Climate Change and Agriculture in East Africa, West Africa and the Indogangetic Plain

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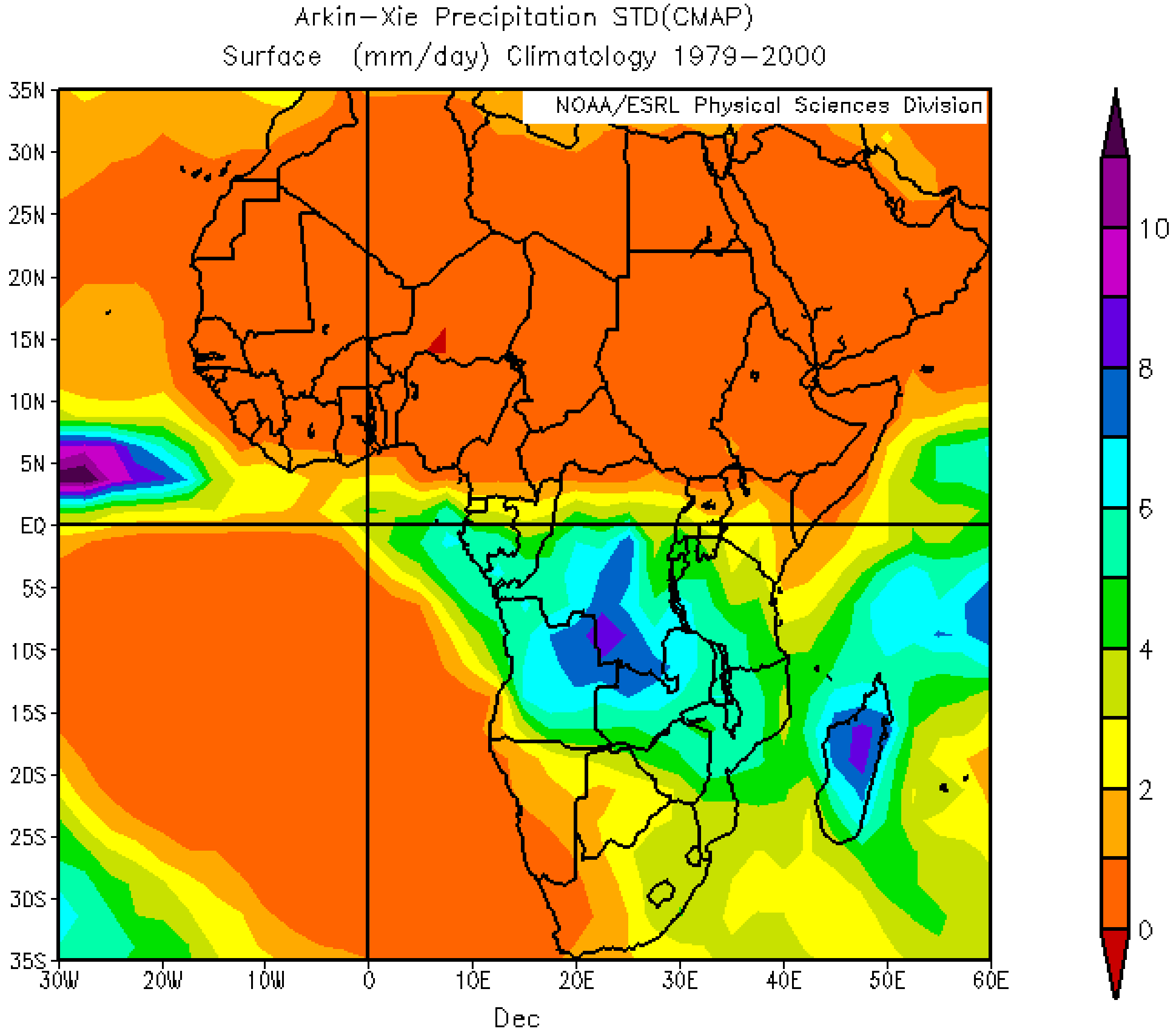
Outline

- West Africa/Sahel
- East Africa
- IGP

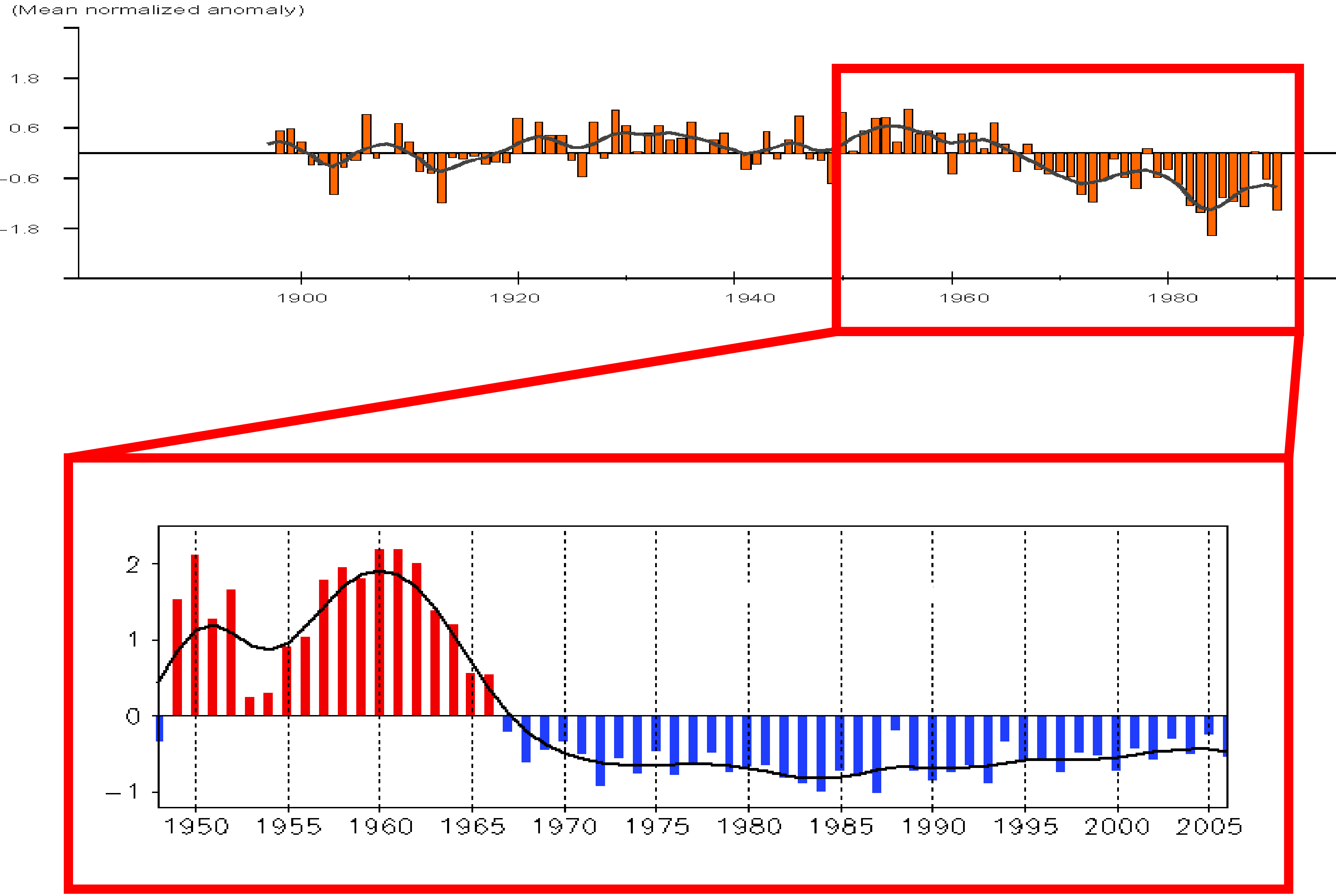
  - Background climate
  - Projected Future Climates
  - Agriculture: What can we say about changing extent of viable cultivation?

