Karlsruher Institut für Technologie

State-of-the-art in climate modelling and CC impact analysis in EA

Patrick Laux

IINSTITUTE OF METEOROLOGY AND CLIMATE RESEARCH, GARMISCH-PARTENKIRCHEN, GERMANY

Patrick Laux

- **Post-Doc Position**

  KIT, IMK-IFU

  Department *Regional Climate Systems* at IMK-IFU

- **Academic background**

  MSc. (Diploma) in *Applied Environmental Sciences*

  PhD at KIT, IMK-IFU, Garmisch-Partenkirchen

- **Research interests**

  Statistical and Dynamical Downscaling of GCMs

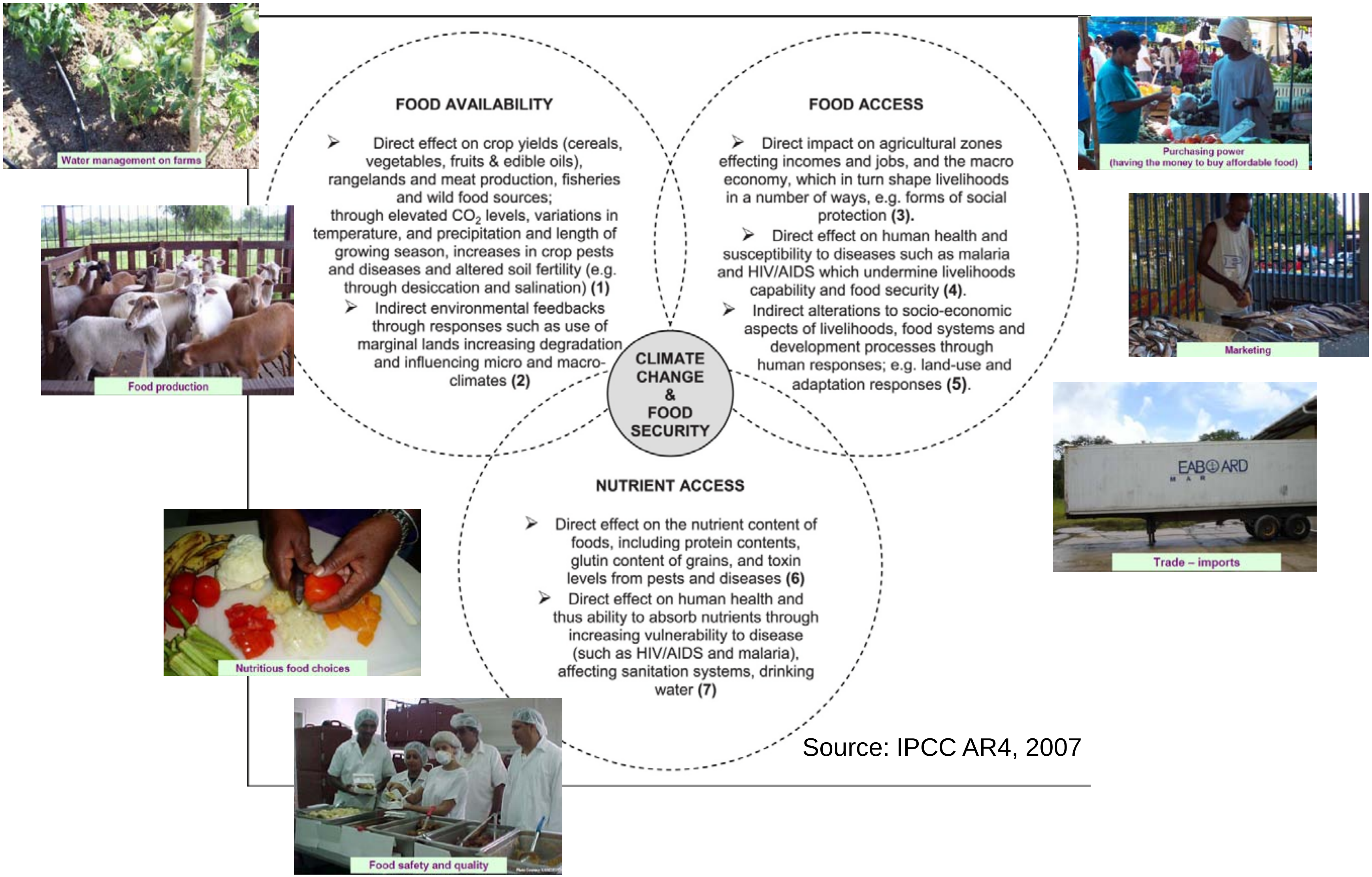
  Bias correction of precipitation

  Hydrometeorology: Precipitation variability in complex terrain and data poor regions

  Agricultural impact studies

- **Geographical Focus:** Alpine Space, **Africa**, South East Asia

Why do we need climate change information?



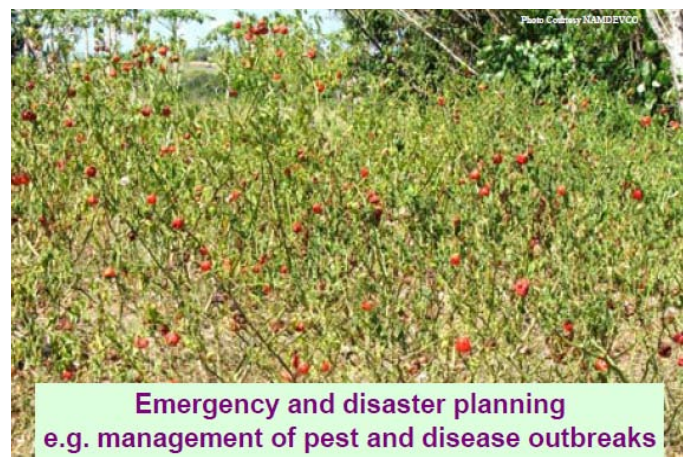
Source: IPCC AR4, 2007

Stability of Food Security


Good conditions for production: Water supply


Good conditions for production: Weather

Emergency and disaster planning
e.g. flood and drought mitigation

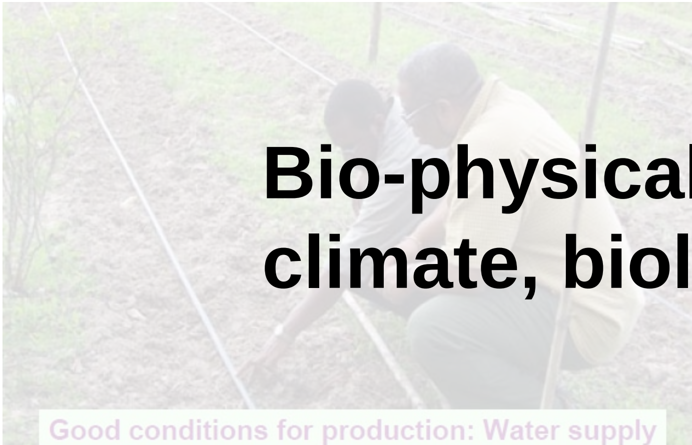


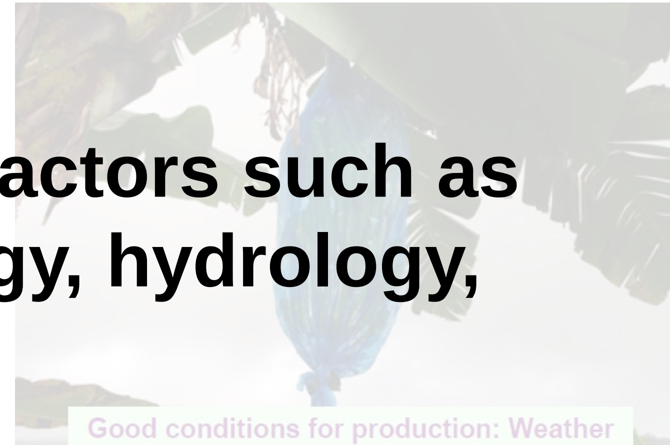
Emergency and disaster planning
e.g. management of pest and disease outbreaks

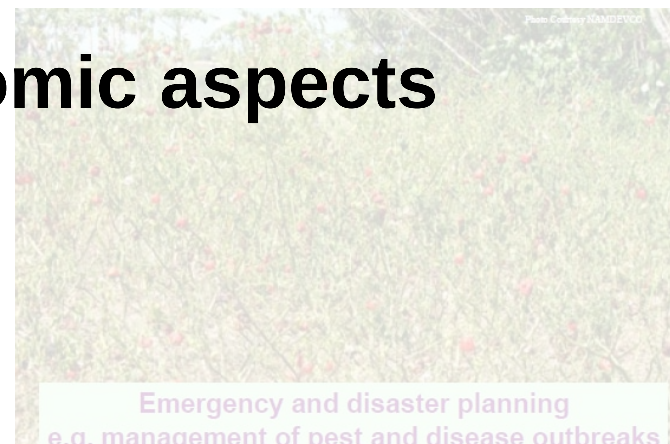
Stability of Food Security

Bio-physical factors such as climate, biology, hydrology,

… but also: socio-economic aspects







Main drivers for *Food Insecurity* in EA

- **Economy** (e.g. GDP) mainly depends on agricultural sector (highly vulnerable to climate, CC and CV)

- Limited **agricultural productivity** (low soil fertility, pest, crop diseases, lack of fertilizers)

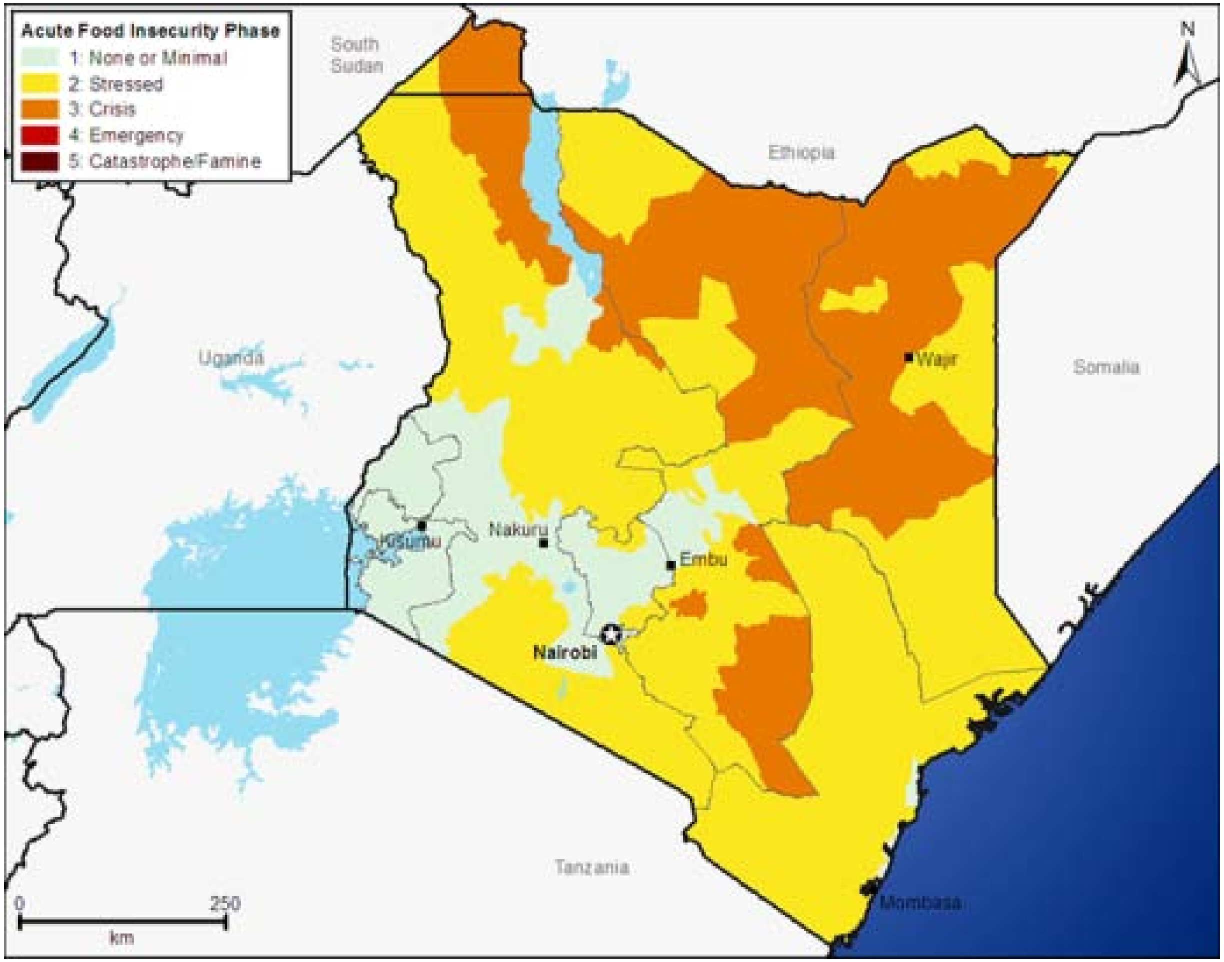
- **Climate:**

  → **Agriculture:** High rainfall variability on different scales (Hulme et al., 2005)

  → **Health:**

  - Droughts/Floods contribute to diseases such as diarrhoe, cholera (Few et al., 2004) through poor nutrition
  - Diseases such as Malaria spreads into new areas such as highlands of Central Kenya (Chen et al., 2006; Pascual et al., 2006)

