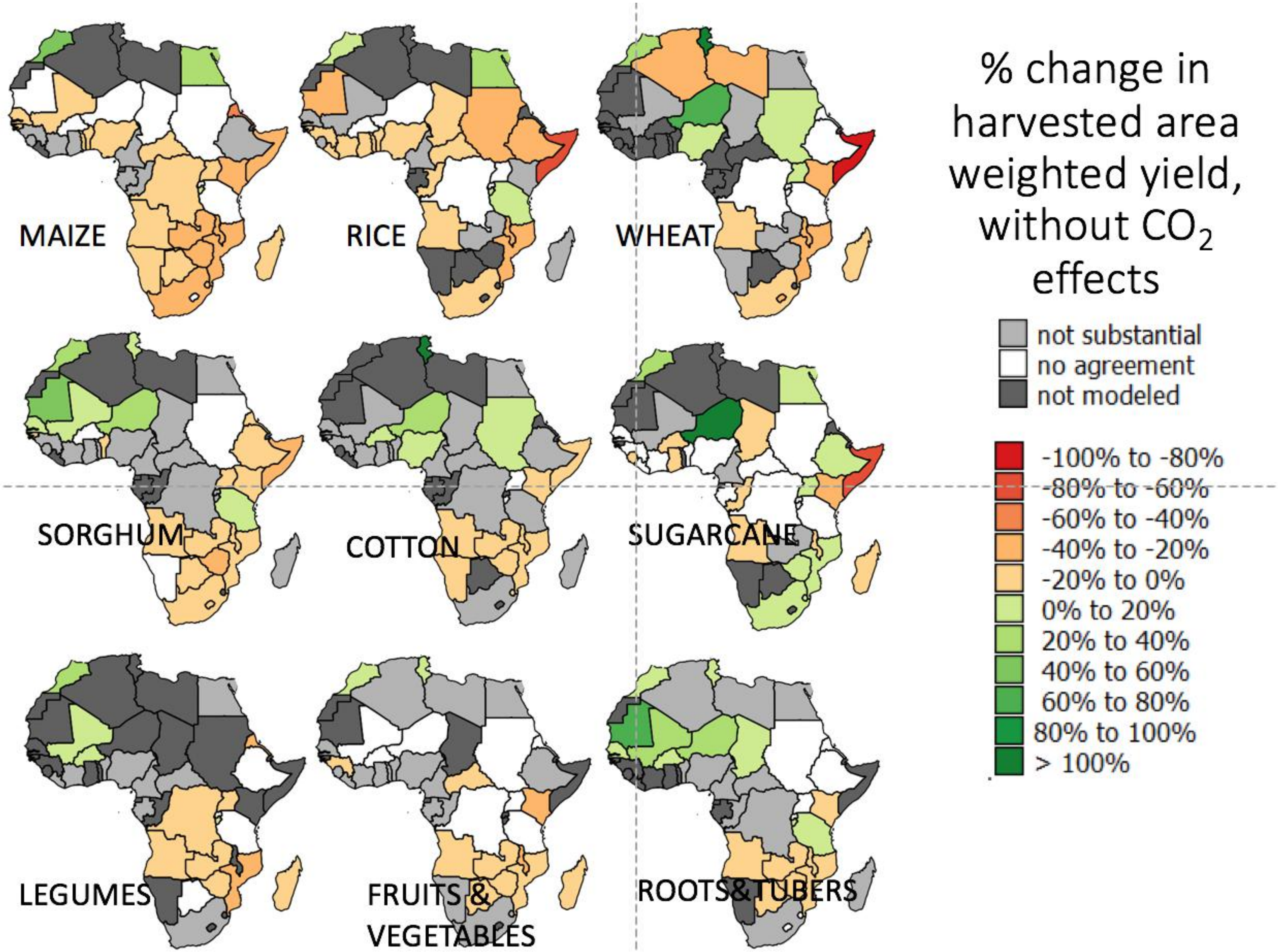
We need risk management strategies that are robust to uncertainty

- Uncertainties in yield changes are large (potential for positive impacts in many regions/nations)
- Uncertainty increases with increasing aridity
- Irreducible internal variability was a major source of uncertainty