- Comments on forthcoming Climate Projections

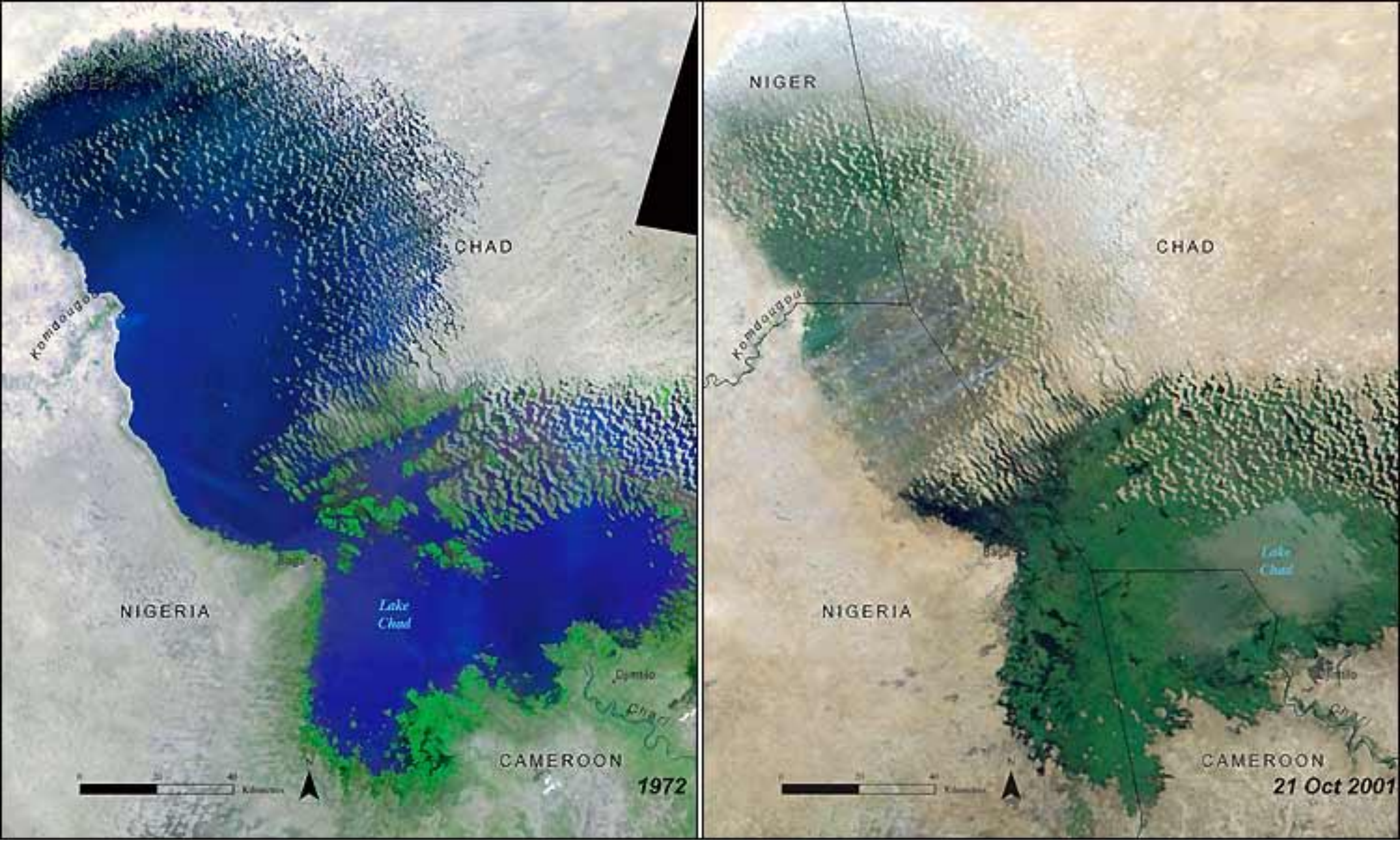
Annual Cycle of Rainfall



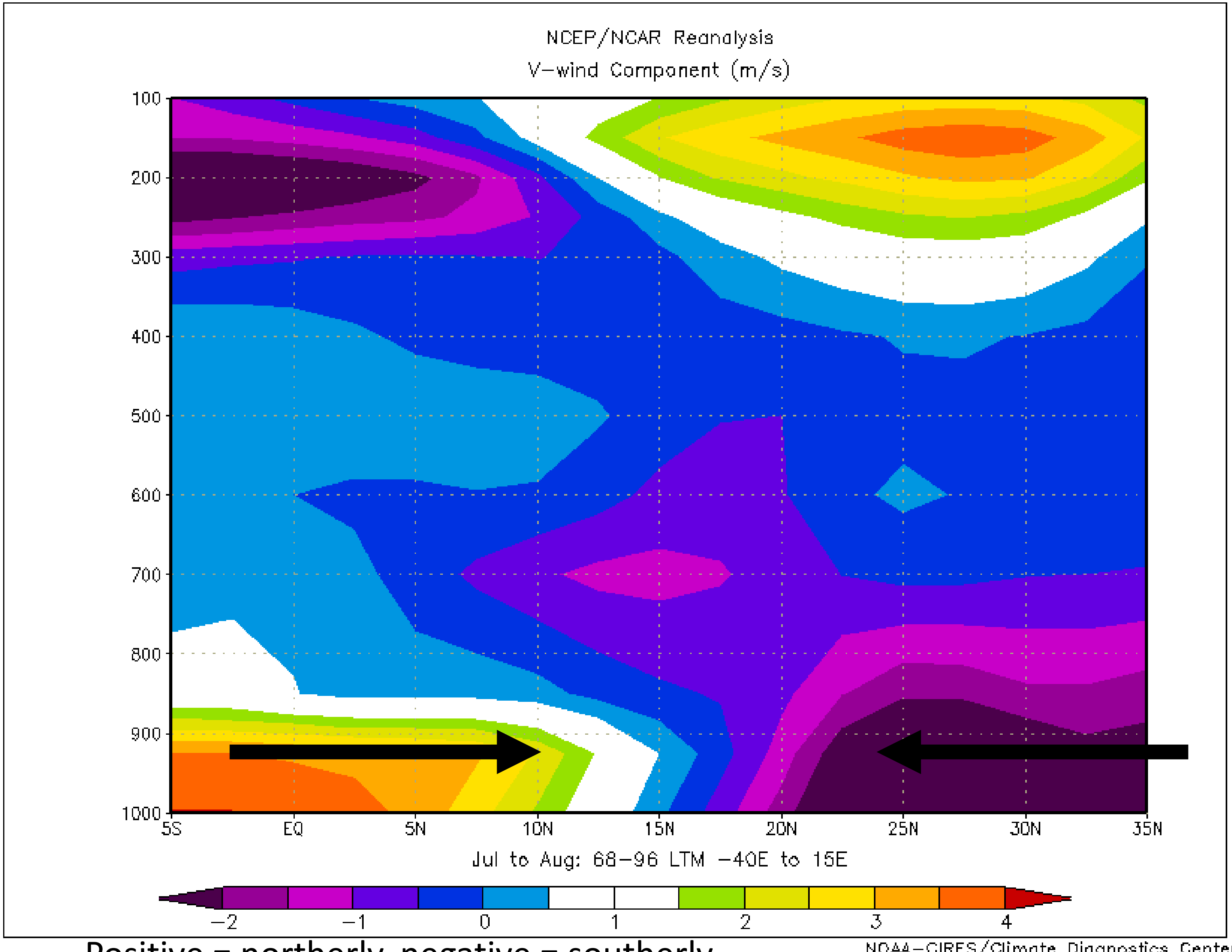
Rain comes to Sahel in June to September



(Mean normalized anomaly)
1.8
0.6
−0.6
−1.8
1900
1920
1940
1960
1980
2
1
0
−1
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005

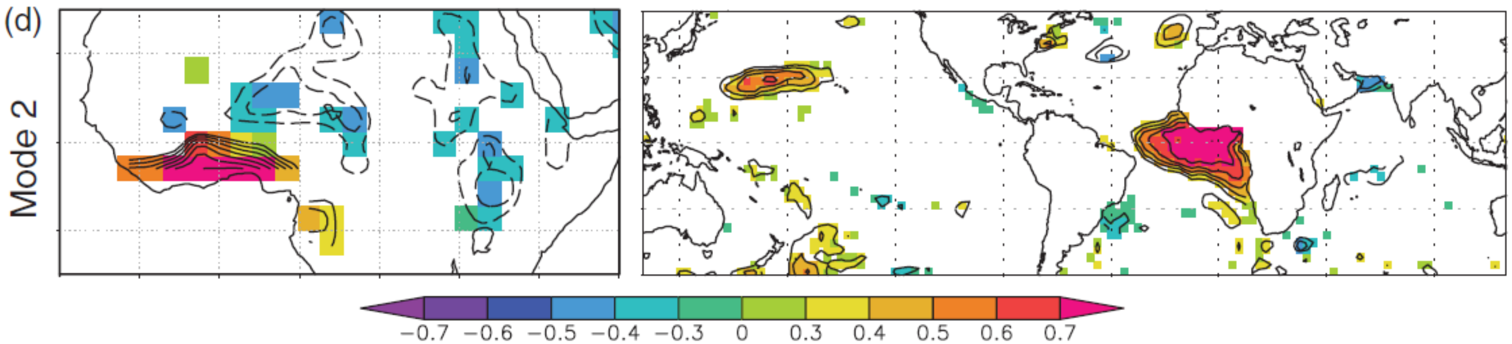

CHAD
Lake Chad
NIGERIA
CAMEROON
1972
NIGER
CHAD
NIGERIA
Lake Chad
CAMEROON
21 Oct 2001

North-south winds: Atlantic/W.Sahel section: water is provided in a very shallow flow of monsoon air near the surface

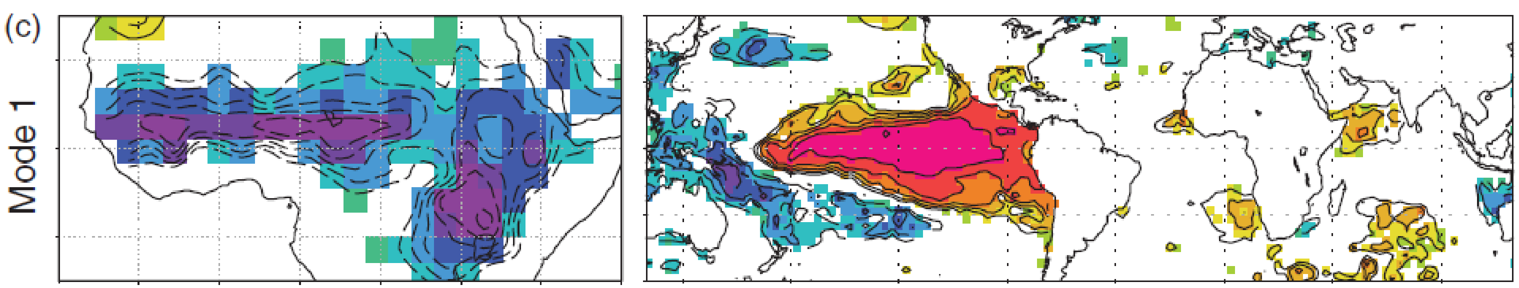


Positive = northerly, negative = southerly

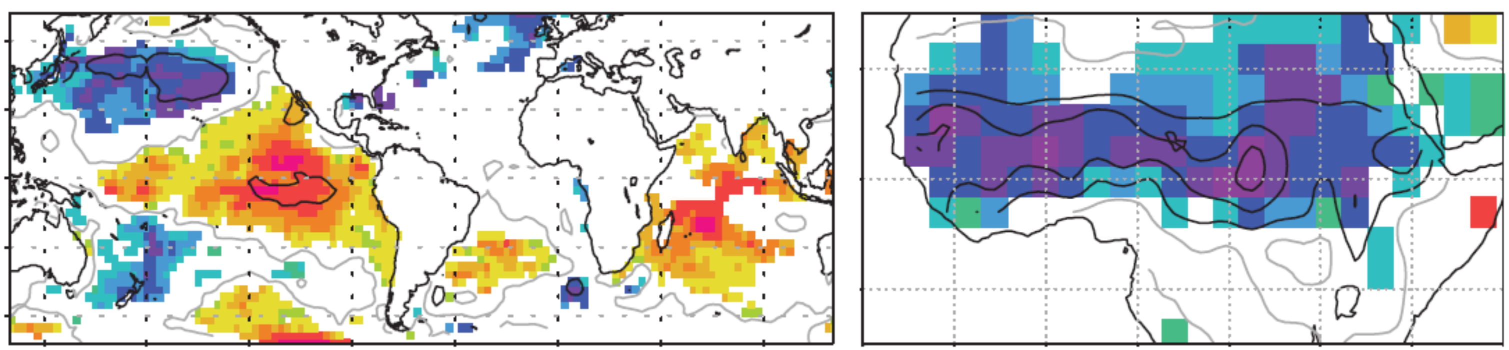
West African rainfall and sea surface temperature patterns