Early warning system: Level Food Security for 04/2012



Source: FEWS-NET

Impacts of CC/CV

Climate Change is expected to aggravate the situation in EA

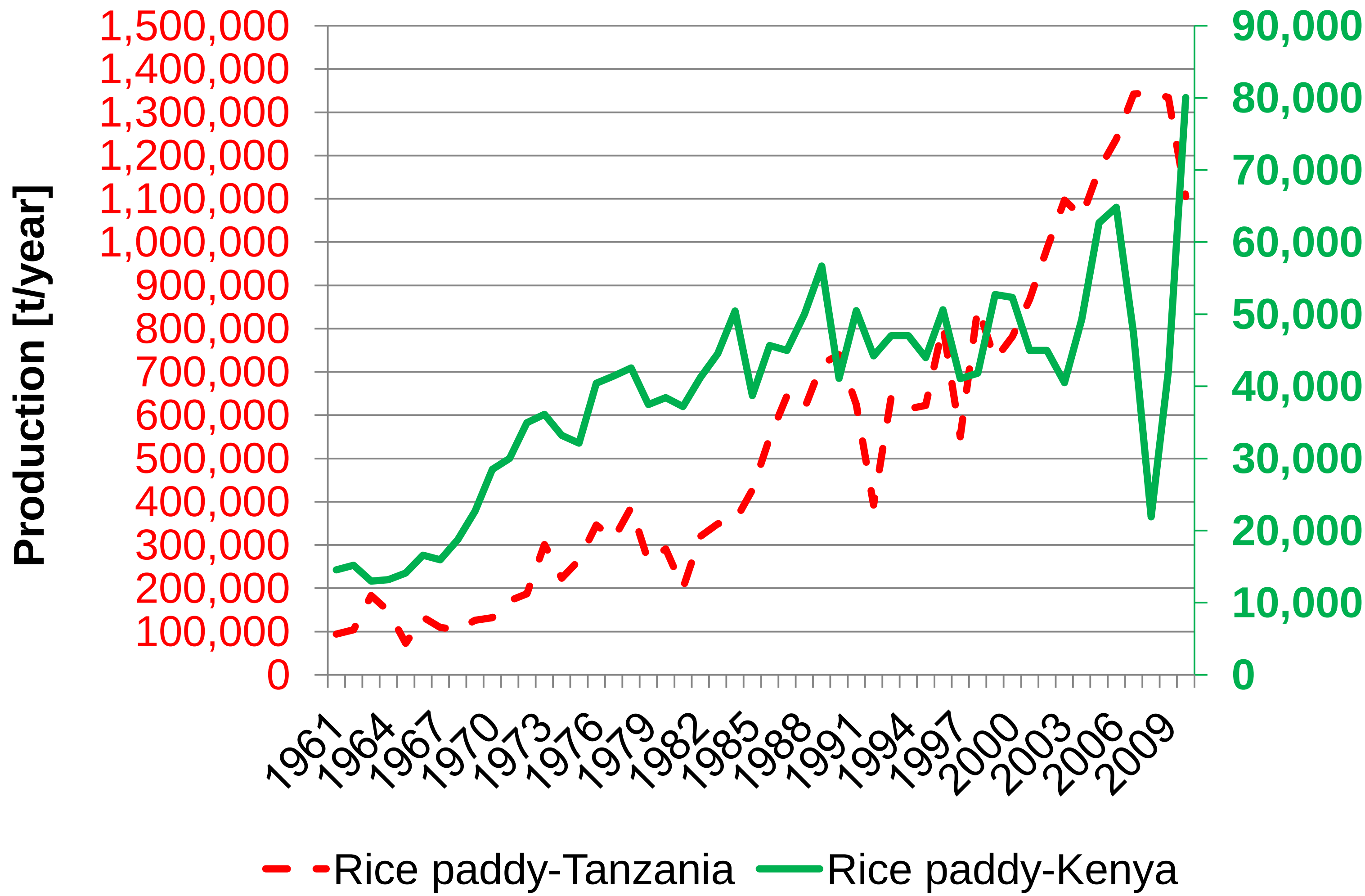
Source: IPCC AR4, 2007

Water availability
Health
Agricultural productivity
Biodiversity

… but:

Little information about recent climate and expected future climate available!

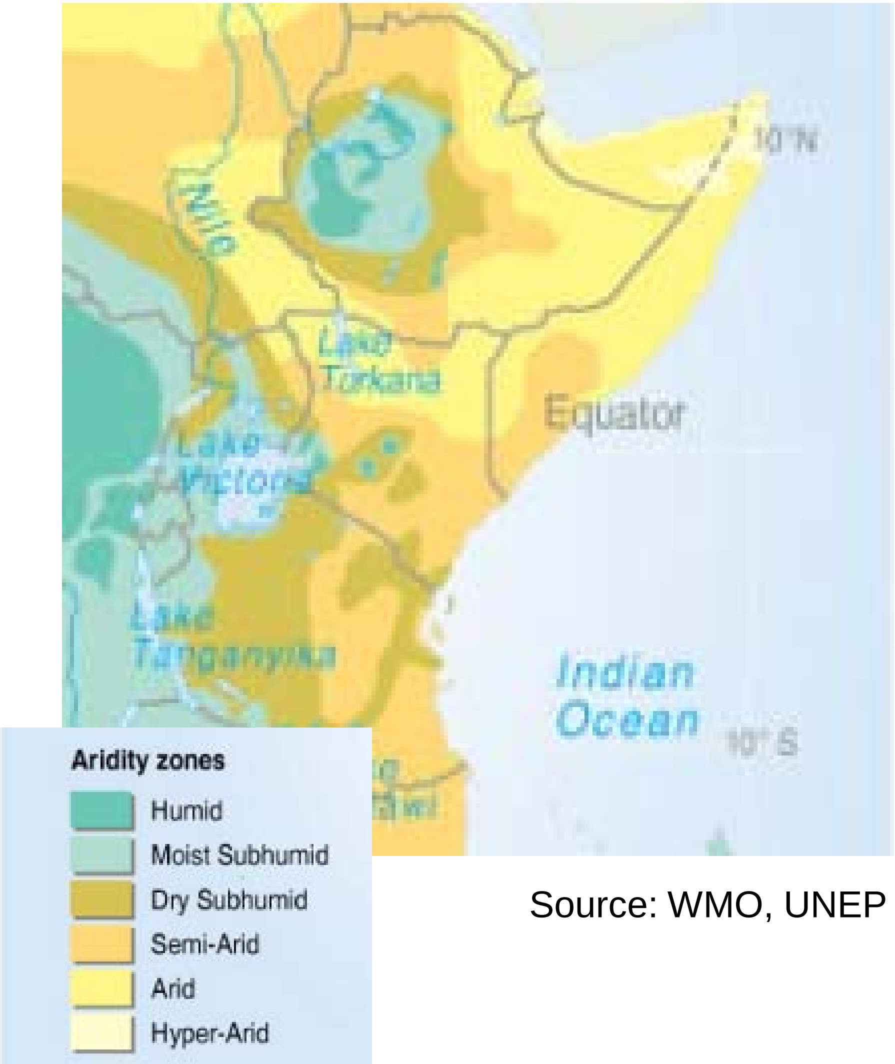
Rice Production in EA



Data Source: FAOSTAT

PRESENT CLIMATIC CONDITIONS IN EA

Climate in EA



Source: WMO, UNEP

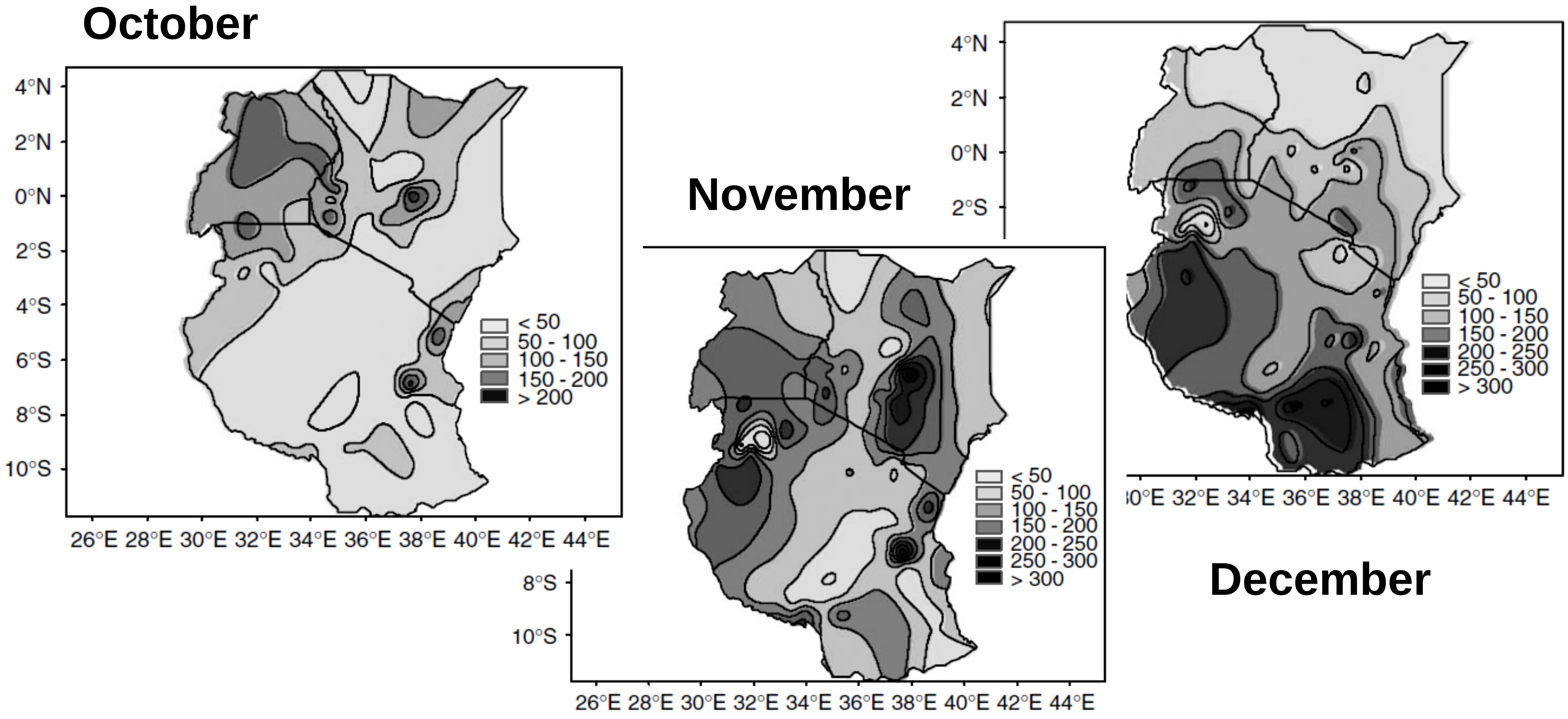
- Arid to humid conditions

- Rainfall is limited to seasons with mono- to bimodal distribution

- High spatial and temporal rainfall variability on different scales

- Alternating wet & dry periods: wet 1960s and dry 1980s

High spatio-temporal rainfall variability (Kenya)



OND rainfall amount [mm/m] (1961-1990)

Source:
Schreck & Semazzi, 2004

Past Climatic Trends in EA

Temperature:

- T_{min} increased faster than T_{max} and T_{mean} (e.g. Conway et al., 2004)
- Decreasing temperature trends at coastal (also inland lakes) stations from 1960-2000 (King'uyu et al., 2000)

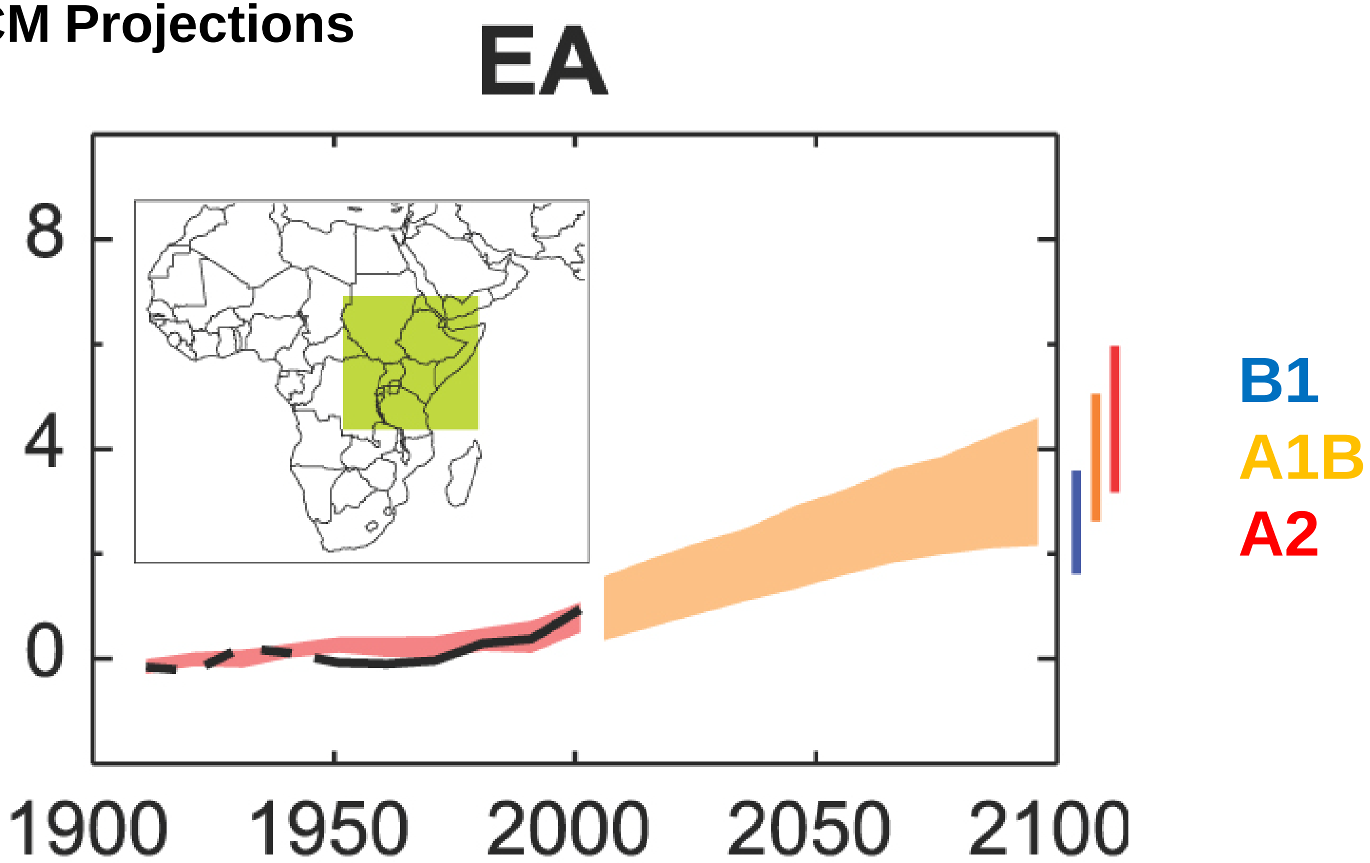
Rainfall:

- *La Nina* years tend to become drier and *El Nino* years tend towards average in MAM season (Funk, 2010) induced by shift of large scale circulation (warming western Indian Ocean)
- EA has experienced intensifying dipole character on decadal scale: increasing (decreasing) patterns over northern (southern) sector (Schreck and Semazzi, 2004)

FUTURE CLIMATE CHANGE PROJECTIONS
-
GCM PROJECTIONS

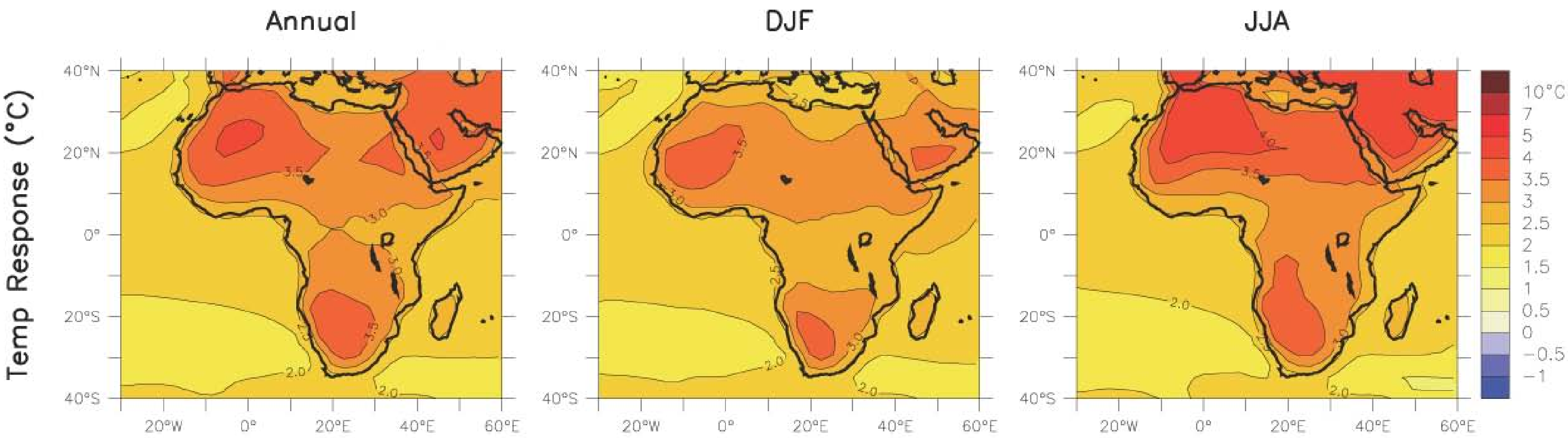
Projected Temperature Anomalies (2001-2100)

AOGCM Projections



Source: IPCC AR4, 2007

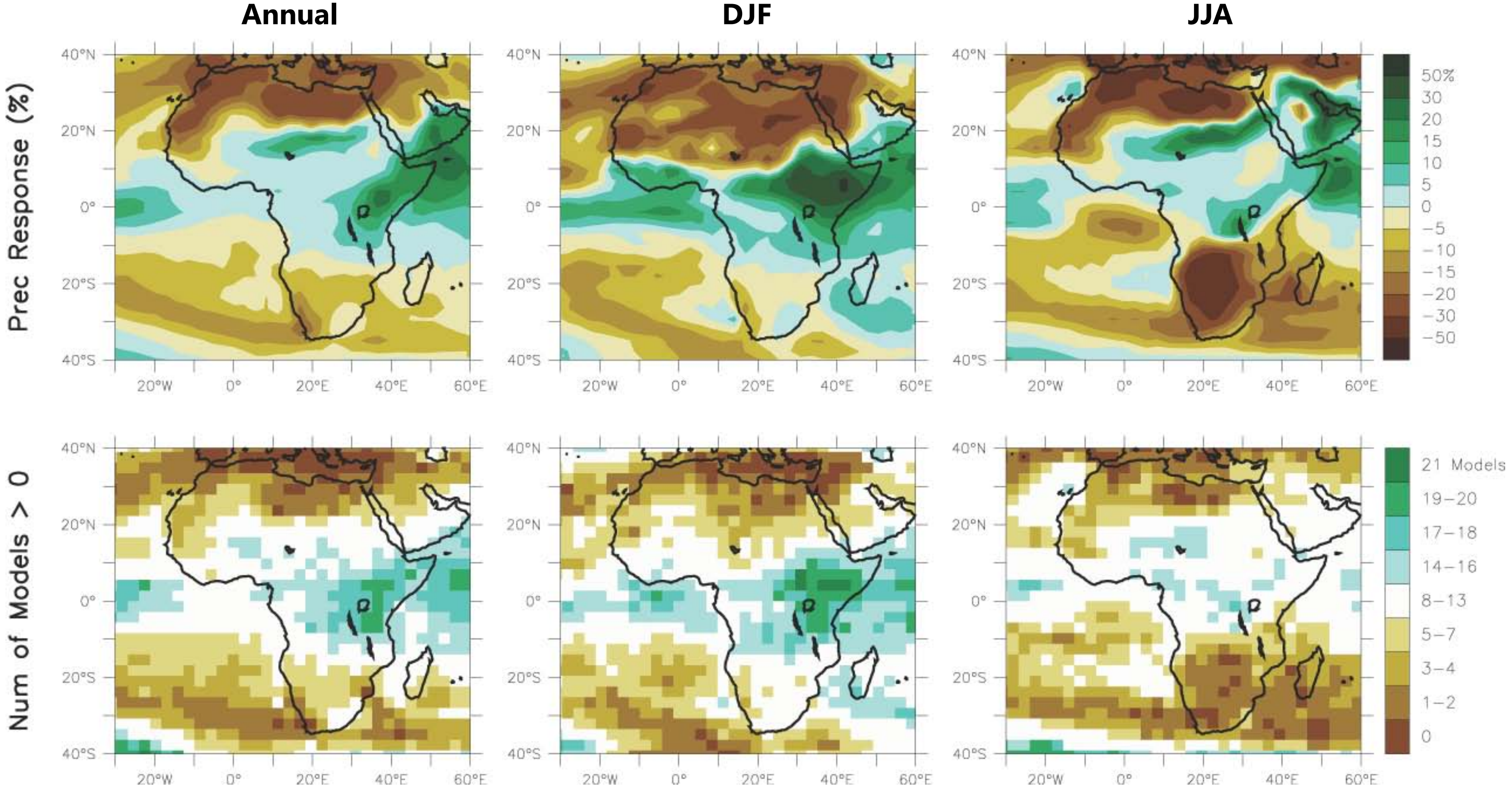
ΔT (2080-2099 - 1980-1999): 21 AOGCMs & A1B



Source: IPCC AR4, 2007

- CC signal: approx. +3°C by end of 21th century (highly certain)
- Signal relatively homogeneous in space and time

ΔP (2080-2099 - 1980-1999): 21 AOGCMs & A1B



Source: IPCC AR4, 2007

- Tendency of increased rainfall (highly certain for DJF)

ΔT & ΔP : 21 AOGCM & A1B

Karlsruher Institut für Technologie

EA	Temperature Response [°C]					Precipitation Response [%]					Extreme Seasons [%] *		
	Min	25	50	75	Max	Min	25	50	75	Max	Warm	Wet	Dry
DJF	2	2.6	3.1	3.4	4.2	-3	6	13	16	33	**100**	**25**	1
MAM	1.7	2.7	3.2	3.5	4.5	-9	2	6	9	20	**100**	**25**	4
JJA	1.6	2.7	3.4	3.6	4.7	-18	-2	4	7	16	**100**		
SON	1.9	2.6	3.1	3.6	4.3	-10	3	7	13	38	**100**	**21**	3
Annual	1.8	2.5	3.2	3.4	4.3	-3	2	7	11	25	**100**	**30**	1

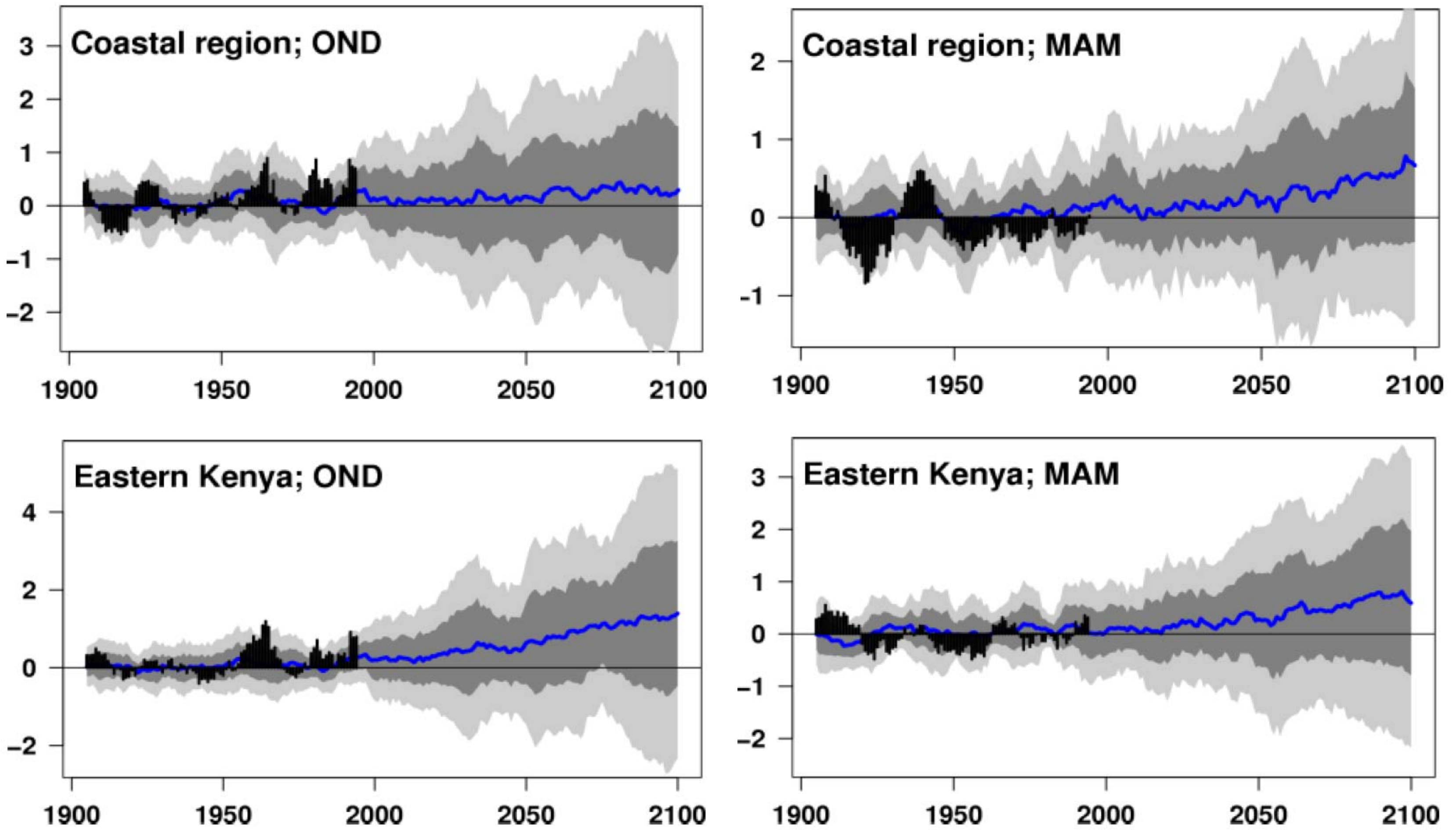
modified from IPCC AR4, 2007

***** Values shown if at least 14 out of 21 agree on increase/decrease in extremes. A value of ≤ 5% indicates no change (nominal value for control period by construction)