Major Crops **WITH** CO2 effects



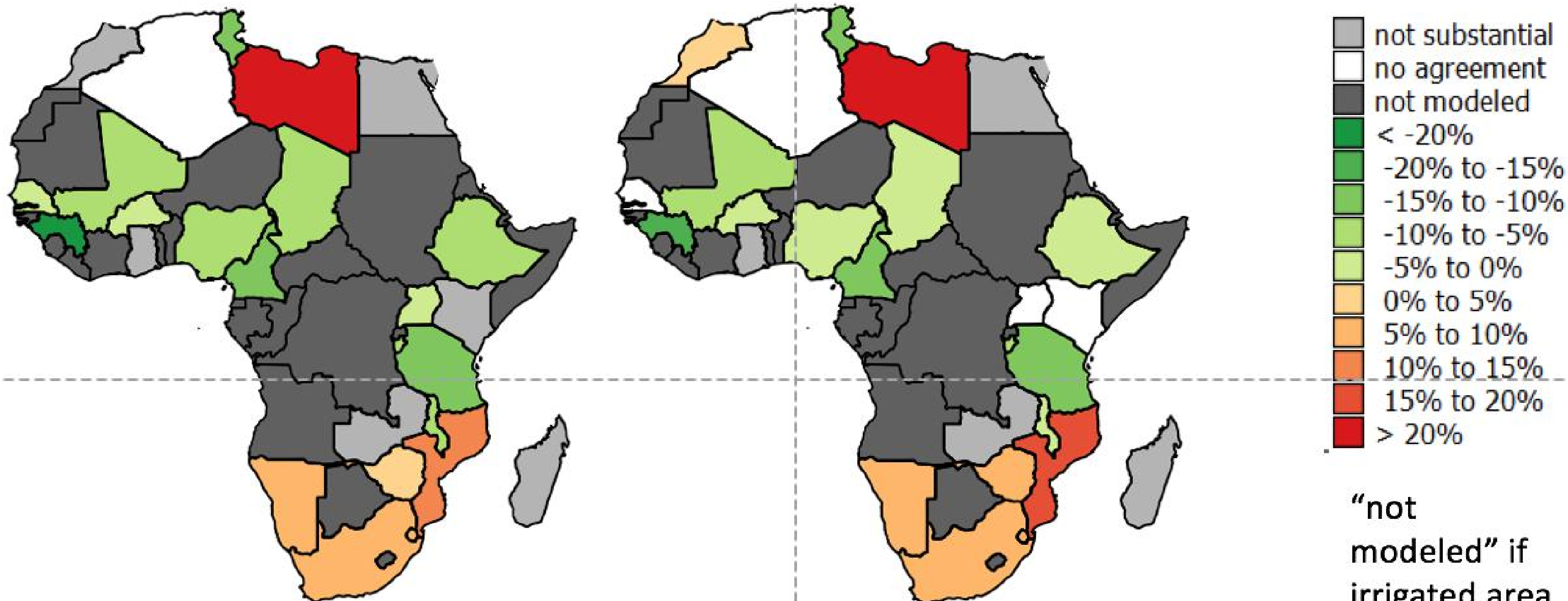
Major Crops **WITHOUT** CO2



% CHANGE IN IRRIGATION WATER REQUIREMENT

RCP8.5, 11-member ensemble median

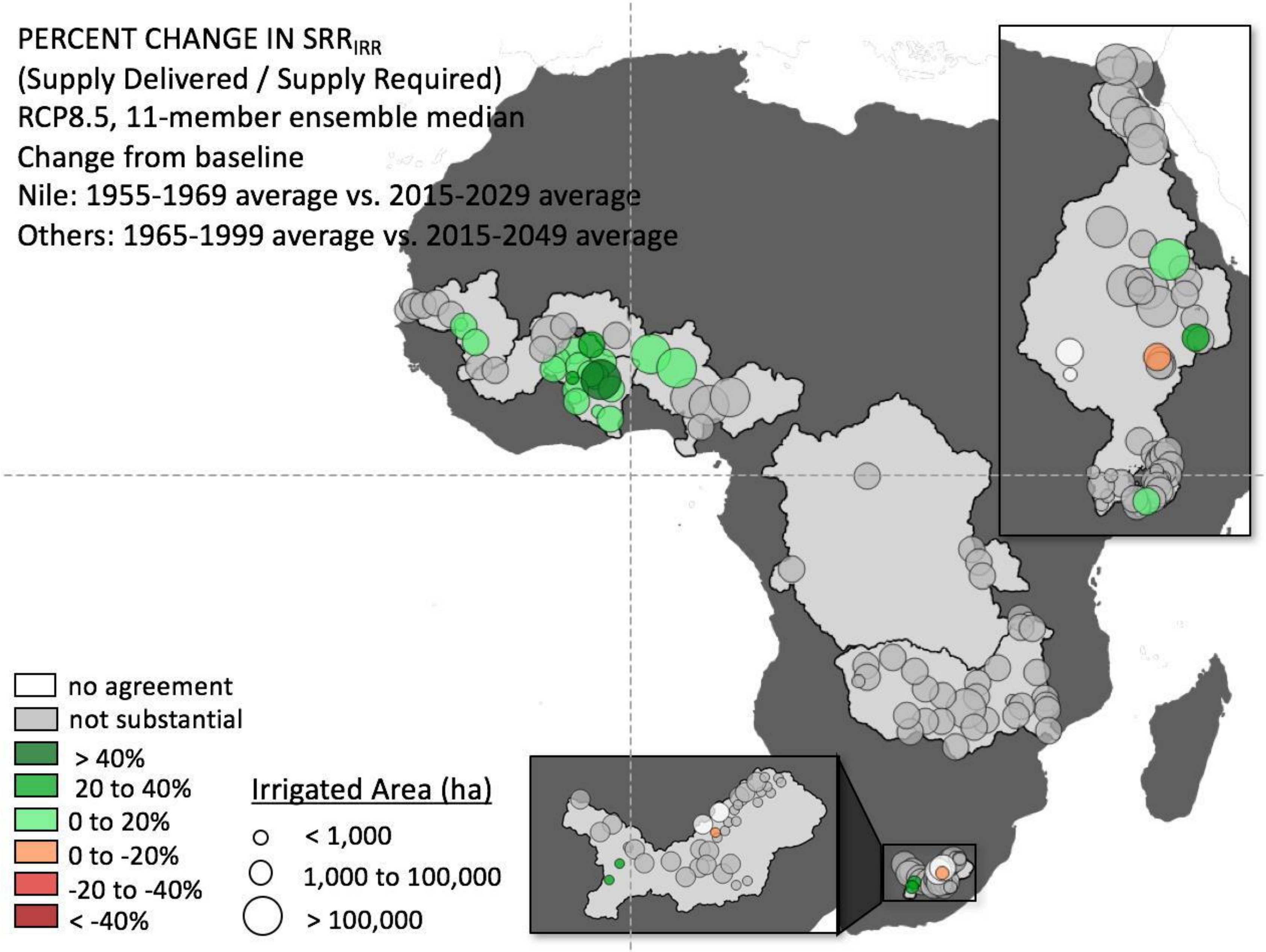
Change from baseline (1965-1999 average vs. 2015-2049 average)



"not modeled" if irrigated area < 1000

with CO_2 effects

without CO_2 effects


PERCENT CHANGE IN SRR_{IRR}
(Supply Delivered / Supply Required)
RCP8.5, 11-member ensemble median
Change from baseline
Nile: 1955-1969 average vs. 2015-2029 average
Others: 1965-1999 average vs. 2015-2049 average
no agreement
not substantial
> 40%
20 to 40%
0 to 20%
0 to -20%
-20 to -40%
< -40%
Irrigated Area (ha)
< 1,000
1,000 to 100,000
> 100,000