Warmer tropical Atlantic = drier Sahel, wetter Guinea coast

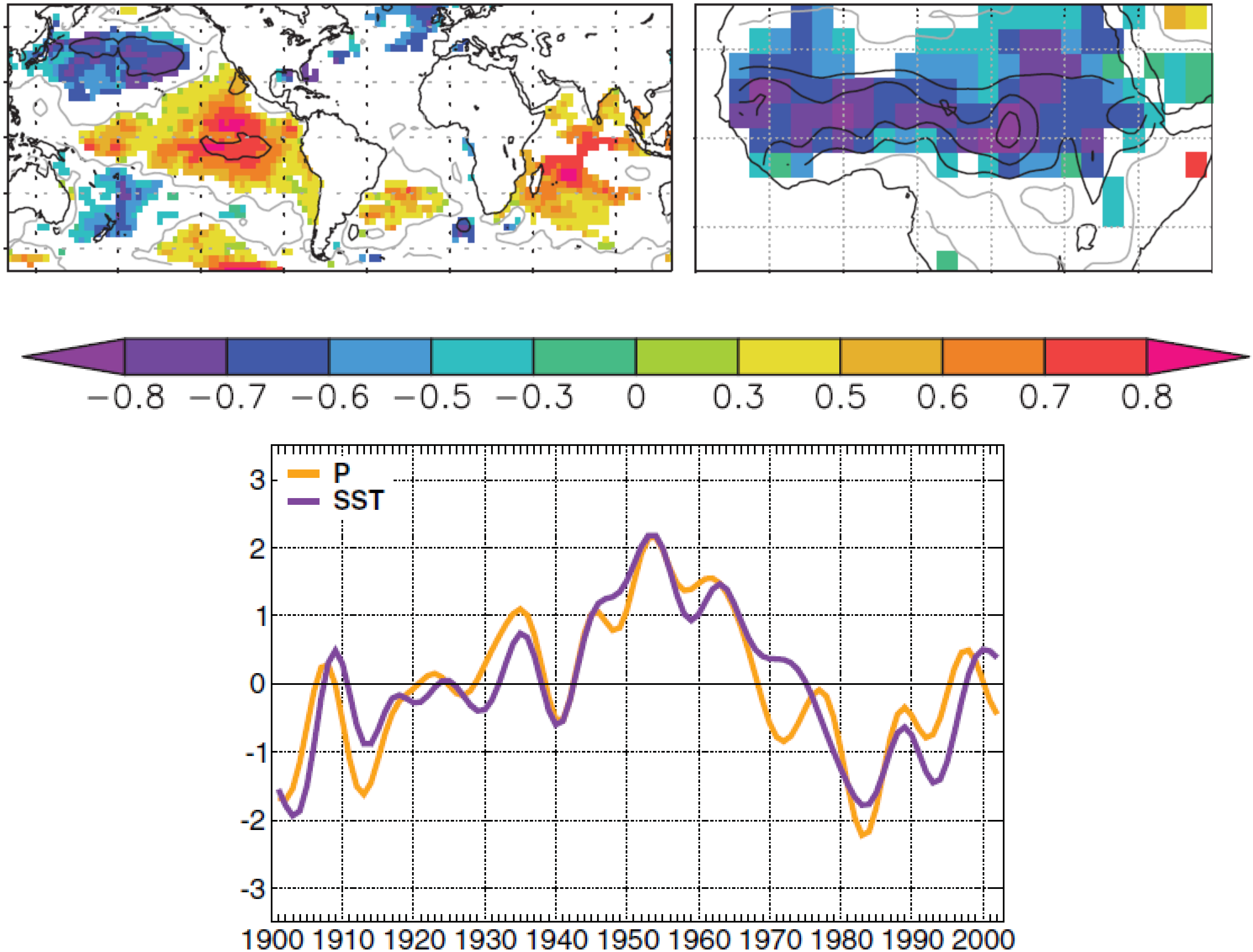


El Nino = drier Sahel

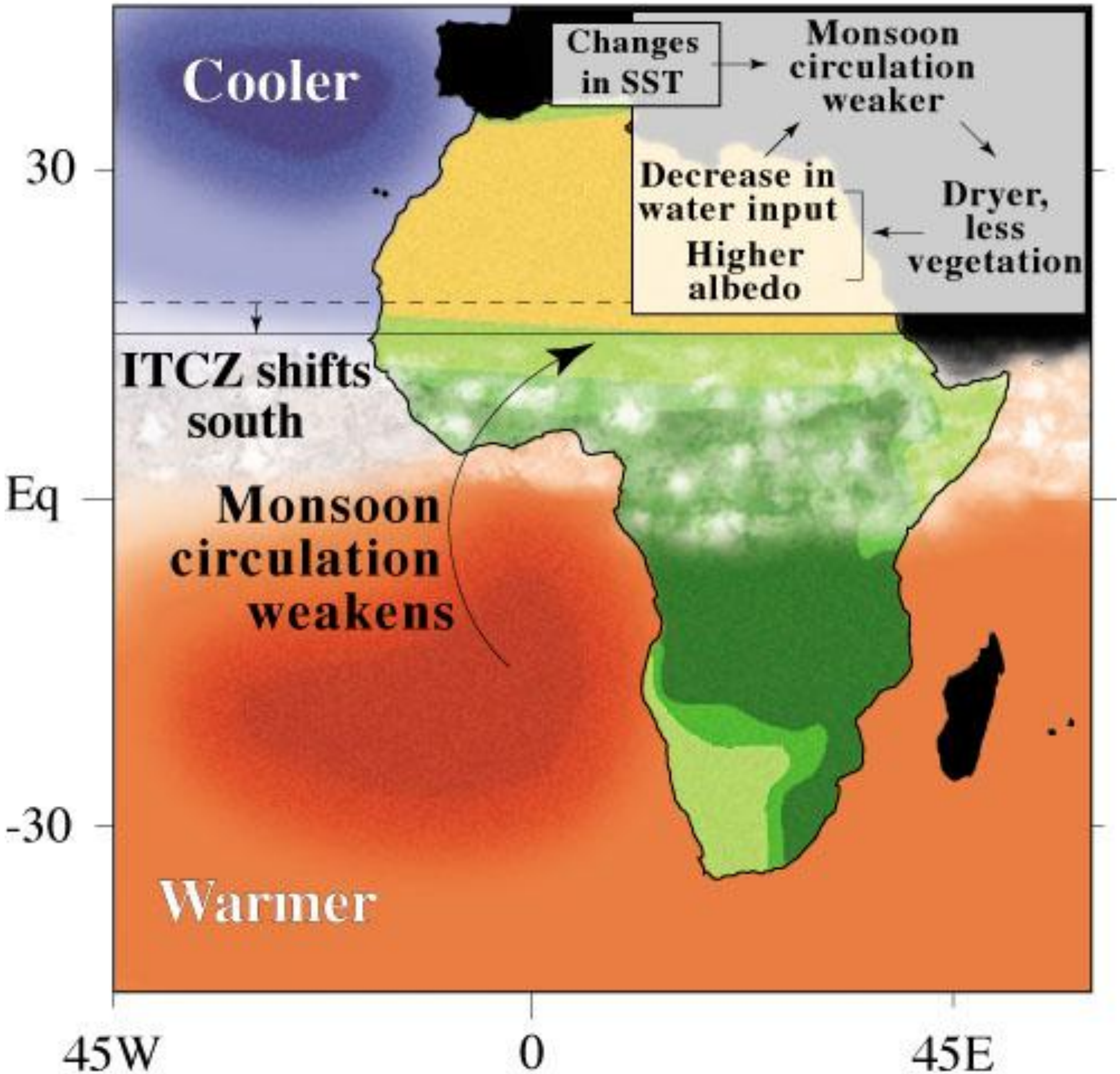


Contrast in hemispheric sea temperatures Driver of long-term drought

Rodriguez-Fonseca et al 2011 ASL



Originally Folland 1986 Nature
Figures from Rodriguez-Fonseca et al 2011 ASL

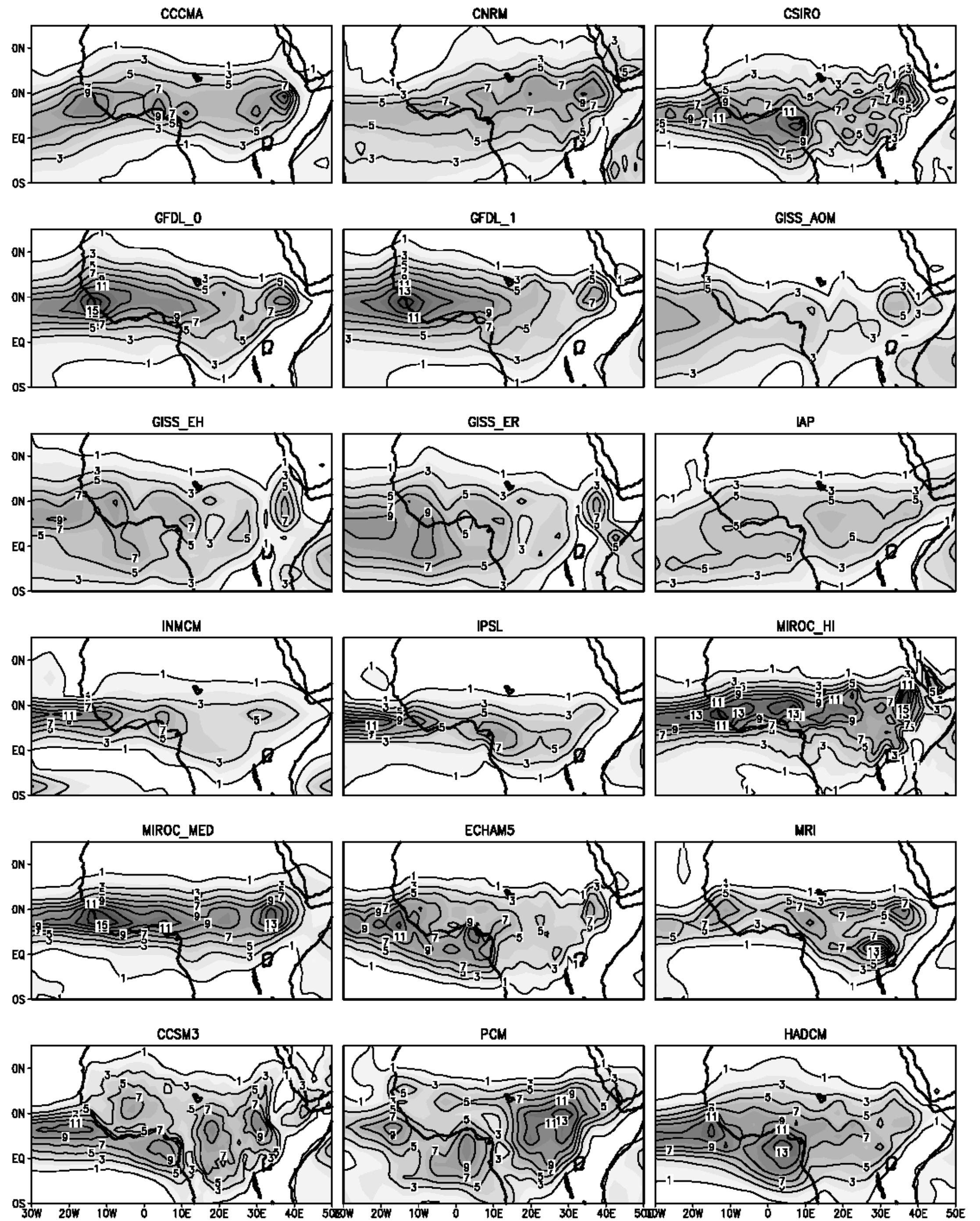

Cooler
Changes in SST
Monsoon circulation weaker
Decrease in water input
Higher albedo
Dryer, less vegetation
30
ITCZ shifts south
Eq
Monsoon circulation weakens
-30
Warmer
45W
0
45E

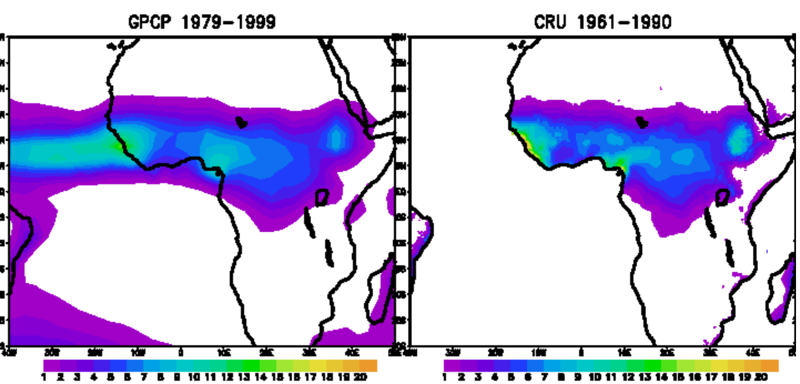
How good are the models?