FUTURE CLIMATE CHANGE PROJECTIONS
-
RCM PROJECTIONS

Regional *Rainfall Anomalies*

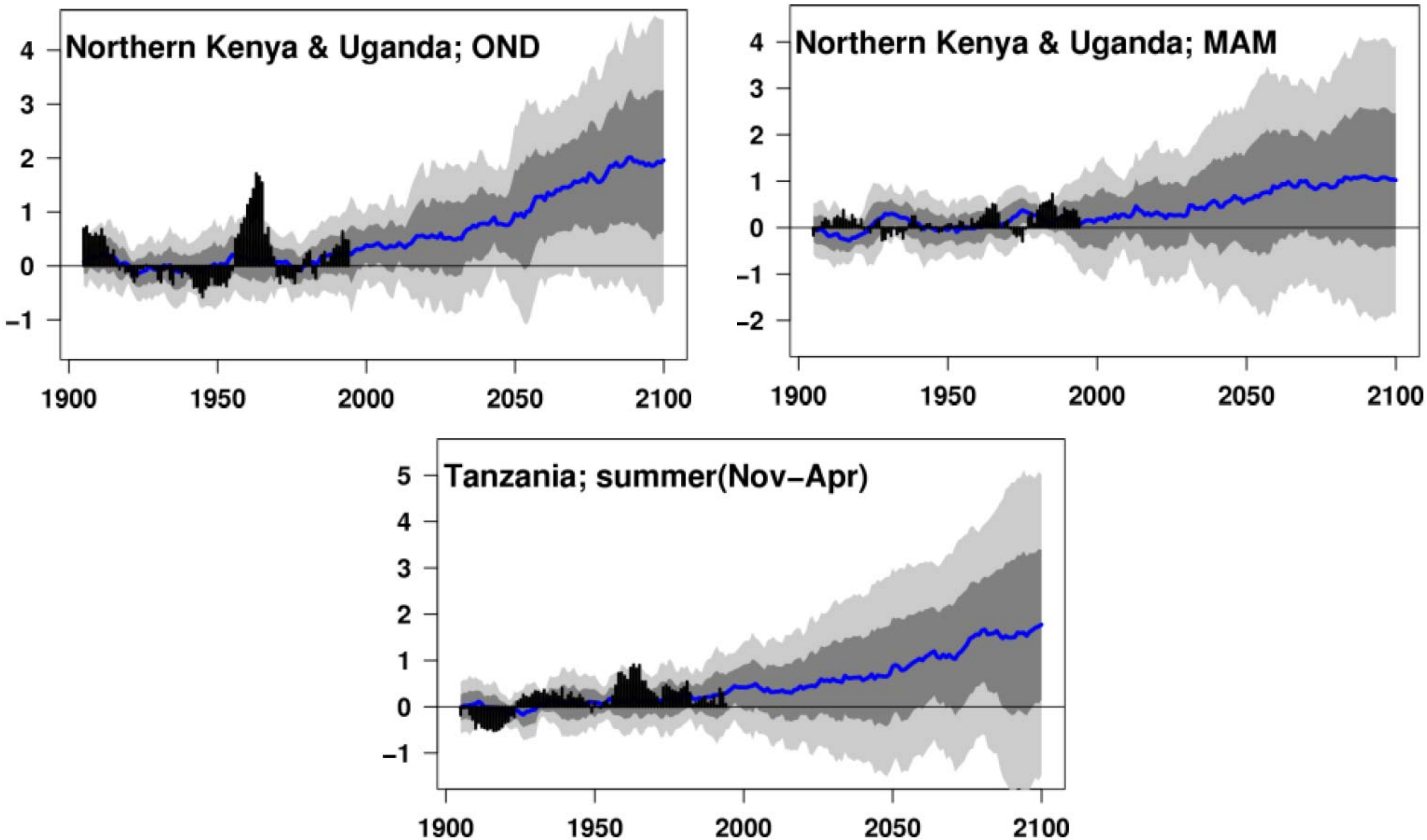
Ensemble of 8 dynamically downscaled AOGCMs



source: KMNI, 2011

Regional *Rainfall Anomalies*

Ensemble of 8 dynamically downscaled AOGCMs



source: KMNI, 2011

Summary: CC Simulations for EA

- Regional projections generally agree with AOGCM projections
  - Past rainfall variability could be reproduced using RCMs (except for Northern Kenya in MAM)
  - Weak increase at coast, high increase in northern regions (OND)

- Warming larger than global mean (all seasons) with drier subtropical regions warming more than moister tropics **(very likely)**
  - Middle distribution indicates +2.5°C to +3.4°C (annual avg)
  - Slightly higher increase in boreal summer than winter

- Increase in annual rainfall, more pronounced in boreal winter **(likely)**
  - Significant increase in rainfall of 10% - 30%, confirmed by Hulme et al.(2001) & Ruosteenoja et al. (2003)
  - Higher tails: +38% for SON
  - Extremely wet seasons increased (about 4 times)

Research Gaps: Climate Modeling

- GCM projections too coarse to capture regional/local climate variations

→ RCM at scale meaningful for decision makers/stakeholders

→ Bias correction methodologies

- Limited research on changes in extreme events

→ Extreme Value Theory

- Future shifts of climate regimes

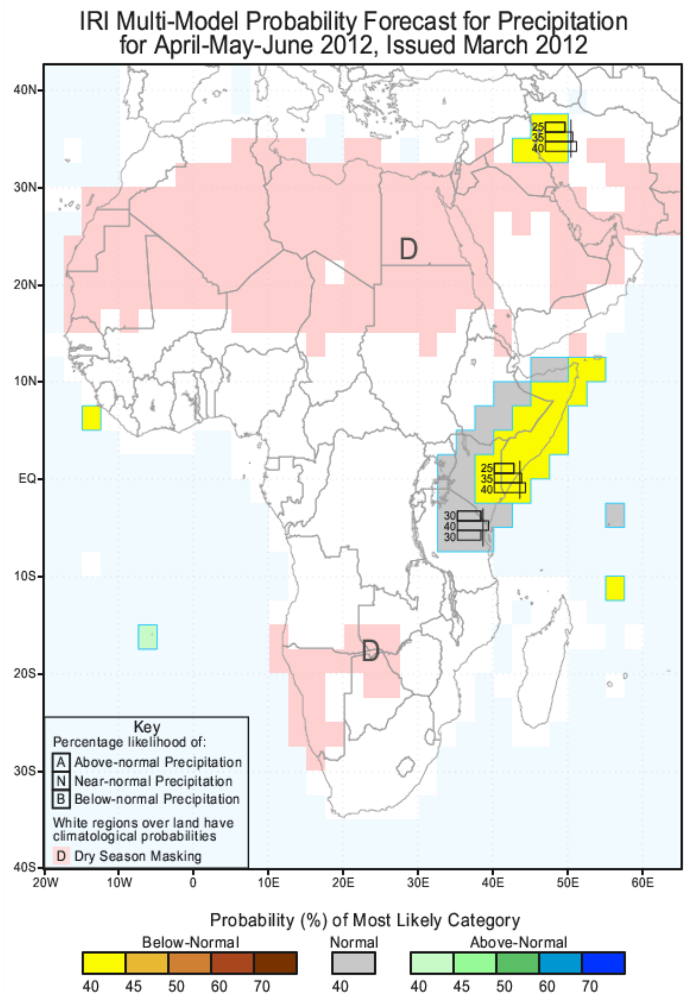
→ Improved analysis of ENSO

- Impact of LUC on climate and vice versa

→ Including dynamic vegetation models and feedbacks from aerosols in climate models

→ "What-if" LUC scenarios

Research Gaps: Climate Modeling (cont'd)



- Seasonal Climate Prediction

→ Quantitative assessment for decision makers/stakeholders

→ Role of teleconnections (ENSO, etc.)

source: International Research Institute (IRI), 2012

CLIMATE CHANGE IMPACT STUDIES

CC Impact Studies

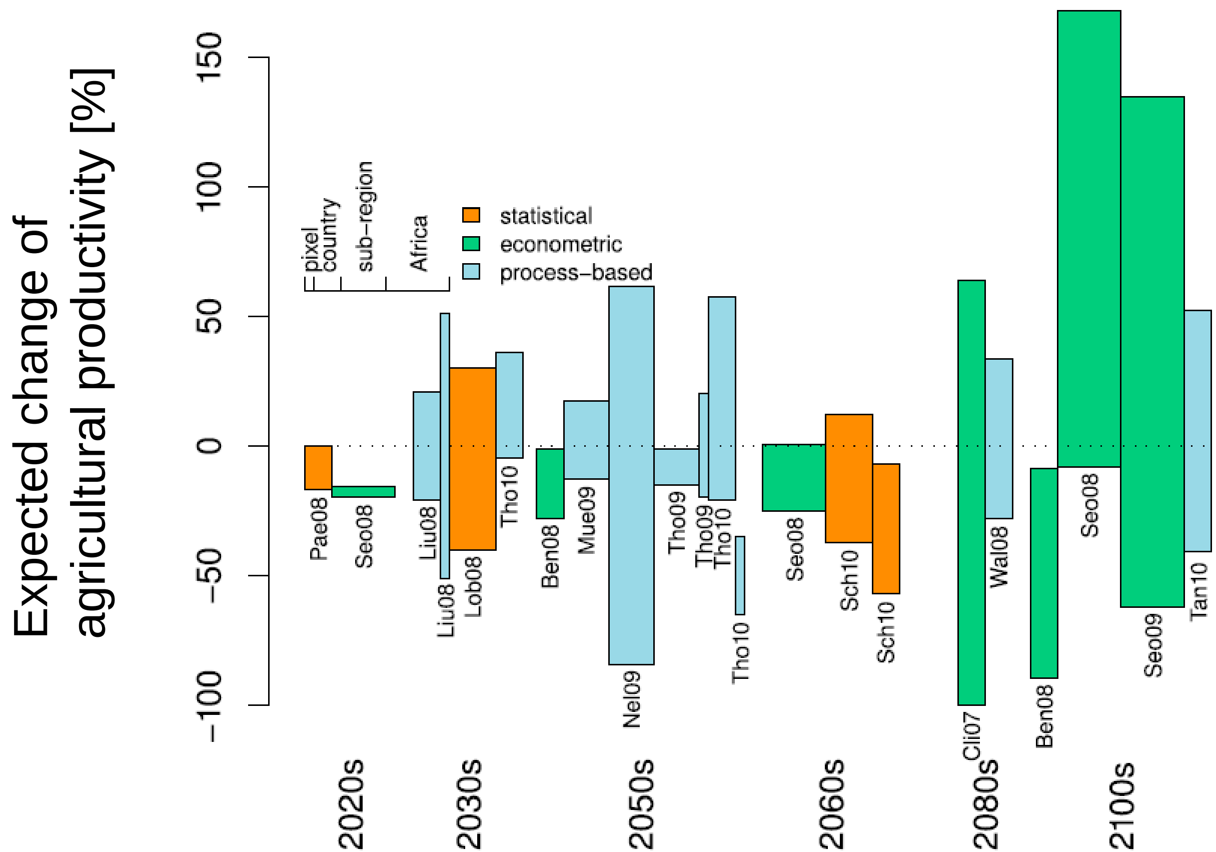
- Many studies dealing with **impact of climate change on crop productivity** on different scales (e.g. Mati, 2000, Lobel, 2008, Laux et al., 2010)

  → low number of studies for Africa and EA

- Rare number of studies accounting for additional factors such as changes in **supply patterns under different trade scenarios** (Lotze-Campen et al., 2010), **consumption, prices, and trade** (Nelson et al., 2009)

- Missing studies accounting additionally for **regional and local supply-and-demand projections**

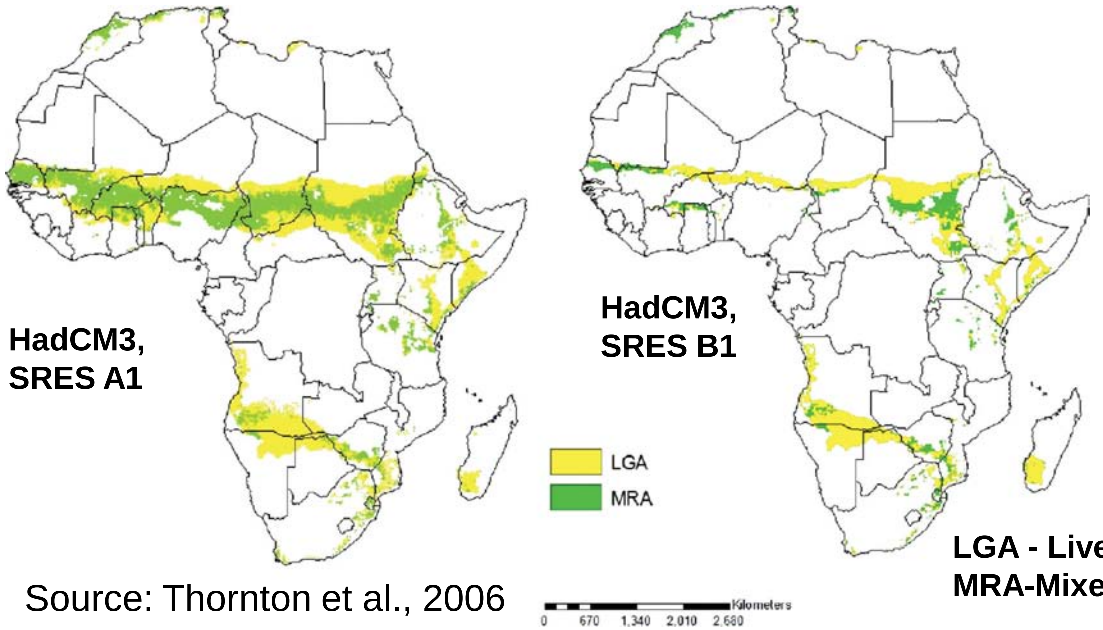
Agricultural Impact Studies for Africa



Source: Müller, 2011

Agricultural Impact Studies for Africa (cont'd)