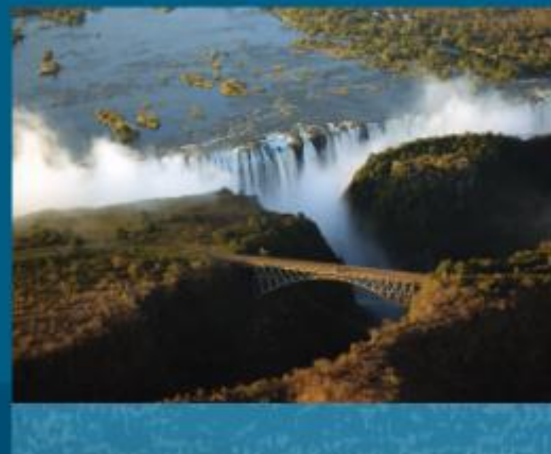
KEY FINDINGS

:

- There appears to be sufficient undeveloped and reallocation of water to meet the increased Irrigation demand
- There are negative impacts on Hydropower
- There are negative impacts on enviromental flows

- NEXT STEPS
- More uncertainty runs
- Evaluate the impacts on the other water sectors

AFRICA DEVELOPMENT FORUM



CONFERENCE EDITION

Enhancing the Climate Resilience of Africa's Infrastructure

The Power and Water Sectors

Raffaello Cervigni, Rikard Liden,
James E. Neumann, and Kenneth M. Strzepek,
Editors