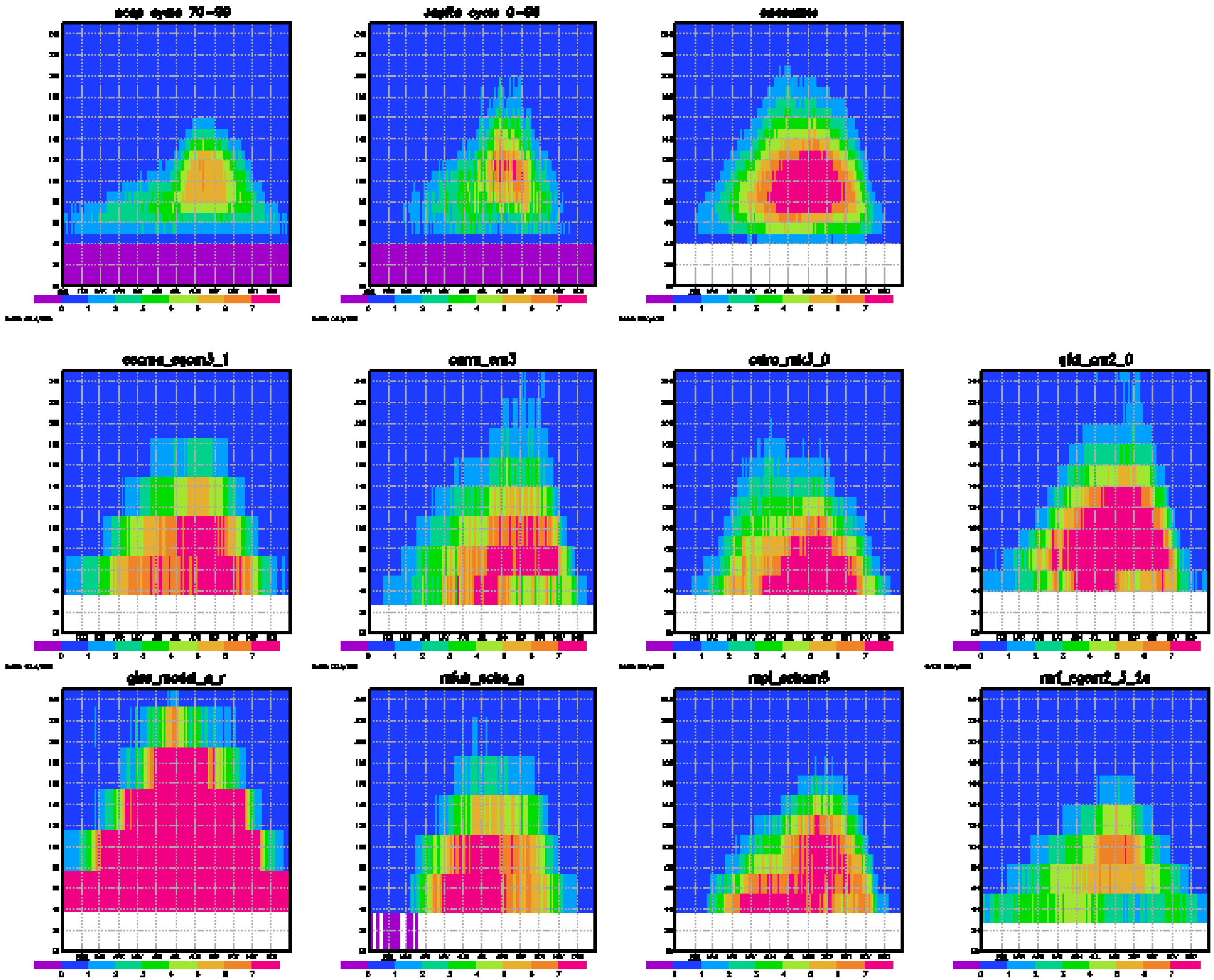
Precipitation climatology in the current generation of climate models

1949 – 2000
JJAS

Kerry Cook



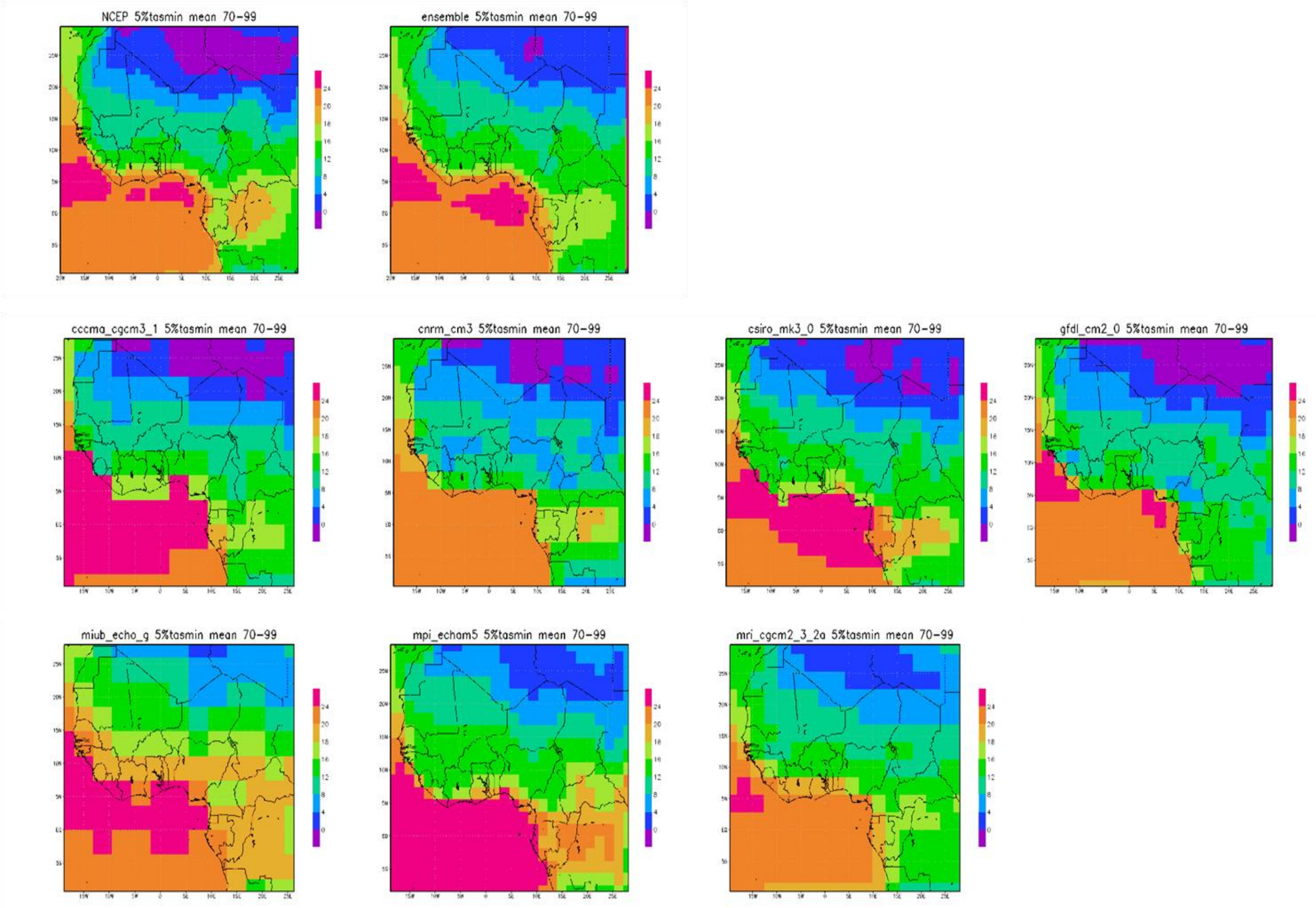




Climate Model annual precipitation cycle averaged zonally across the West Africa domain for the 1970-99 period.

Dataset/Model	Start	End	Length	Trend 1970-1999 (days/year)	Standard Deviation (days)
NCEP	**28th June**	**28th Oct**	**122**	**-0.59**	**18**
JapRe	**6th July**	**1st Sept**	**75**	**-0.32**	**17**
CCCMA	20th May	3rd Nov	168	-0.44	23
CNRM	17th Jun	11th Nov	149	-0.32	26
CSIRO	**19th Apr**	**17th Oct**	180	-0.36	16
GFDL	2nd May	15th Oct	165	0.28	14
MIUB	18th Jun	20th Oct	134	-0.74	20
MPI	5th Jun	15th Oct	132	-0.21	22
MRI	**11th Jul**	**10th Nov**	121	-0.01	15
Model average	**29th May**	**26th Oct**	**150**	**-0.26**	**19**

Monsoon start and end dates, monsoon length, trends in the length of the monsoon (for the 1970-99 period, figures in days/year) and the standard deviation of the length of the monsoon. Figures are provided for the NCEP and JapRe reanalyses for comparison, the 7 models and the average of the 7 models. Significant at 90% is shown in red.



Model derived maximum temperature climatologies and trends during the 1970-1999 period. The NCEP output is shown for comparison. The trend figures are °C/decade.

Trends in intense rainfall are of opposite sign in two data sets

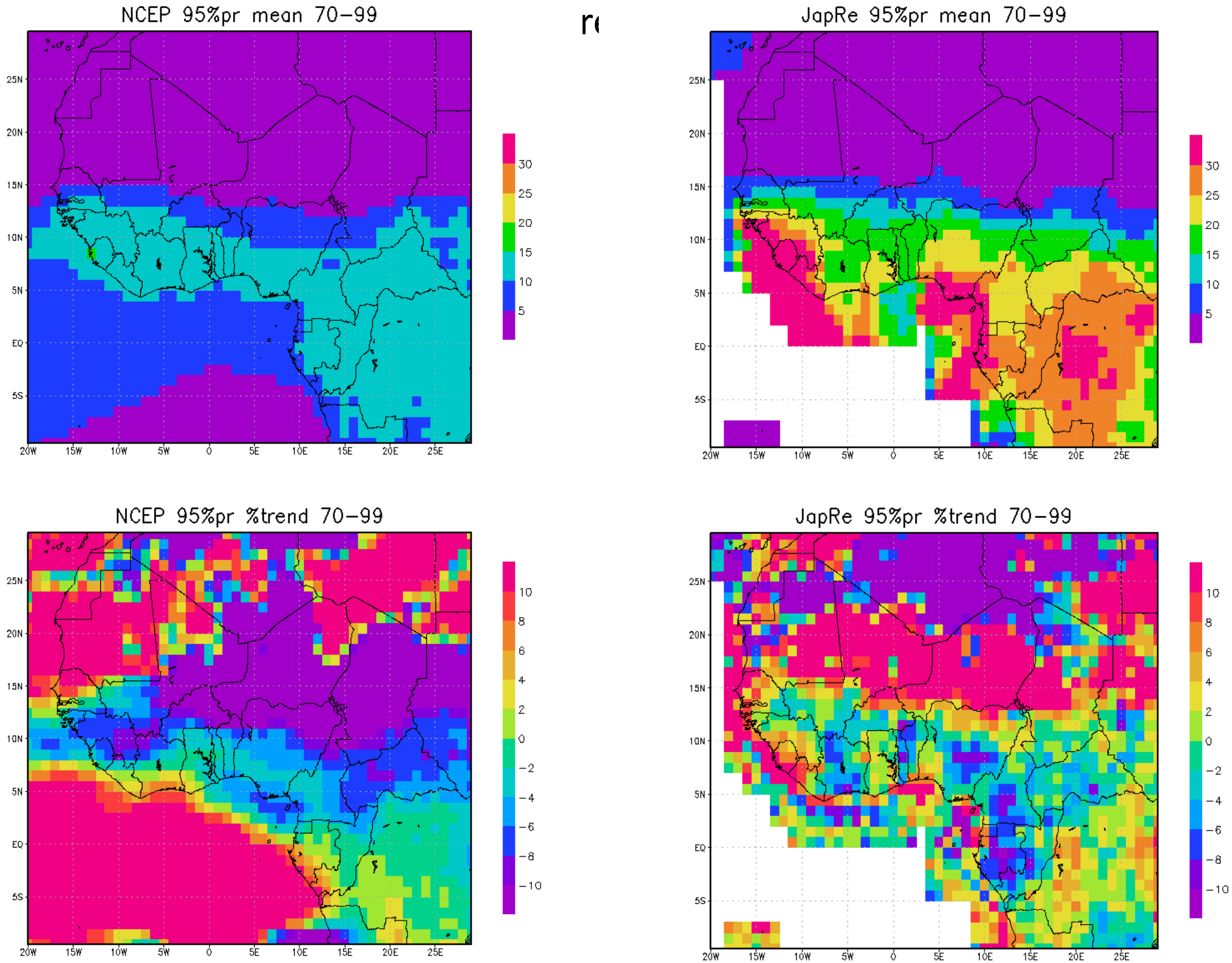


Figure 2.9: Climatologies (top) and percentage trends (bottom) 1970-1999 period of 95% daily precipitation events taken from NCEP (left) and JapRe (right). The trends are percent per decade.