- By 2100, large parts of Africa may undergo negative changes: parts of Sahara have to expect losses of 2-7% of GDP, Western and Central Africa 2-4% of GDP (Mendelsohn et al., 2000)
- SRES B1: Marginal areas will become more marginal, especially in context of rainfall seasonality such as onset & intensity of rains (e.g. Jones & Thornton, 2003; Huntingford et al., 2005; Thornton et al., 2006)

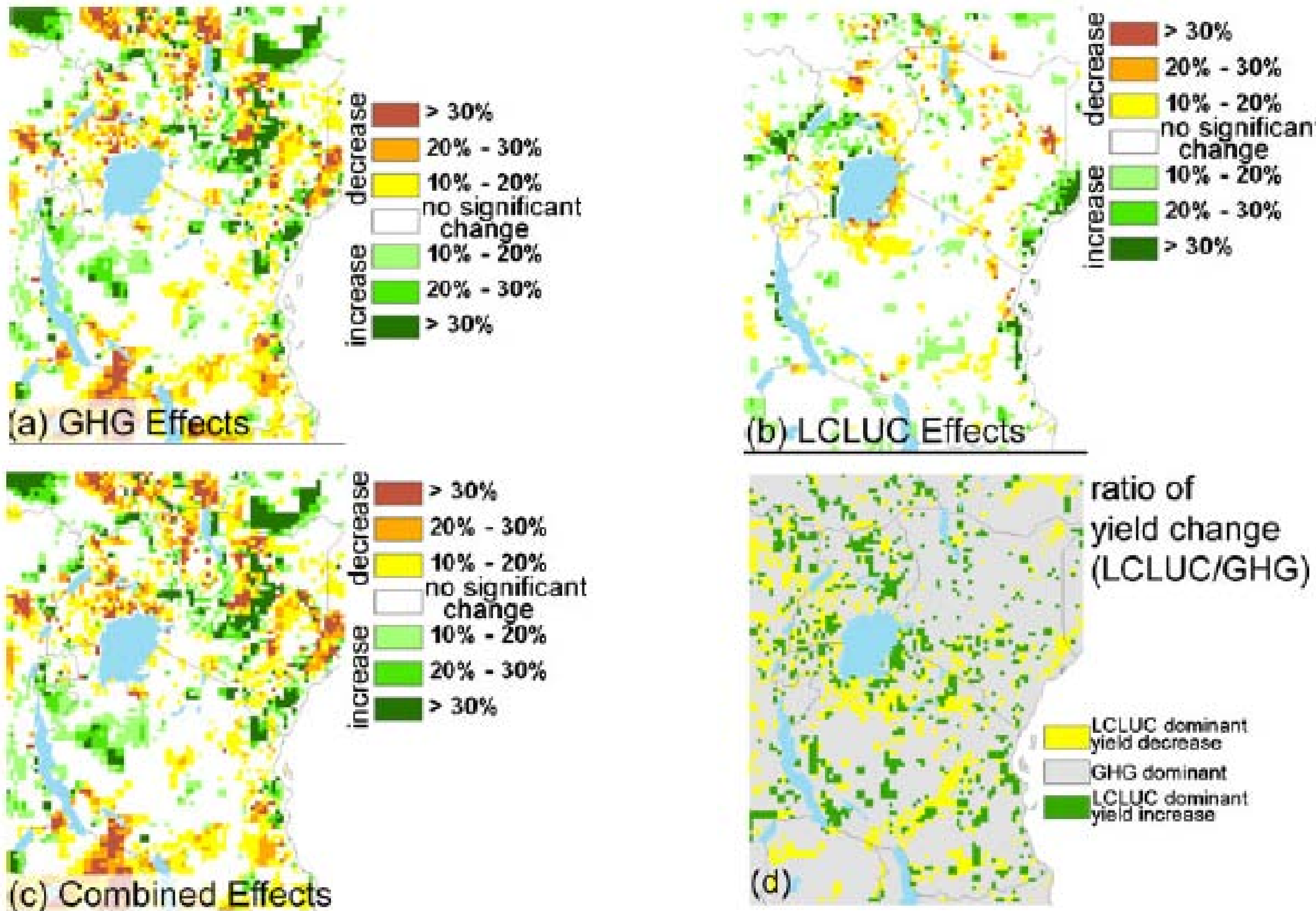


LGA - Livestock-only system
MRA-Mixed crop/livestock systems

Source: Thornton et al., 2006

Agricultural Impact Studies for EA

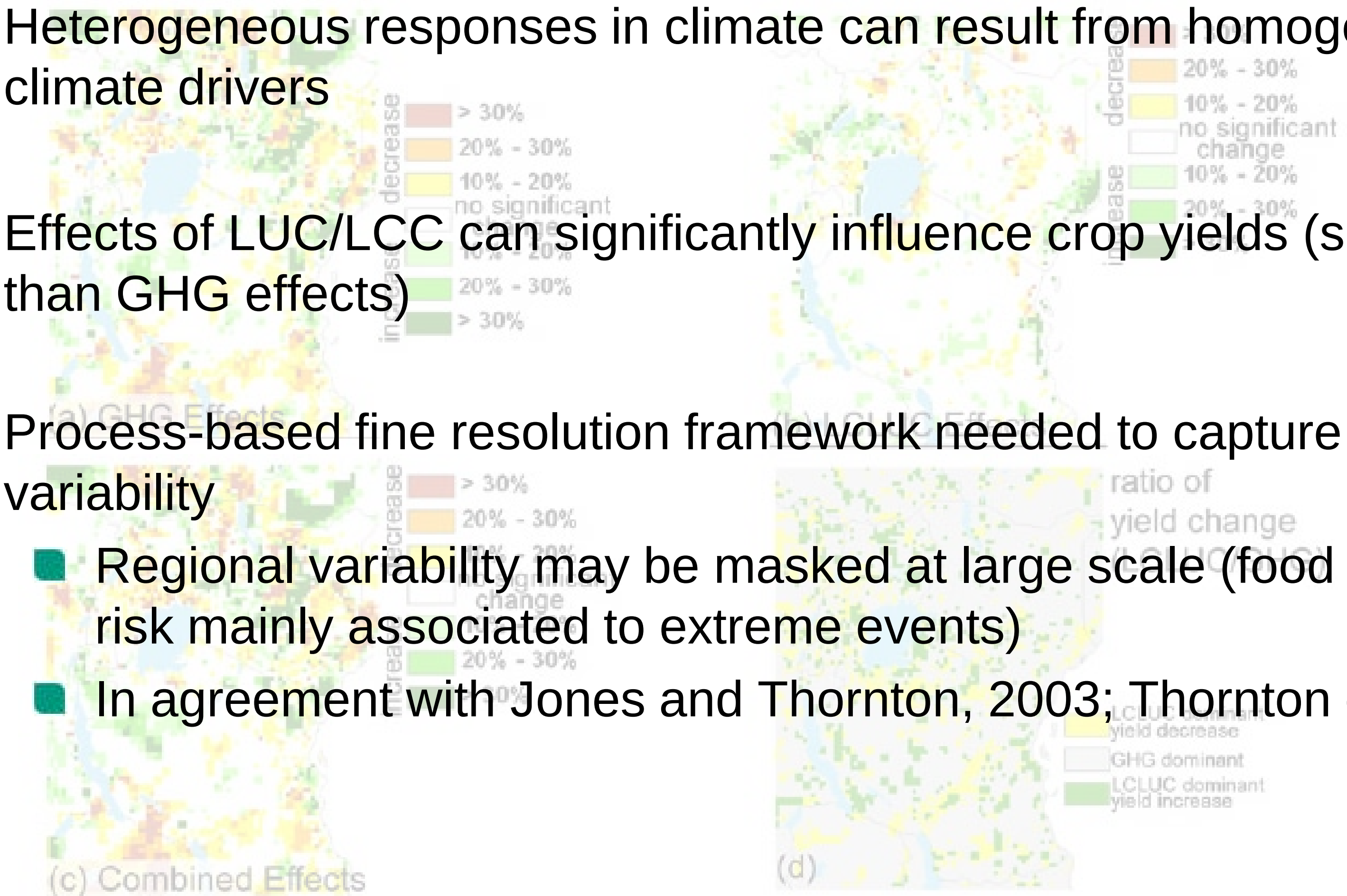
Maize productivity (2050-2059 – 2000-2009)



Moore et al., 2012

Agricultural Impact Studies for EA

- Heterogeneous responses in climate can result from homogeneous climate drivers
- Effects of LUC/LCC can significantly influence crop yields (similar order than GHG effects)
- Process-based fine resolution framework needed to capture this variability
  - Regional variability may be masked at large scale (food production risk mainly associated to extreme events)
  - In agreement with Jones and Thornton, 2003; Thornton et al., 2009



Moore et al., 2012

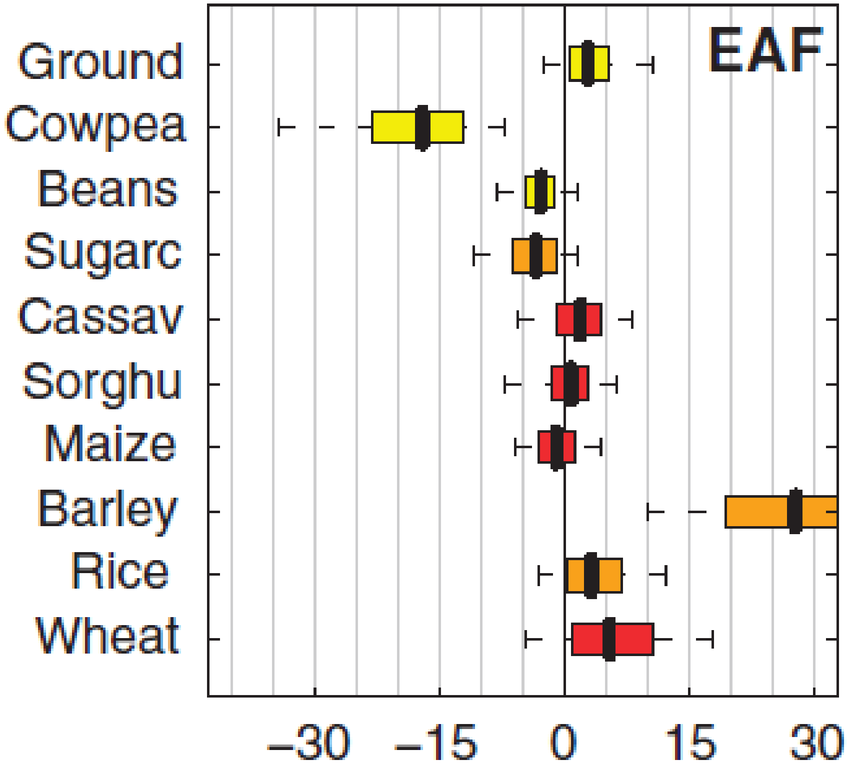
Agricultural Impacts in EA

- Growing season e.g. in Ethiopian highlands may lengthen (Thornton, 2006)

- By the 2080s, a significant decrease in suitable rainfed land extent and production potential for cereals is expected (Fischer et al., 2005)
  - Semi-arid to arid could increase by 5-8% (60-90 million ha)
  - Wheat production is likely to disappear

- By end of 2030, Kenyan maize yields are predicted to increase / decrease depending on the location, yields changes relatively low <500 kg/ha (Mati, 2000)

ΔProduction (2020-2039 – 1980-1999)



Lobell, 2008

20 GCM projections, 3 scenarios and statistical crop models

Hunger importance ranking (HIR):

Red: **more important**
Orange: **important**
Yellow: **less important**

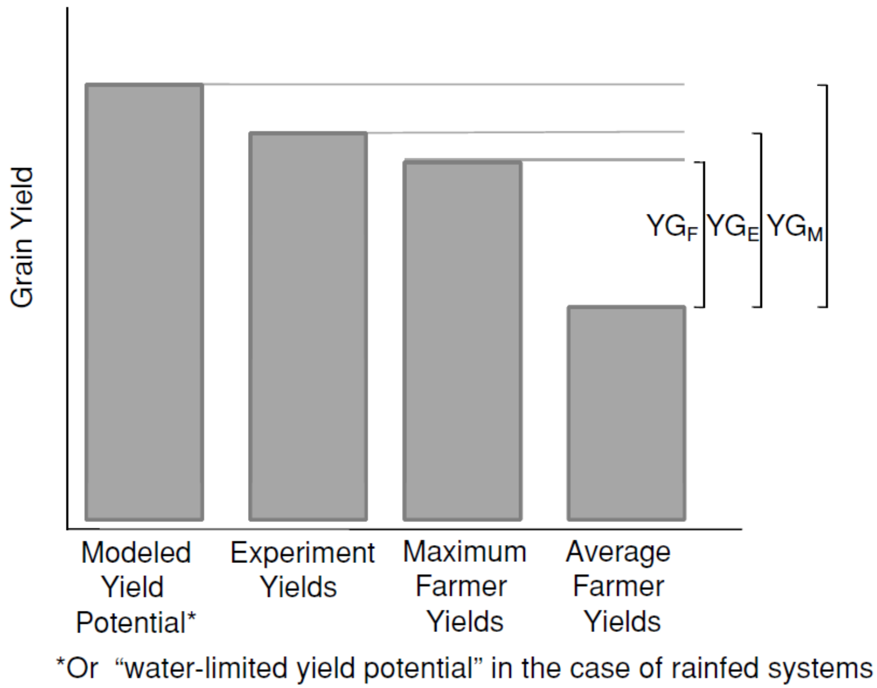
Research Gaps: Agricultural Impact Modeling