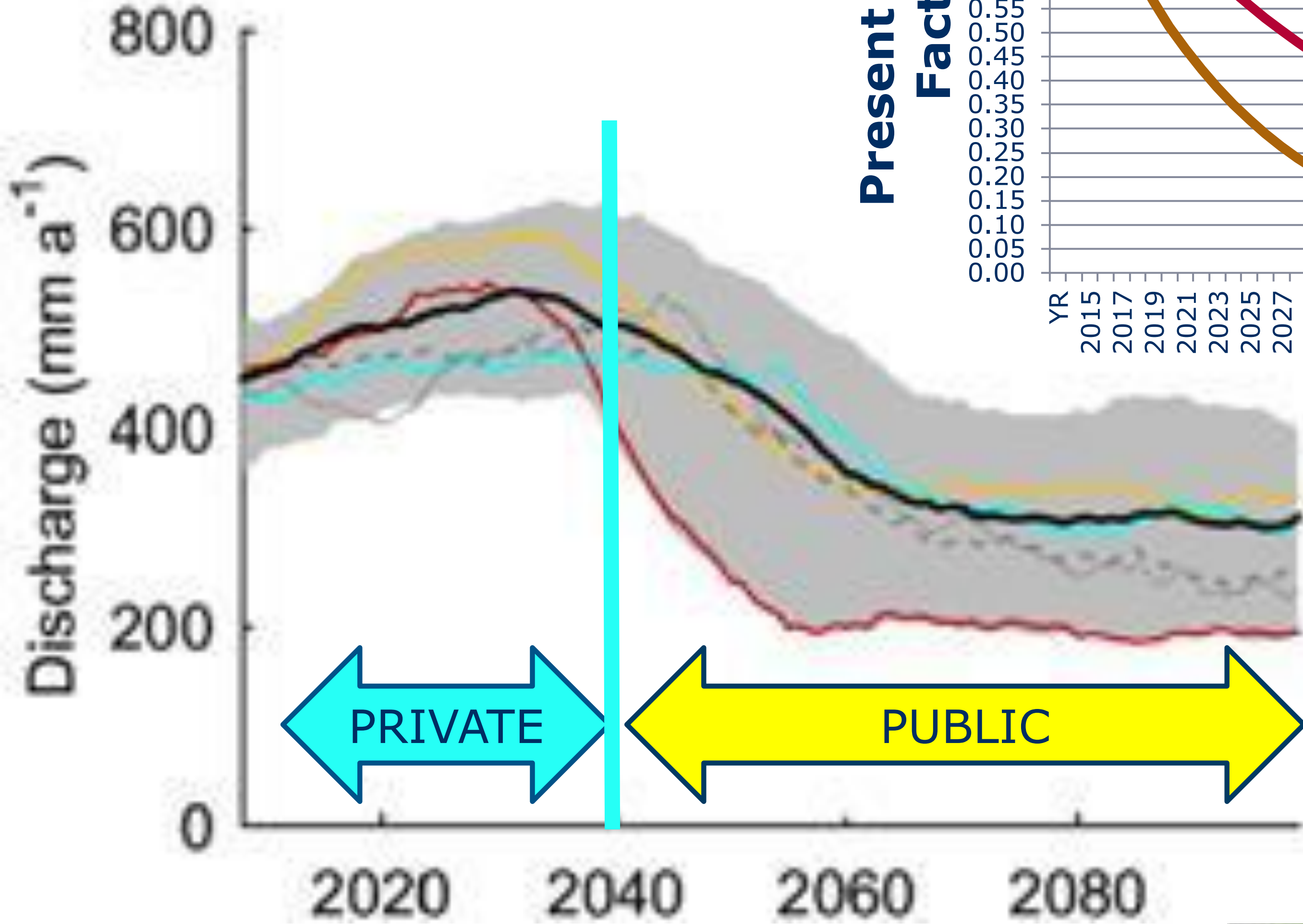
WORLD BANK GROUP

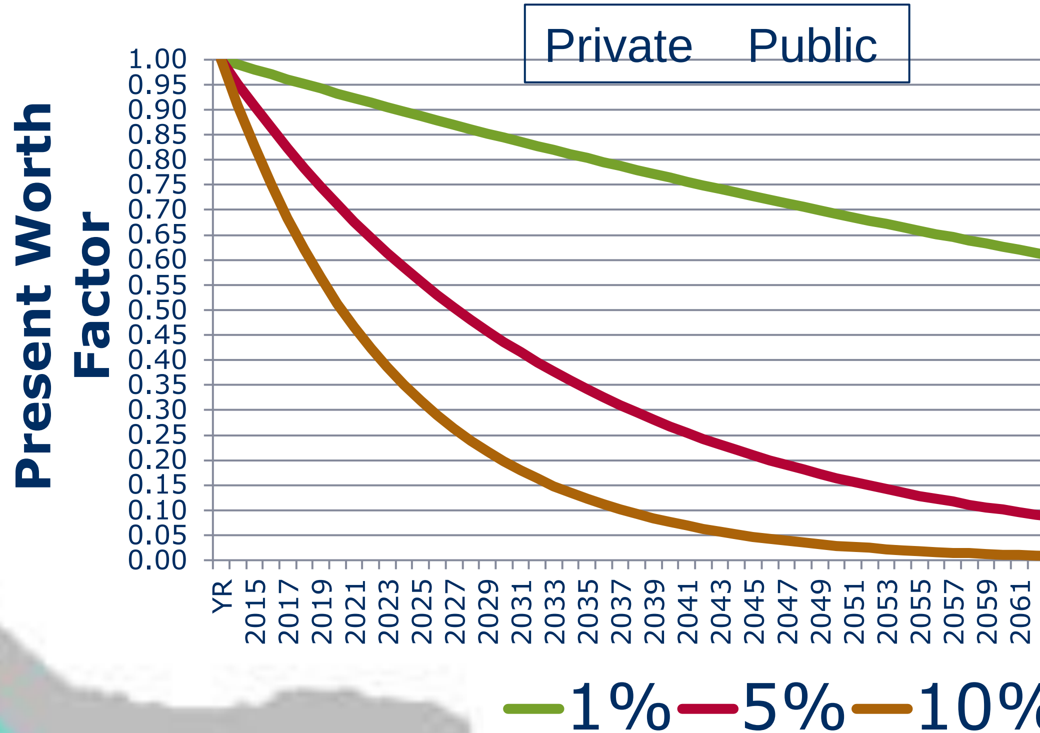
United Nations
Economic Commission for Africa

Types of Adaptation

		Anticipatory	Reactive
Natural system			Changes in length of growing Changes in ecosystem composition Wetland migration
Human system	Public	Early-warning systems New buildings codes, design standards Incentives for relocation	Compensatory payments, subsidies Enforcement of building codes Reparation of protective structures
	Private	Purchase of insurances Adjustment of housing conditions to extreme weather events	Changes in farm practices Changes in farm insurance premiums Purchase of air-conditioning (maladaptation) Production of artificial snow (maladaptation)