Crop Assessment Methodology

- Choose relevant crops
- Establish the climate related limits to crop growth
- Establish how well these climatically controlled limits are reproduced for climate models
- Evaluate how the area under potential cultivation could change in the future

Crop	Total value ($1000s), including Nigeria	Total value ($1000s), excluding Nigeria
Cassava	**3,071,029**	**591,445**
Millet	**2,085,272**	**926,554**
Rice	**1,659,813**	**1,007,268**
Sorghum	1,435,564	514,911
Maize	957,857	422,720
Cowpea	309,181	309,181

Cassava primary limitation: absolute precipitation range which cassava is capable of withstanding. Optimum growing conditions are found along the Gulf of Guinea coast, with the higher average and lower minimum continental temperatures limiting the range of optimum growth within the absolute domain

Rice delineated by the decreasing northward precipitation gradient alone

Millet With a low minimum and maximum precipitation threshold the variability in the two data sets used to delineate the crop is more pronounced than for the other crops.

How well can climate models reproduce the climatically controlled extent of viable cultivation?

Cassava model ensemble pattern follows the observed data well. But slightly more northerly boundary of both the absolute and optimum growth thresholds This is a function of the wet precipitation climatologies produced in the majority of the models.

Millet The ensemble domain and those produced by many models are close to the observed pattern. In a small number of models, excessive average temperatures provide a secondary threshold, but the majority reproduce the observed/reanalysis thresholds adequately.

Rice The ensemble domain correlates well with both observed/reanalysis domains. The thresholds produced by all variables are similar to observed, with the exception of minimum temperature where the model domain is too extensive.

What happens to the extent of viable cultivation with projected climate change?

Cassava

•The absolute extent of the ensemble domains do not change significantly with climate change. The ensemble, however, represents the average of a wide divergence in precipitation projections across the CMIP3 dataset.

•Comparing the change in domain of two of the model outputs with strong wetting (MIUB) and drying (GFDL), the projections vary over the Sahel, with a maximum southward migration of around 2˚ in the driest scenario.

•No scenarios indicate a significant northward expansion of cultivatable land.

•The relatively high precipitation threshold for cassava explains the broad consensus across the models, with greater variability in projections occurring in the driest areas.

•the outlook for growth of cassava in the region: uncertain change in the northern limits of growth, + conditions within the currently cultivatable area will become more challenging due to increased temperatures.

What happens to the extent of viable cultivation with projected climate change?

Millet

- The ensemble average future projections diverge relatively little from current, with the primary changes resulting from areas which are too warm for optimum growth.
- The growth domains of the wettest and driest projections have very little overlap, with the southern limit of growth by the end of the century around the same latitude (10-12˚N) as the northerly limit in the driest scenario.
- The area of suitable conditions migrates northward and expands under the wettest scenario, with the southern boundary moving around 1˚ and the northern boundary up to 3˚ in the central Sahel.
- The driest scenario contracts the domain at both the northern and southern boundaries, becoming centred on the southern Sahel.
- Optimum temperatures also cross the upper threshold of 28˚C across almost all of the projected growth domains in all models and in all forcing scenarios.
- Optimum temperature thresholds are exceeded early in the century, so response thereafter (though likely to be non-linear) is already above the thresholds analysed here.
- The outlook for millet is highly uncertain, largely as a result of the comparatively narrow precipitation thresholds which growth is constrained by.

What happens to the extent of viable cultivation with projected climate change?

Rice

•the higher minimum precipitation requirements of rice leads the limit of cultivation to lie further south than the other crops. As a result, the models show less divergence in their projections for future growth domains.

•The ensemble absolute growth domain changes very little, with an expansion of optimal conditions driven by the increase in average temperatures passing the 25˚C threshold in the few areas within the existing growth domain where it is not already satisfied. The greatest inter-model divergence is of 2-3˚ (including uncertainty derived from the reanalysis discrepancies) in the projections for the northern limit of cultivation by the 2090s under an sresa2 scenario.

•The outlook for rice appears better constrained than cowpea or cassava, with the higher precipitation thresholds more consistently produced across the models. The primary uncertainty is the northern boundary of cultivation with a projected change of less than 2˚ either north or south under the most extreme forcing scenario. Where changes in precipitation do not adversely impact on growth, increasing temperatures should improve growth conditions.

A Drier Sahel in the C21st?

- Cook and Vizy, 2006 selected 3 GCMs (based on the quality of their C20th simulations) for C21st simulations with various GHG emissions scenarios.

- Models;
  - GFDL_0
    - Severe drying in later part of C21st, with complete shutdown of WAM system
    - BUT significant inaccuracy in simulation of present-day regional climate so predictions may be implausible

  - MIROC
    - Quite wet conditions in C21st, with strong warming in the Gulf of Guinea reversing monsoonal flow and greatly reducing precipitation for Guinea coast countries.
    - Increased westerly inflow near 15degN leads to increased precipitation in the Sahara
    - BUT changes are very strong and very sudden in response to a 2K SST anomaly in the Gulf of Guinea- may be more representative of C22nd.

A Drier Sahel in the C21st

- MRI
  - Warming in the Gulf of Guinea leads to more modest drying in the Sahel due to a doubling of the number of anomalously dry years by the end of the century.
  - Long-term trend in warming over many years.

- Analysis suggests MRI provides the most reasonable projection of C21st climate.

- By end C21st, with increased GHG according to IPCC SRES A2, the number of dry years in the Sahel will approximately double.

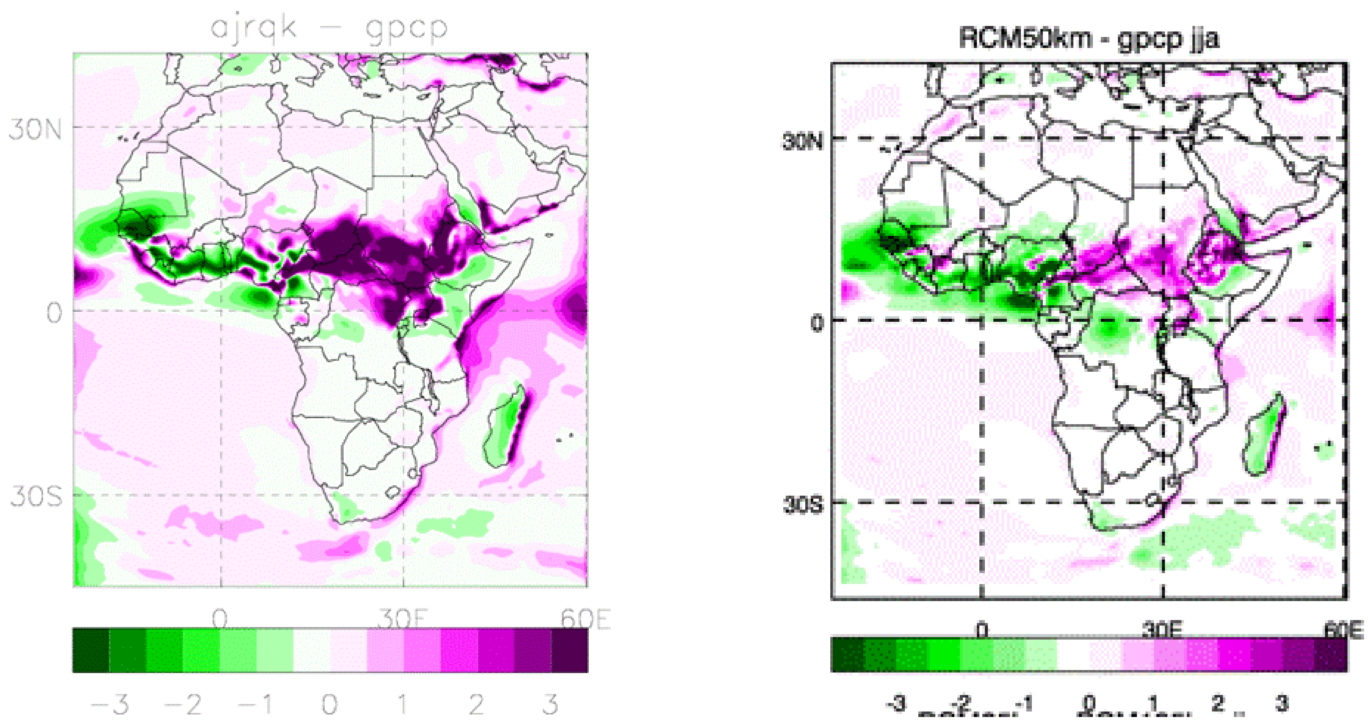
- This will lead to a decrease of ~10% in the summer precipitation climatology over the Sahel, and a similar decrease over the Guinean Coast.

A Wetter Sahel in the C21st

- Hoerling et al. (2006) analysed results from a whole suite of AGCM ensembles, focusing on the Sahel.

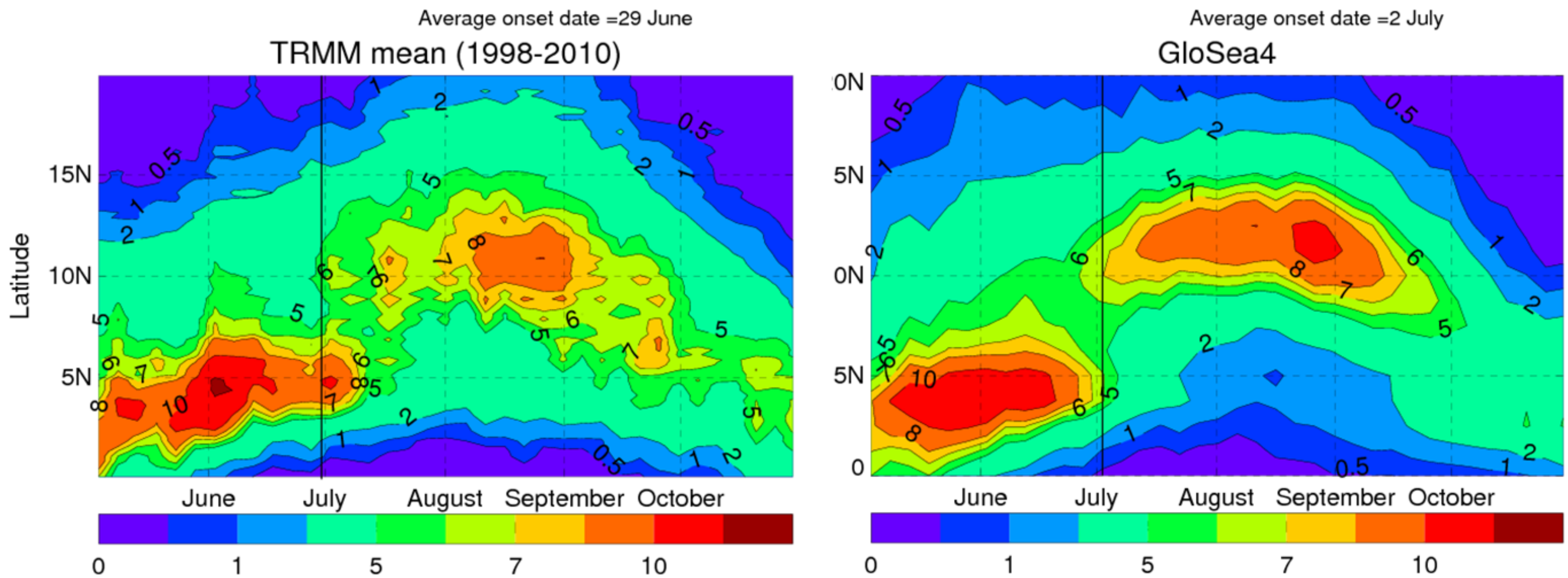
- Averaging all models produces a wet future Sahel

Model resolution and Model improvements in rainfall bias



Average (1990-2006) June-August precipitation biases (mm/day) for model at 50km grid-spacing. Left: GA2.0 model version (assessed last year); right latest (GA3.0) version.