- Number of model applications for rice in EA
- Model implementation:
  - Plant pests/diseases (type and prevalence of pests)
  - Extremes: temperature thresholds
  - Parameterization of new varieties (NERICA)
  - Improved (adapted) management options (Planting date, SRI)
- **Lack of coupled approaches for adaption / risk reduction:**

→ Integrated climate-water-crop-economic approach accounting for global, regional, and local projections

- Discrepancies field experiments and model results (e.g. CO_2 fertilization effect)

Research Gaps: Impact Modeling (cont.'d)



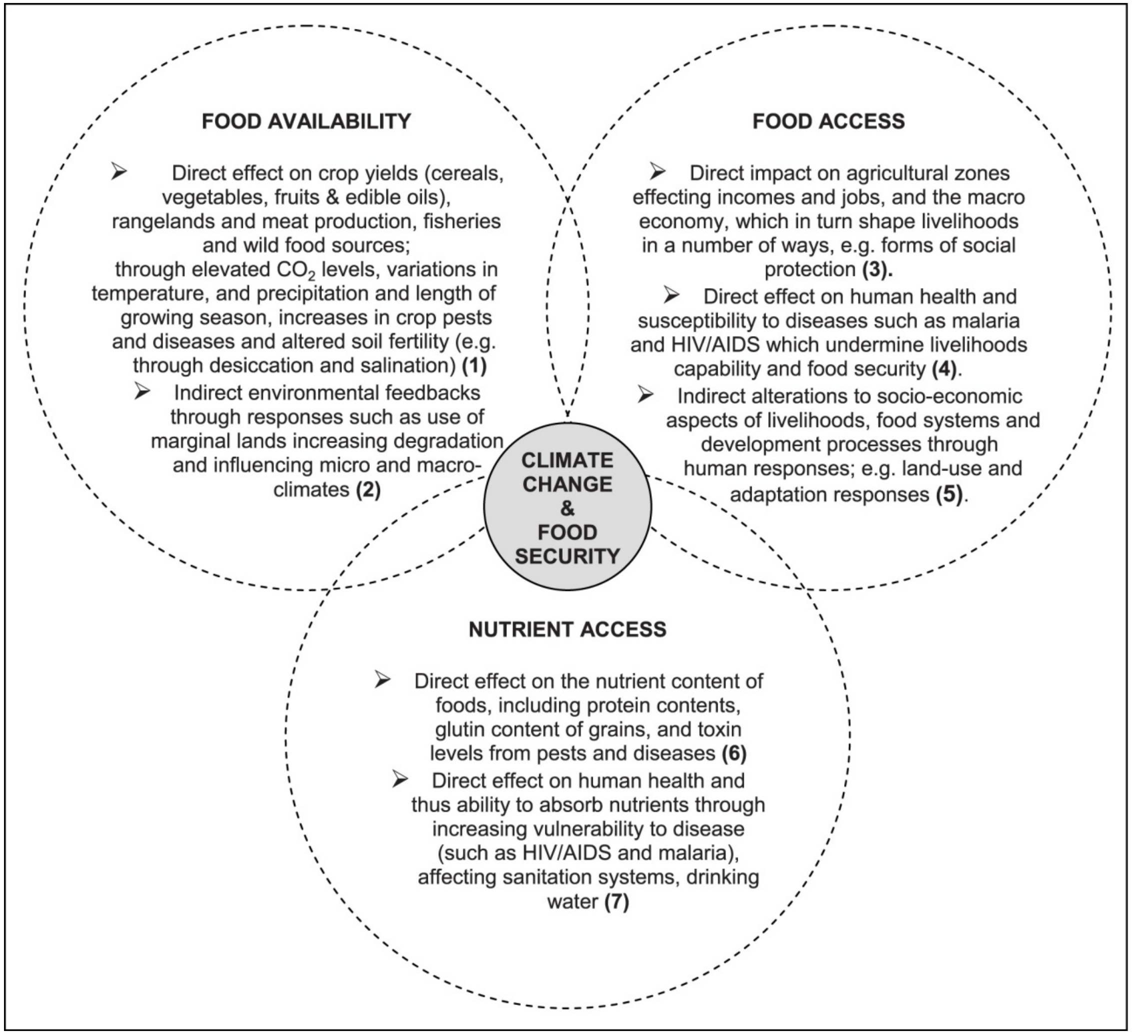
Yield Gap (YG_M) $\overset{!}{\rightarrow}$ min.

Lobell et al., 2009

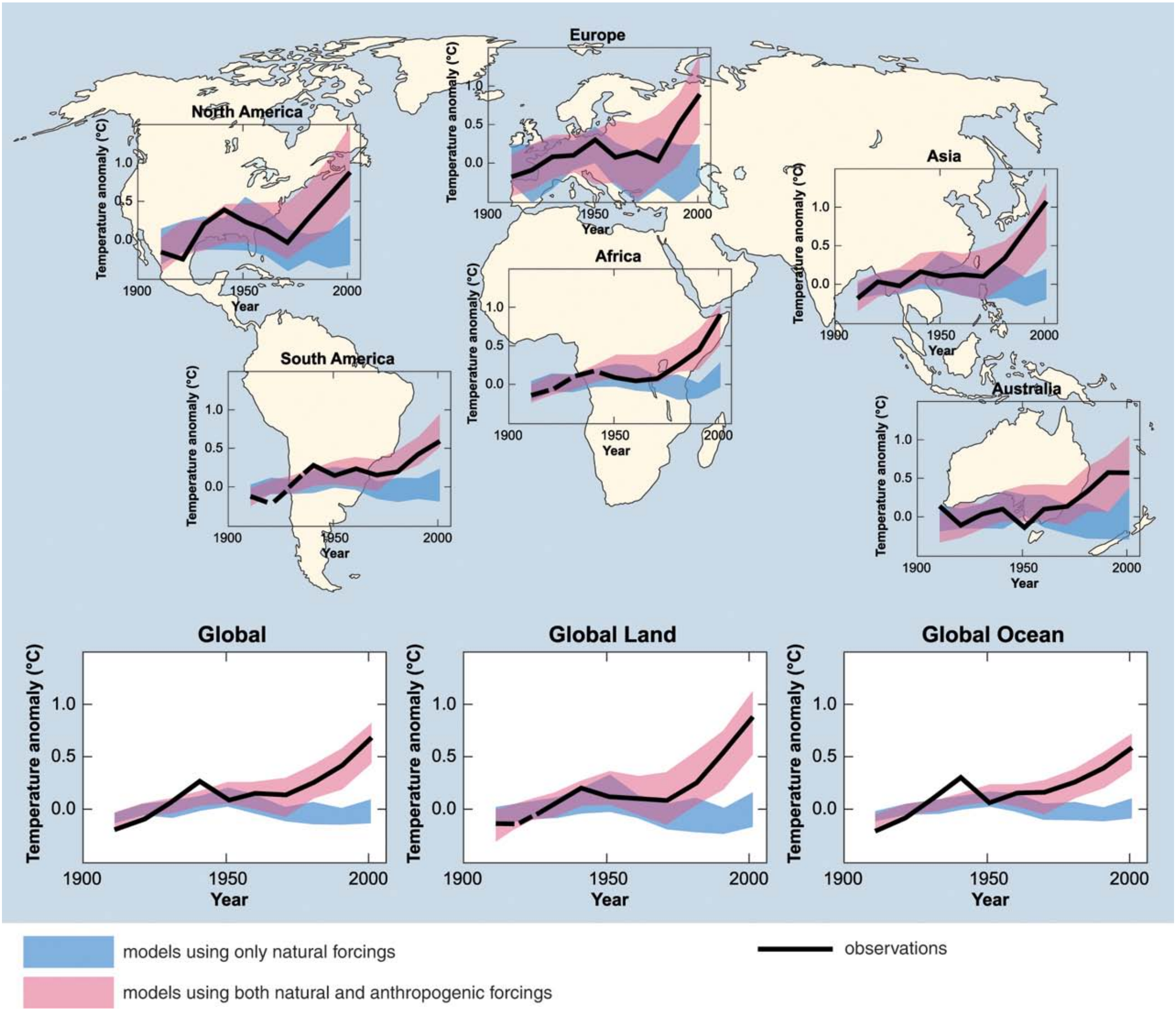
- What is the potential yield in EA under present and future conditions?
- Identification of reasons for YG_M to improve the models, but also to improve the yields of the farmers