Public-Private-Partnership PPP Hydropower





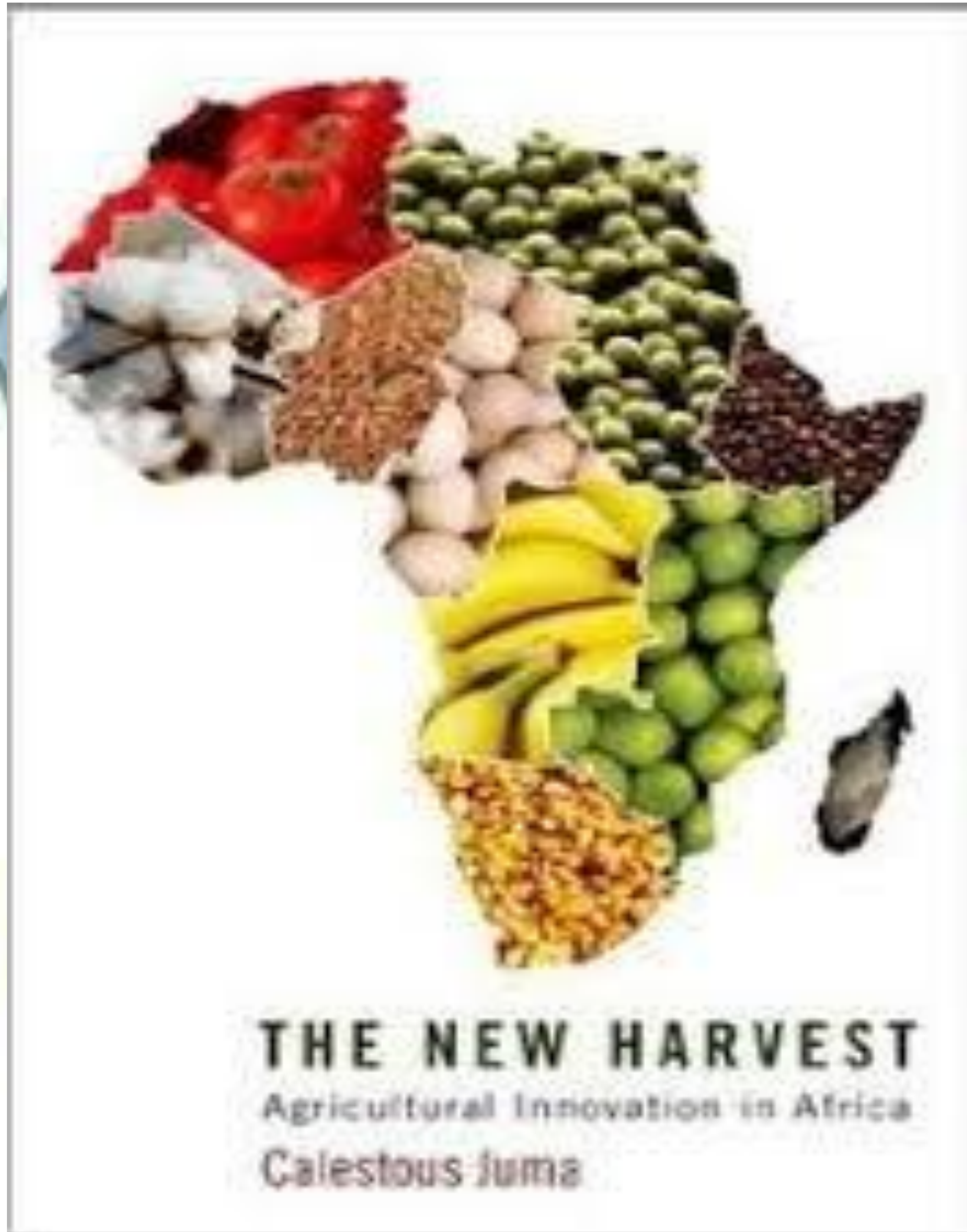
Food Sec… …mber of

- ***Rapid Ener…***
- ***Environme…***
- ***Economic M…***

A… …f of

Environm… … Security

ALL IN TH…



J-WAFS

THANK YOU