Met Office CSRP



Evolution of the WAM as observed by TRMM measurements, 1998-2010 (left) and in the GA3.0-based GloSea4 seasonal hindcast climatology.

Met Office CSRP

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Crop Assessment Methodology

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- Evaluate how the area under potential cultivation could change in the future

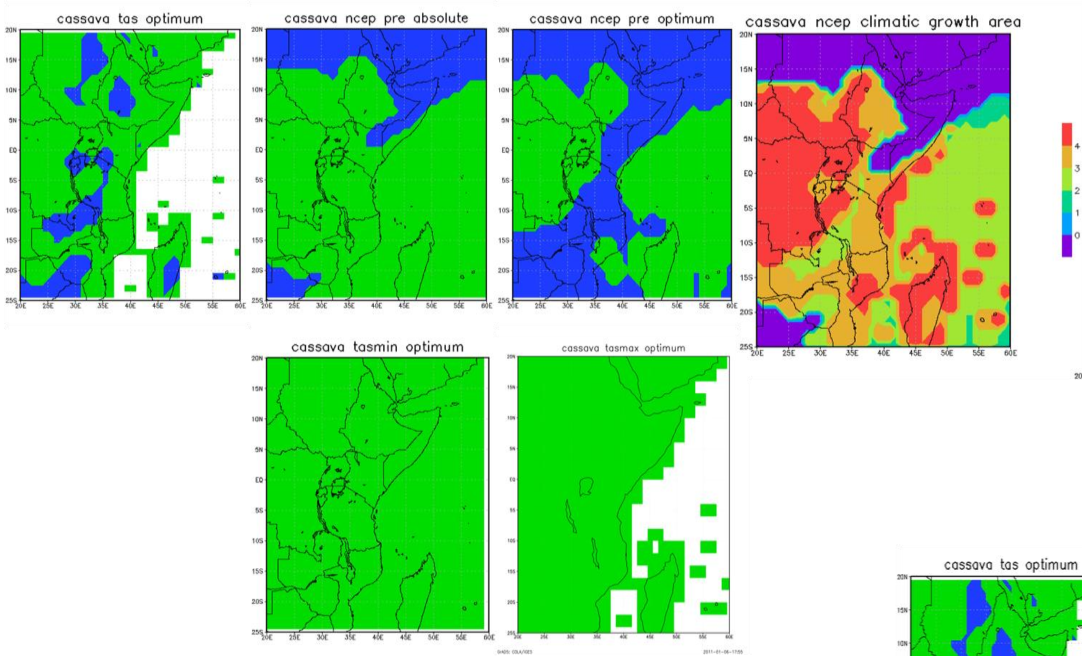
Crop	Total value ($1000s)	No. countries grown in
Maize	1277201	8
Cassava	1142874	6
Bananas	980947	7
Sorghum	938746	7
Rice	896989	5
Sweet Potatoes	728192	8
Wheat	447076	6
Potatoes	413219	7
Millet	247345	3
Pigeon Pea	99863	4

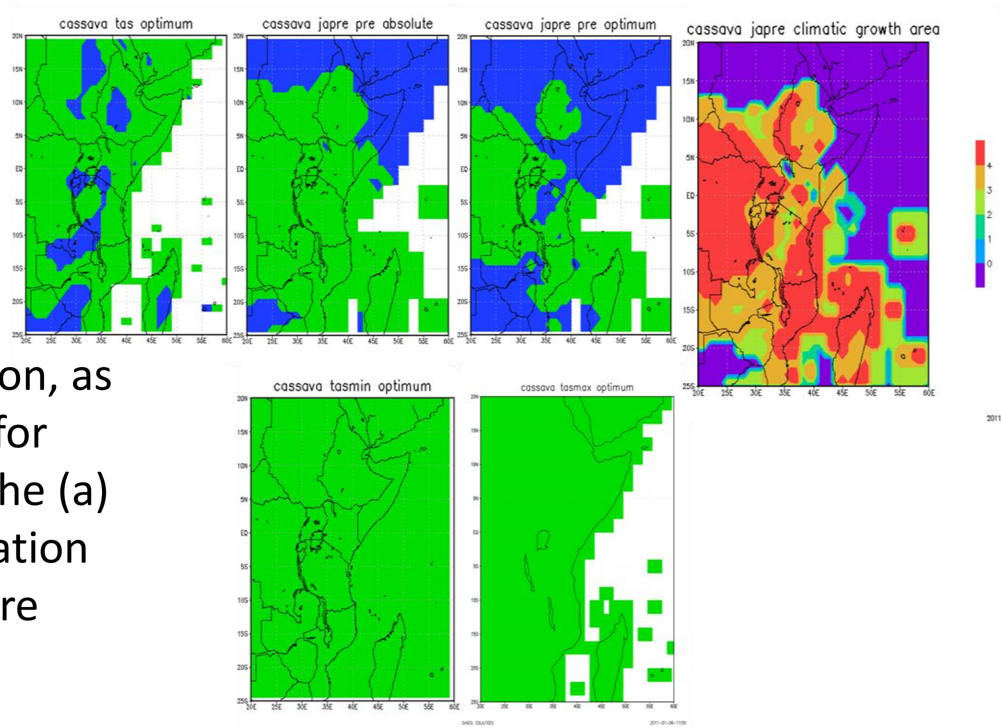
Table 3.1 Crops selected for East African study, their value across the East African region
and number of the study countries they are grown in. Figures from UN FAO.

Maize limited areas of optimal growth in the East African domain, restricted to the Indian Ocean coastline of Kenya and Tanzania and much of southern Sudan under both reanalysis precipitation datasets.

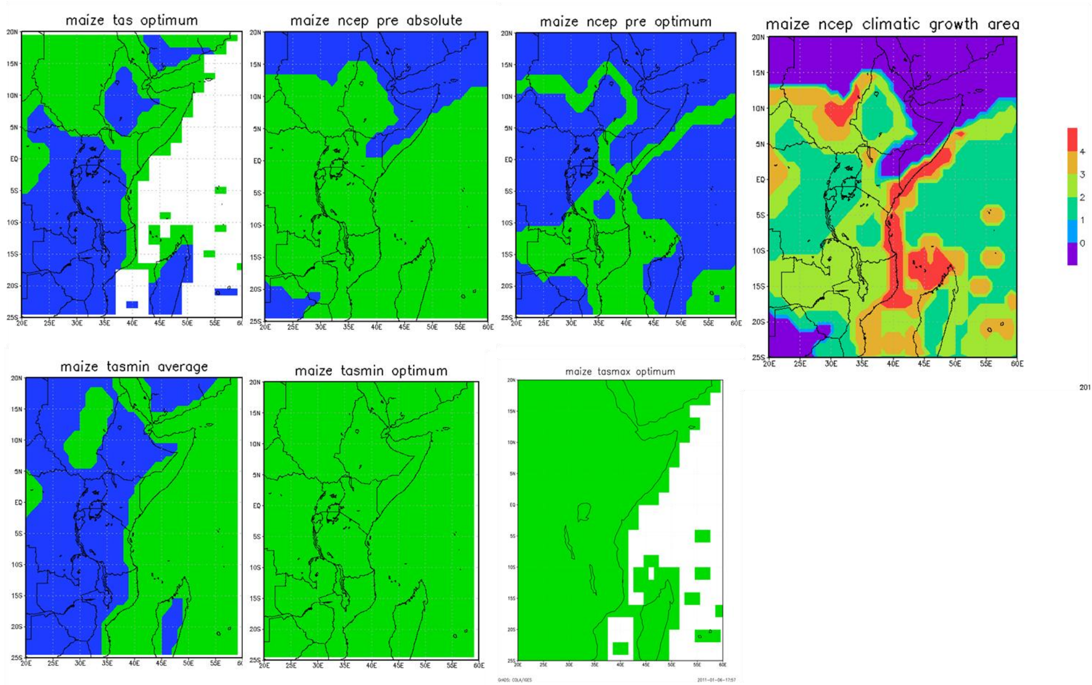
Cassava most of the East African domain, with the exception of northern Kenya and eastern Ethiopia.

Banana primary limiting factor on growth is precipitation; however it would be possible to grow bananas outside of the indicated climatological area through irrigation. Optimum growing conditions (with NCEP reanalysis precipitation) are found in the west of the domain, from northern Tanzania up through Burundi and Rwanda and into western Ethiopia. The JapRe precipitation dataset indicates optimum growing conditions are similarly co-located but over a smaller region.