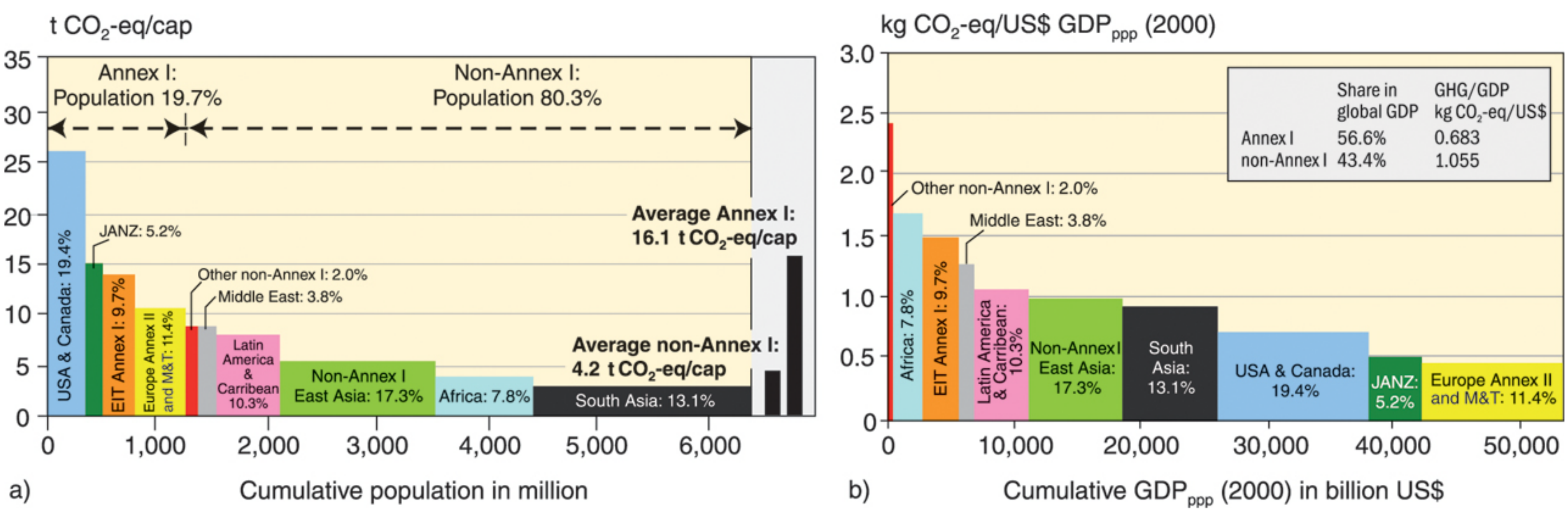

THANK YOU FOR YOUR ATTENTION

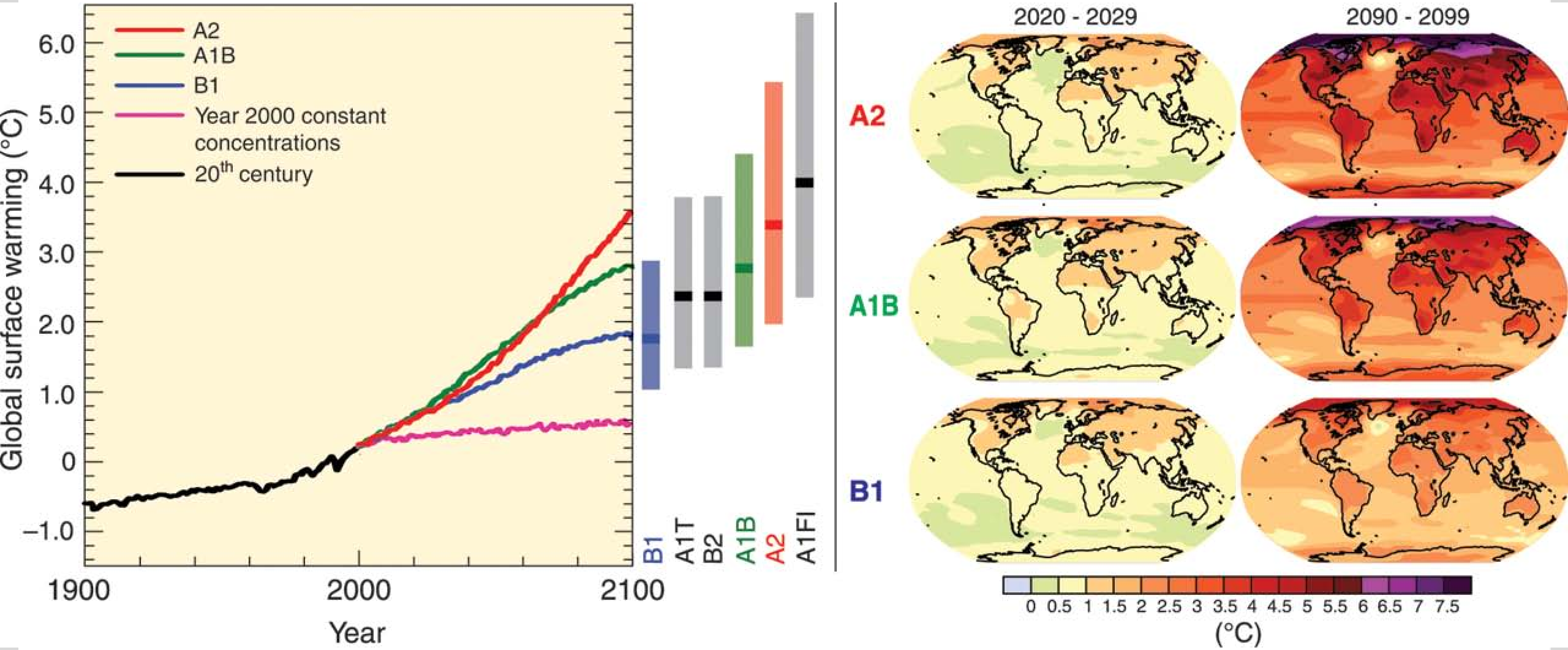
Motivation RICE-EA *cont.*



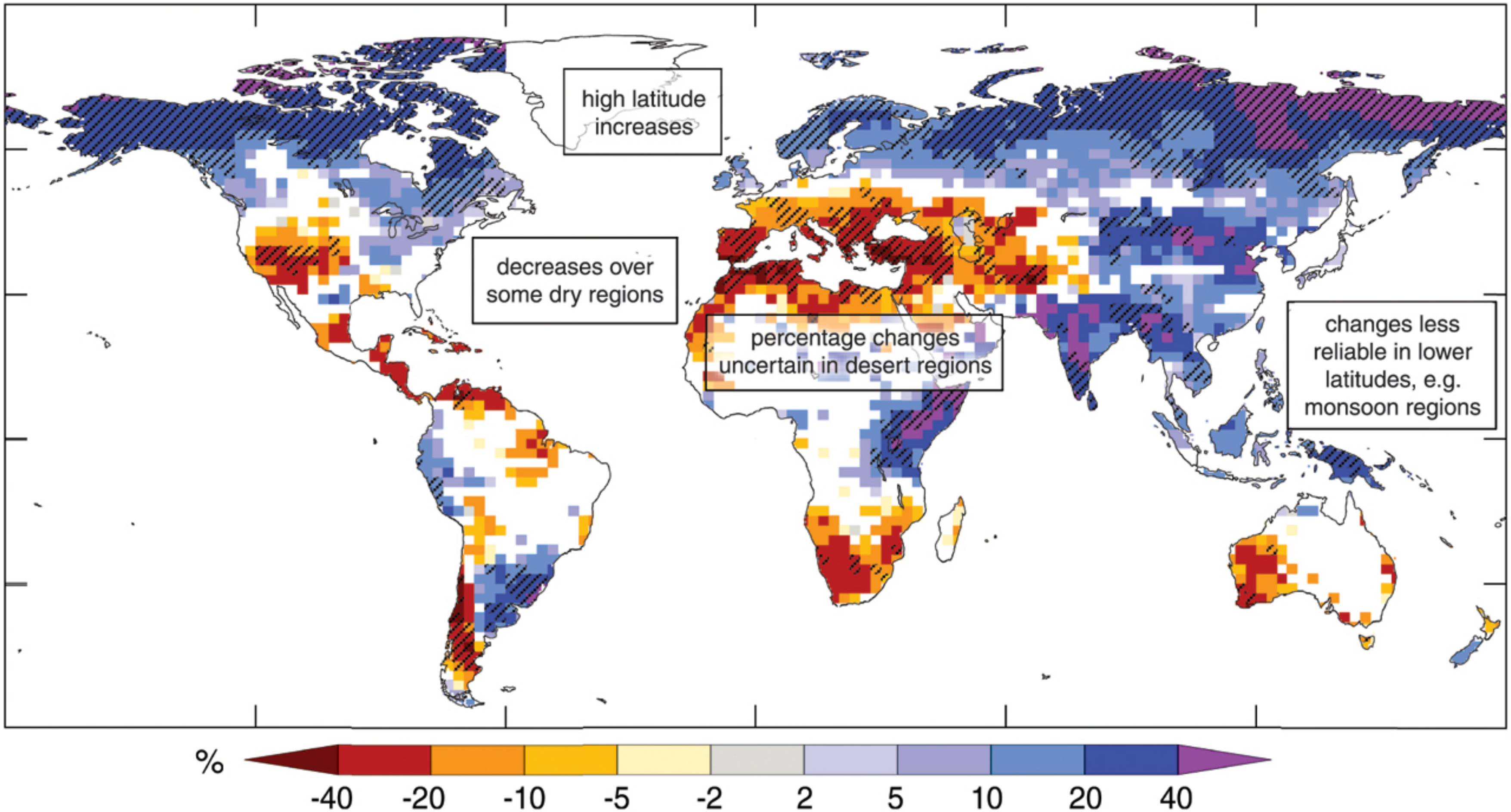
Source: IPCC AR4, 2007


Europe
North America
Asia
Africa
South America
Australia
Global
Global Land
Global Ocean
Temperature anomaly (°C)
Year
models using only natural forcings
models using both natural and anthropogenic forcings
observations


t CO2-eq/cap
Annex I:
Population 19.7%
Non-Annex I:
Population 80.3%
Average Annex I:
16.1 t CO2-eq/cap
Average non-Annex I:
4.2 t CO2-eq/cap
USA & Canada: 19.4%
JANZ: 5.2%
EIT Annex I: 9.7%
Europe Annex II and M&T: 11.4%
Other non-Annex I: 2.0%
Middle East: 3.8%
Latin America & Carribean 10.3%
Non-Annex I East Asia: 17.3%
Africa: 7.8%
South Asia: 13.1%
a)
Cumulative population in million
kg CO2-eq/US$ GDPppp (2000)
Share in global GDP
GHG/GDP kg CO2-eq/US$
Annex I 56.6% 0.683
non-Annex I 43.4% 1.055
Other non-Annex I: 2.0%
Middle East: 3.8%
Africa: 7.8%
EIT Annex I: 9.7%
Latin America & Carribean: 10.3%
Non-Annex I East Asia: 17.3%
South Asia: 13.1%
USA & Canada: 19.4%
JANZ: 5.2%
Europe Annex II and M&T: 11.4%
b)
Cumulative GDPppp (2000) in billion US$



A2
A1B
B1
Year 2000 constant concentrations
20th century
Global surface warming (°C)
6.0
5.0
4.0
3.0
2.0
1.0
0
–1.0
1900
2000
2100
Year
B1
A1T
B2
A1B
A2
A1FI
2020 - 2029
2090 - 2099
A2
A1B
B1
0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5
(°C)


high latitude increases
decreases over some dry regions
percentage changes uncertain in desert regions
changes less reliable in lower latitudes, e.g. monsoon regions
%
-40
-20
-10
-5
-2
2
5
10
20
40

Motivation RICE-EA

- Poor rains in last two seasons have led to one of most severe droughts in EA (food insecurity across Kenya, Ethiopia, Somalia, Uganda, Djibuti)
- Climate plays crucial role in day-to-day economic development of Africa particularly for agricultural and water resources sector at different scales (regional, local, household)
- Agricultural productivity, one of most important factors for food security, strongly linked to climatological conditions in EA (mostly seasonal rainfall amount, but also intraseasonal distribution of rainfall)
- Agriculture already challenging under present climatic conditions: Impact of climate change?

Motivation RICE-EA *cont.*

- Many studies dealing with **impact of climate change on crop productivity** on different scales (e.g. Lobel, 2008, Laux et al., 2010)

- Rare number of studies accounting for additional factors such as changes in **supply patterns under different trade scenarios** (Lotze-Campen et al., 2010), **consumption, prices, and trade** (Nelson et al., 2009)

-

- Missing studies accounting additionally for regional and local supply-and-demand projections

Karlsruher Institut für Technologie


Nutritious food choices


Purchasing power
(having the money to buy affordable food)

Food Security

FOOD UTILISATION
- *Nutritional Value*
- *Social Value*
- *Food Safety*

FOOD ACCESS
- *Affordability*
- *Allocation*
- *Preference*

FOOD AVAILABILITY
- *Production*
- *Distribution*
- *Exchange*


Food safety and quality


Marketing


Water management on farms


Food production


Trade – imports

Agricultural facts …

	Population			Area		GDP	
	Total	Density	Active in Agriculture	Total	Cultivated	Per Capita	Agric. Fraction
	(1000 inh.)	(inh./km²)	(%)	(1000 ha)	(%)	(US$)	(%)
Europe	732,396	32	6	2,300,711	13	29,026	2
Africa	981,127	33	54	3,004,568	8	1,592	16
SSA	817,158	34	59	2,429,279	9	1,222	18
EA	211,414	72	77	292,718	14	481	33

Source: FAO-AQUASTAT, 2010

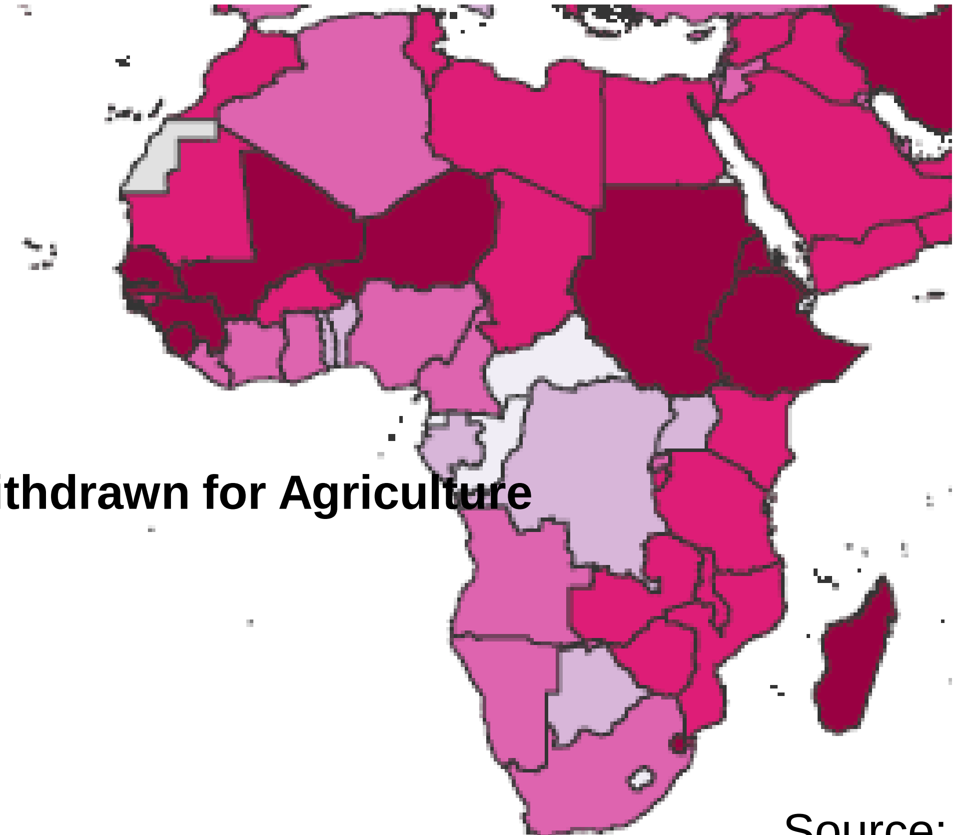
Agricultural facts … *cont.*

	Area equipped for irrigation (mio ha)			Irrigated land (% of cultivated land)		
	1970	**1990**	**2009**	**1970**	**1990**	**2009**
Europe	15.1	25.7	22.7	4.6	8	7.7
Africa	8.4	11	13.6	4.7	5.4	5.4
SSA	4.1	5.9	7.2	2.6	3.3	3.2
EA	0.2	0.4	0.6	0.7	1	1.5

Source: FAO-AQUASTAT, 2010

Agricultural facts … *cont.*

Karlsruher Institut für Technologie



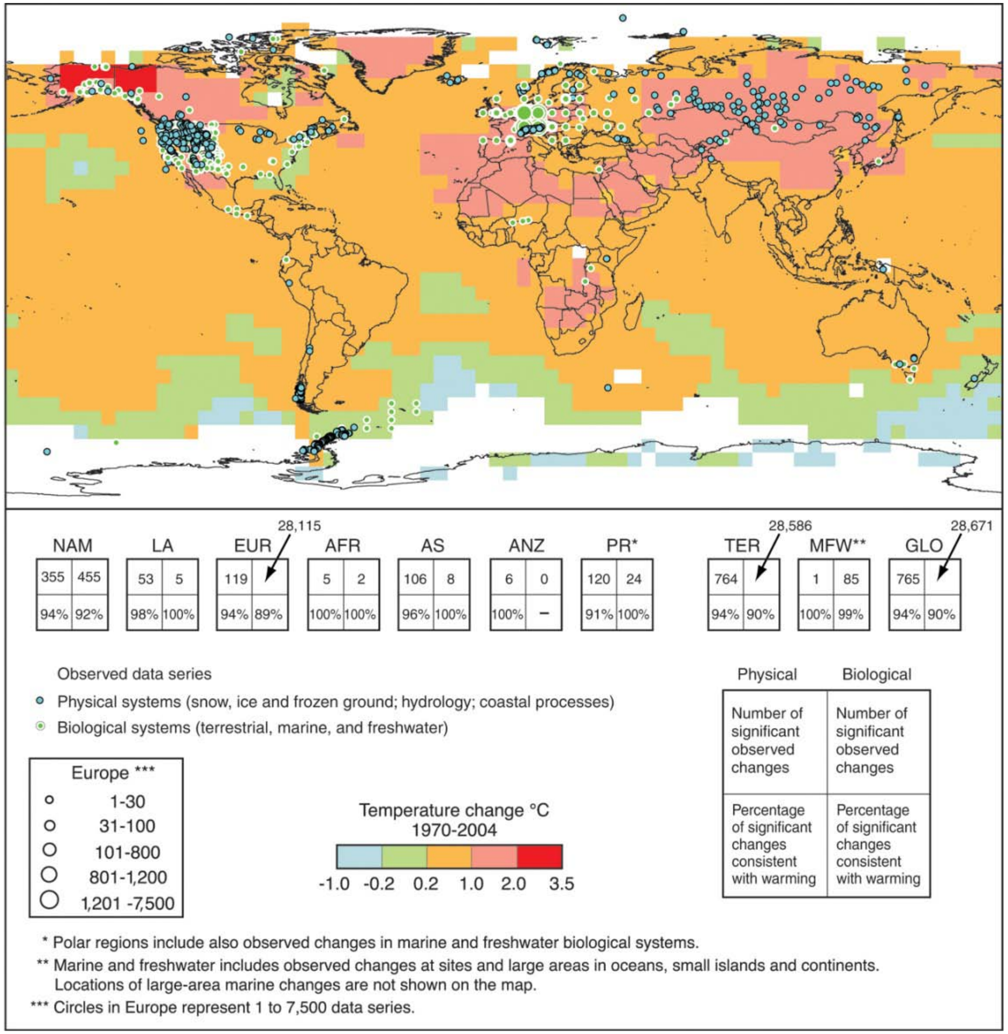
Water withdrawn for Agriculture

Source: FAO-AQUASTAT, 2008

Legend

No Data | < 25 | 25 - 50 | 50 - 75 | 75 - 90 | > 90 %

Lack of Information for (East) Africa



Climate: Impacts on human Health

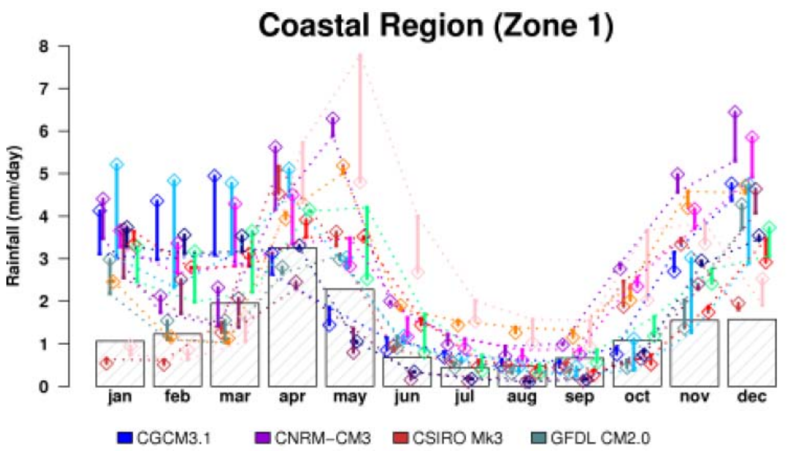
- Drouhts/Floods contribute to deseases such as diarrhoea, cholera (Few et al., 2004) through poor nutrition

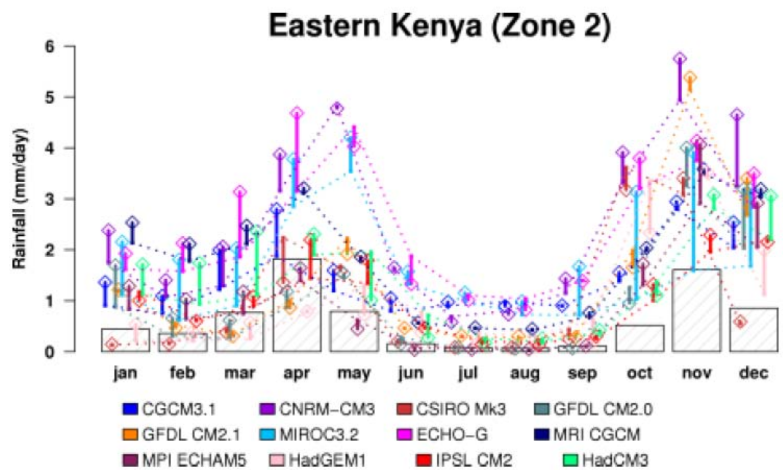
- Malaria is spreading into new areas such as highlands of Central Kenya (Chen et al., 2006; Pascual et al., 2006)

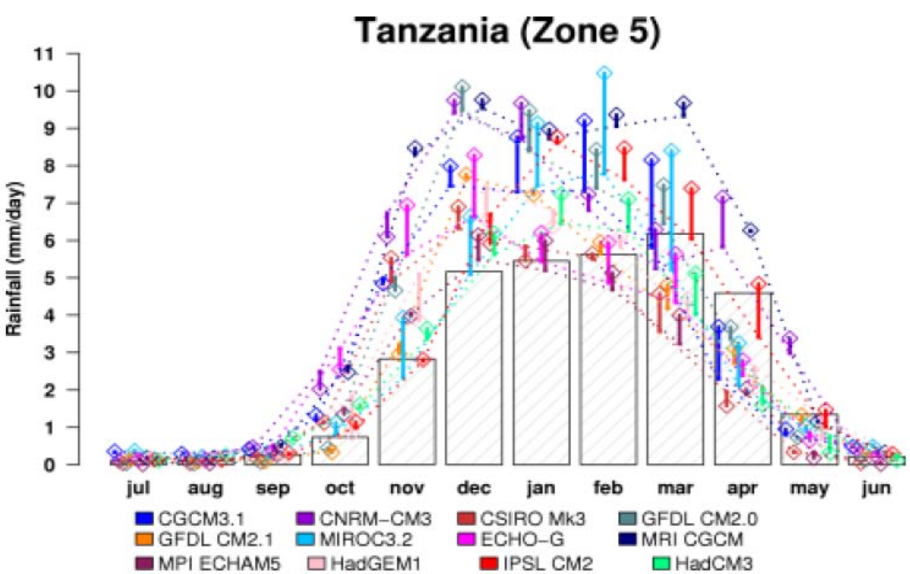
Increased Vulnerability EA

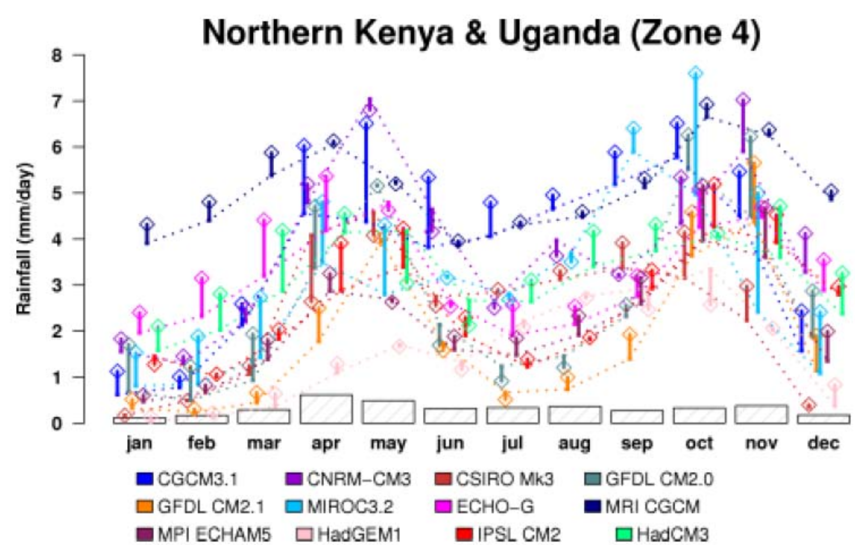
- **Malaria transmission:**
  - Increased temperature and rainfall in Northern sector (during SON) will increase malaria transmission by reduction in larval development length
  - LUC: swamp reclamation for agricultural use, deforestation in highland of western Kenya (Munga et al., 2006; Afrane et al., 2005)

Complementary material to RCM simulations by KMNI

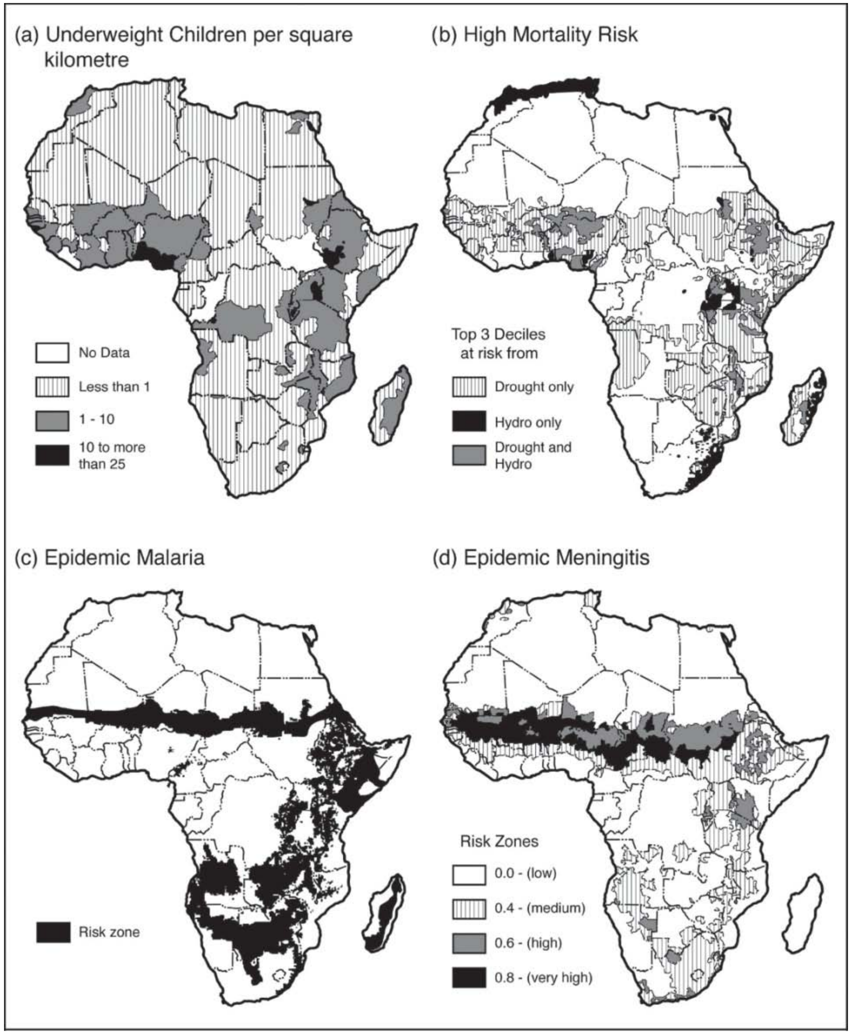




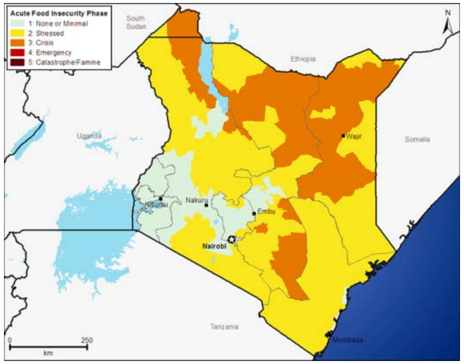




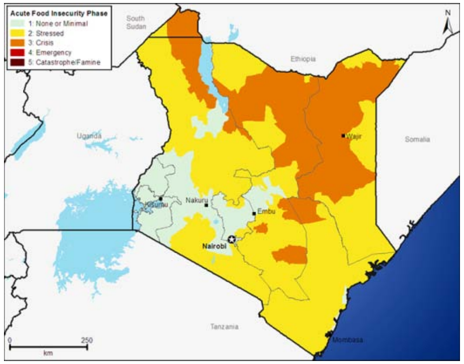
Health Aspects



Source: IPCC AR4, 2007



Acute Food Insecurity Phase
1: None or Minimal
2: Stressed
3: Crisis
4: Emergency
5: Catastrophe/Famine
South Sudan
Ethiopia
Uganda
Somalia
Wajir
Kisumu
Nakuru
Embu
Nairobi
Tanzania
Mombasa
N
0
250
km



Acute Food Insecurity Phase
1: None or Minimal
2: Stressed
3: Crisis
4: Emergency
5: Catastrophe/Famine
South Sudan
Ethiopia
Uganda
Somalia
Wajir
Nakuru
Embu
Nairobi
Tanzania
Mombasa
N
0
250
km