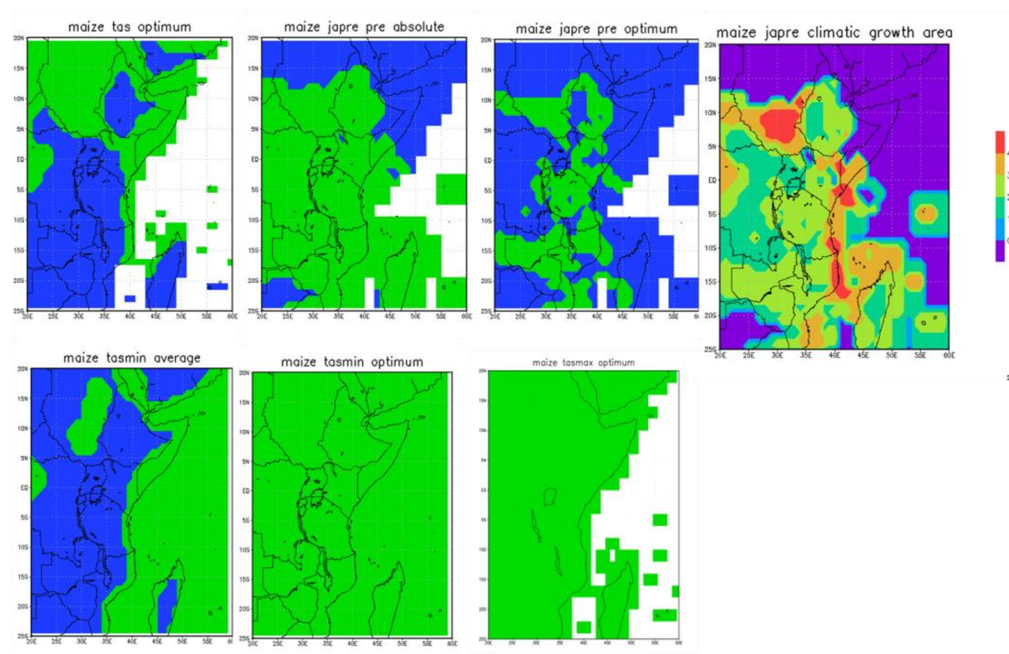


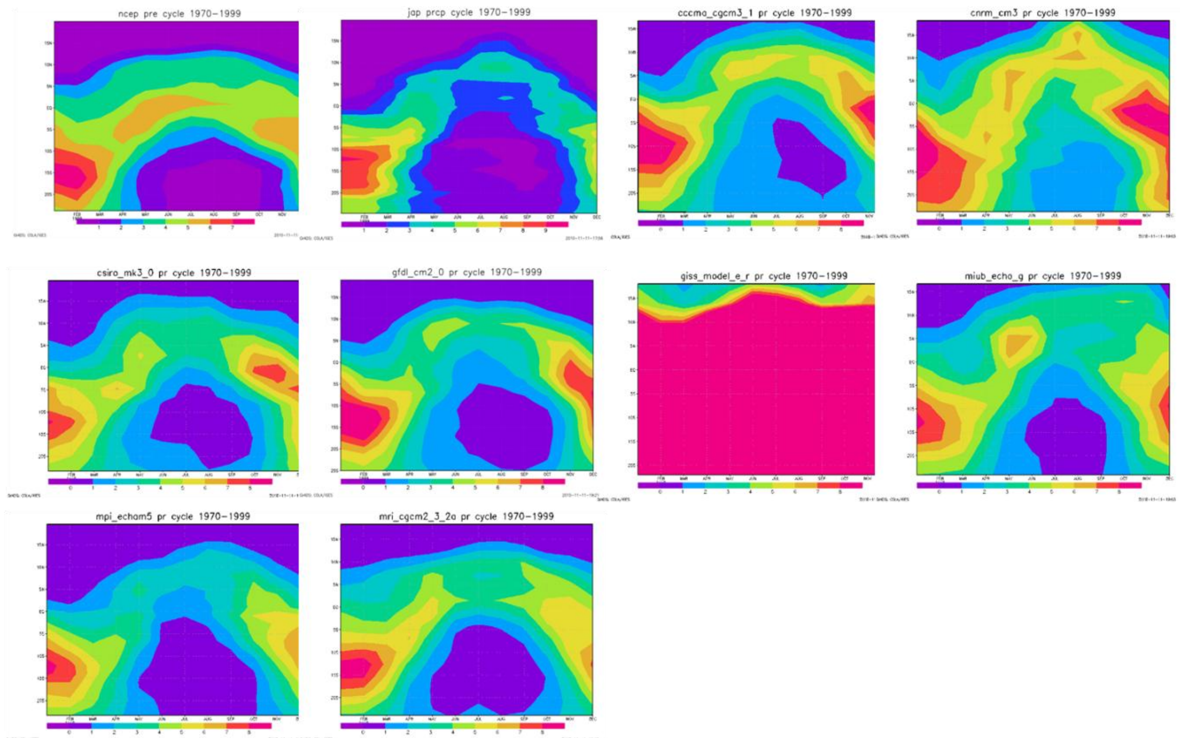


Thresholds of production across the region, as realised from mean climatic conditions, for **cassava.** Maps are provided using both the (a) NCEP (top) and (b) (right) JapRe precipitation reanalyses, both use the CRU temperature dataset.



Thresholds of production across the region, as realised from mean climatic conditions for **maize**. Maps are provided using both the (a) NCEP and (b) JapRe precipitation reanalyses, both use the CRU temperature dataset.





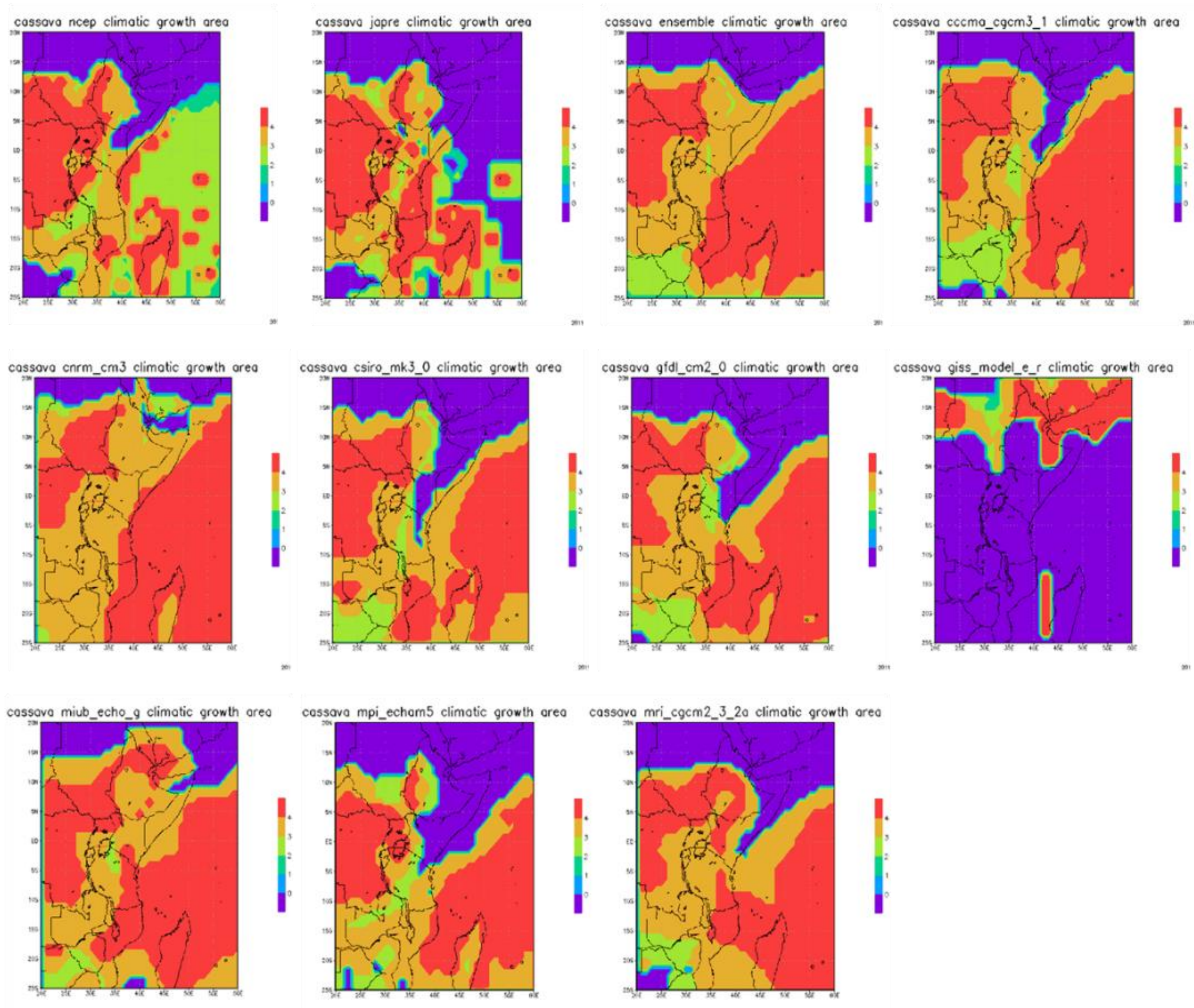
The annual precipitation cycle averaged zonally across the domain for the 1970-99 period for 'observed' (top left) and climate models.

How well can climate models reproduce the climatically controlled extent of viable cultivation?

Banana The ensemble output follows the climatological growth region well, although the optimum area in the ensemble is slightly smaller and does not extend into Uganda. The southern border of growth is further south in the ensemble due to the precipitation distribution biases in the models.

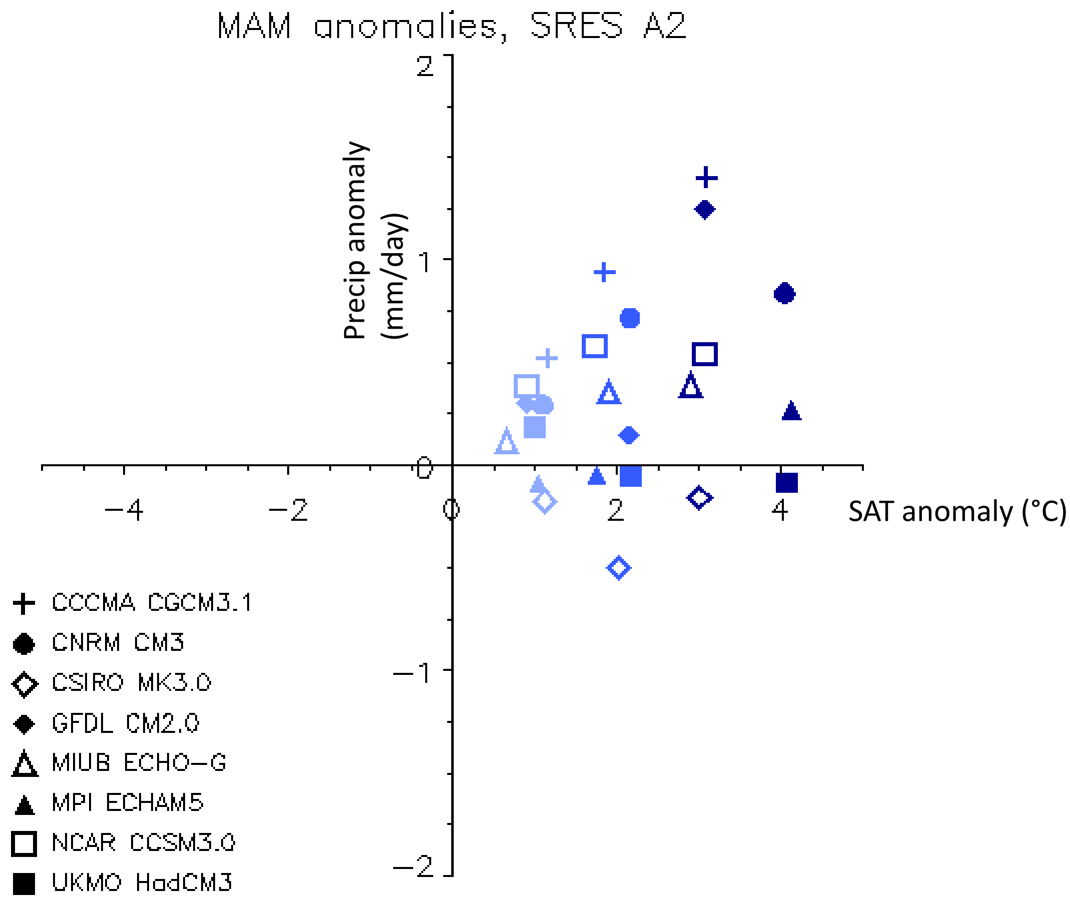
Cassava Cassava is a crop that can be widely grown over East Africa and the model ensemble domain reflects this. One key difference is that the precipitation distribution in the models suggests that cassava can be grown over northern Kenya and eastern Ethiopia when observed precipitation makes these regions inappropriate for cassava cultivation.

Maize The key optimal region of maize growth over central-southern Sudan is well replicated by the model ensemble as are other areas of varying suitability. As with cassava, the weakest element of the model simulation of the crop cultivation region is in eastern Ethiopia and northern Kenya where the models overestimate precipitation. However, half of the individual models robustly capture the precipitation limitations on maize growth in this region.



Model derived crop domains for cassava created using climatology data for the 1970-99 period. The NCEP and JapRe domains are included for comparison.

Change in precip against change in SAT relative to 1961-90 climatology for 2020s (pale blue), 2050s (mid blue) and 2080s (dark blue)



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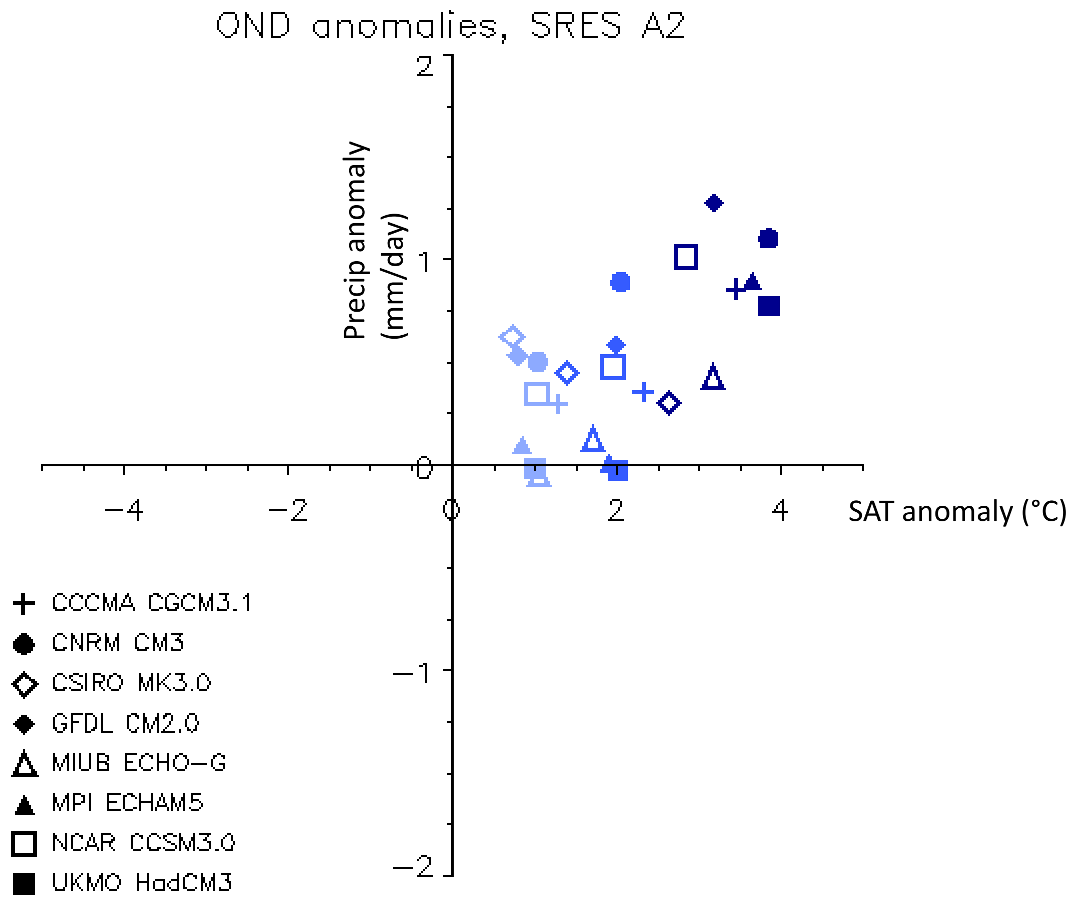
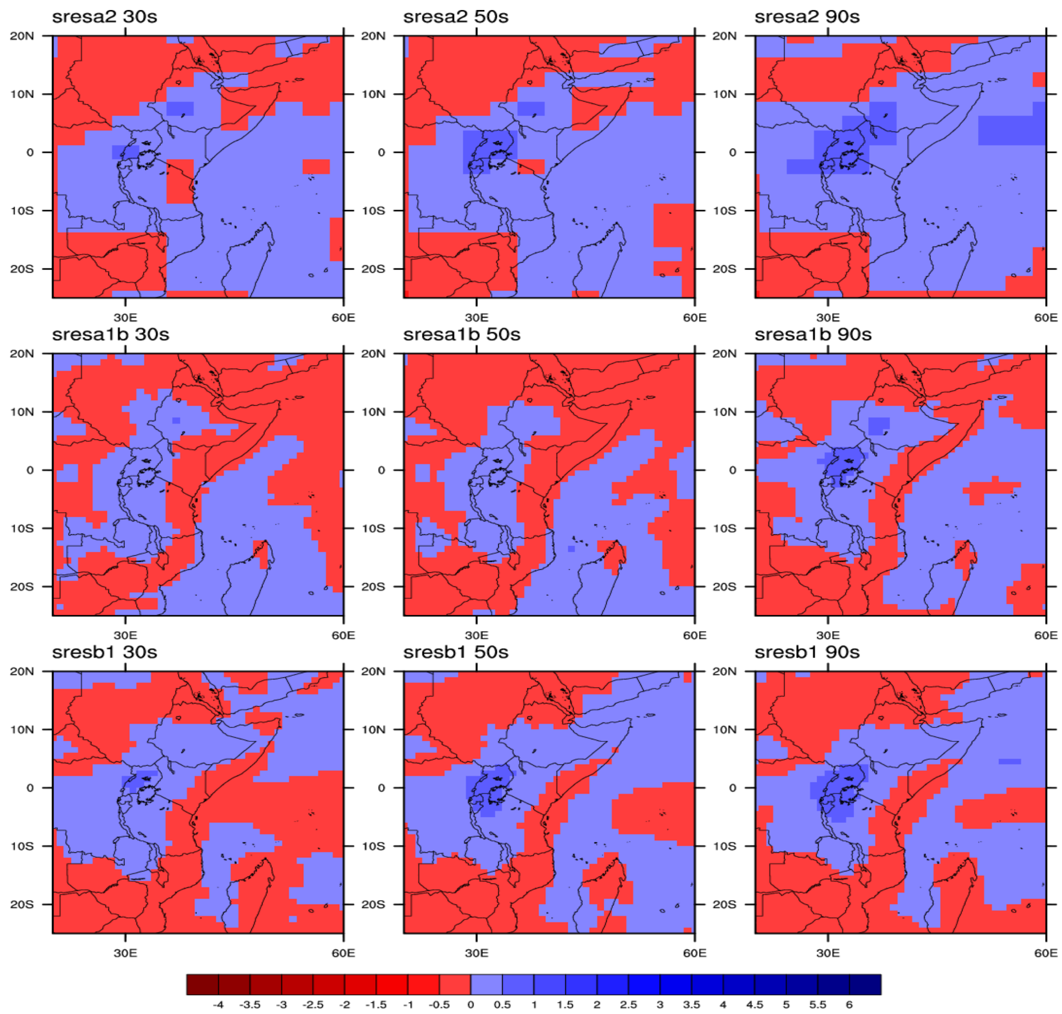




Precipitation anomalies (in mm/day) from the model ensemble for the 2030s, 2050s and 2090s under sresb1, sresa1b and sresa2 scenarios relative to a 1970-99 climatology.

What happens to the extent of viable cultivation with projected climate change?

Banana

•The absolute extent of the crop growth domain does not change significantly in the ensemble output through the twenty-first century.

•The plots based on the NCEP climatology show a significantly larger area suitable for cultivation and this remains the case through the three periods of analysis.

•There may be opportunities for growth in Uganda, Burundi, Rwanda and the westernmost fringes of Tanzania and Kenya.

Maize

Under current climatic conditions maize experiences optimal growth conditions in very few regions in East Africa.

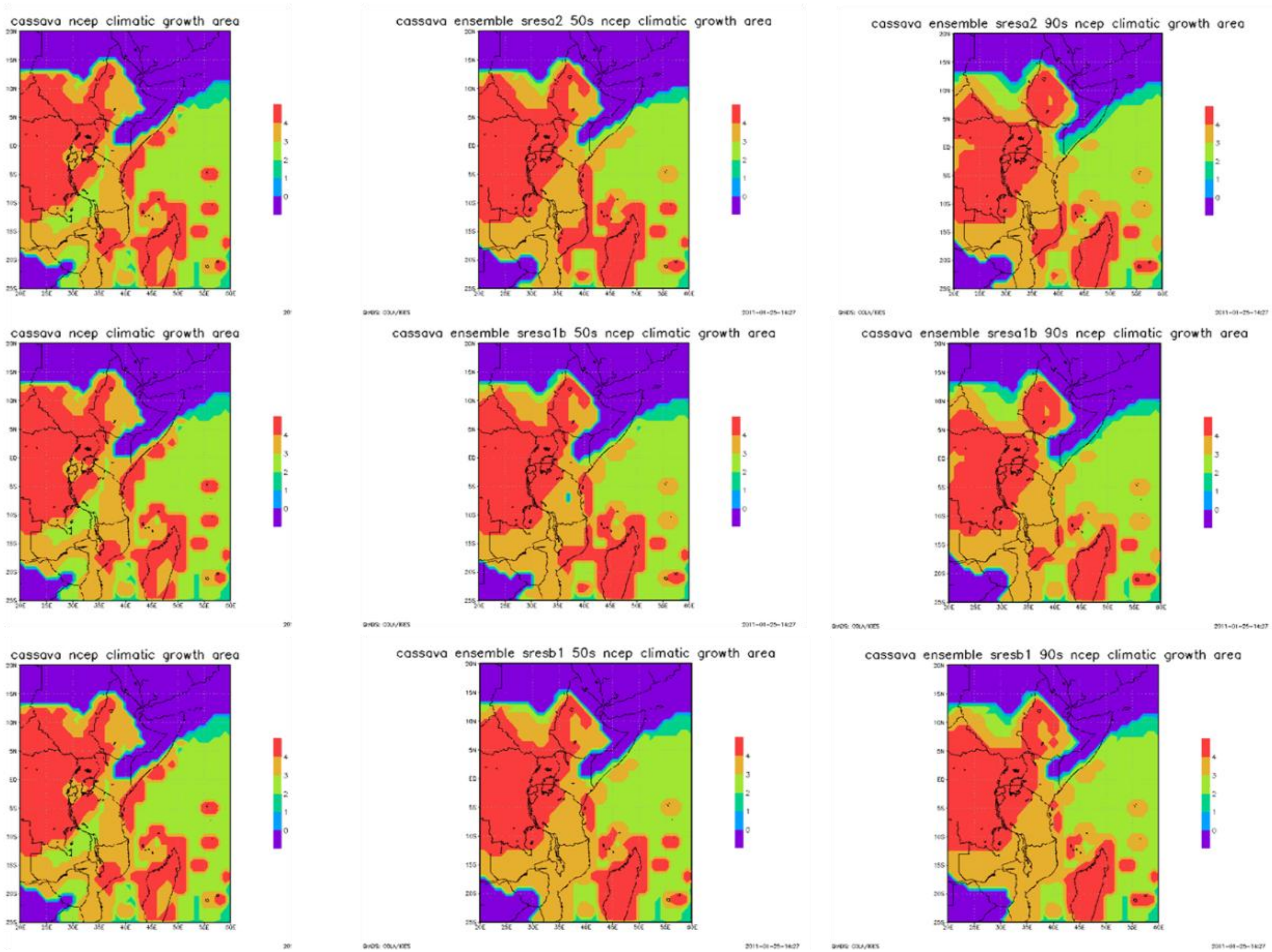
This scenario is not projected to change significantly over the twenty first century;

Small region of southern Sudan where conditions were optimal contracts using both base datasets and under all scenarios by the 2090s

Cassava

Climate chnages introduces few adverse impacts on the climatic suitability of current optimal cassava growing regions

Contraction occurs at the northern boundary of cultivation in southern Sudan and measures up to about 5º under the A2 scenario in the 2090s



Model ensemble derived crop domains for cassava for the three periods and three forcing scenarios

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IGP Basic Climate

- Dominated by Indian Monsoon
  - Local rainfall (~70%)
  - Himalayan sources for Indus and Ganges
- Winter snowfall also important
  - Mid-latitude westerly disturbances

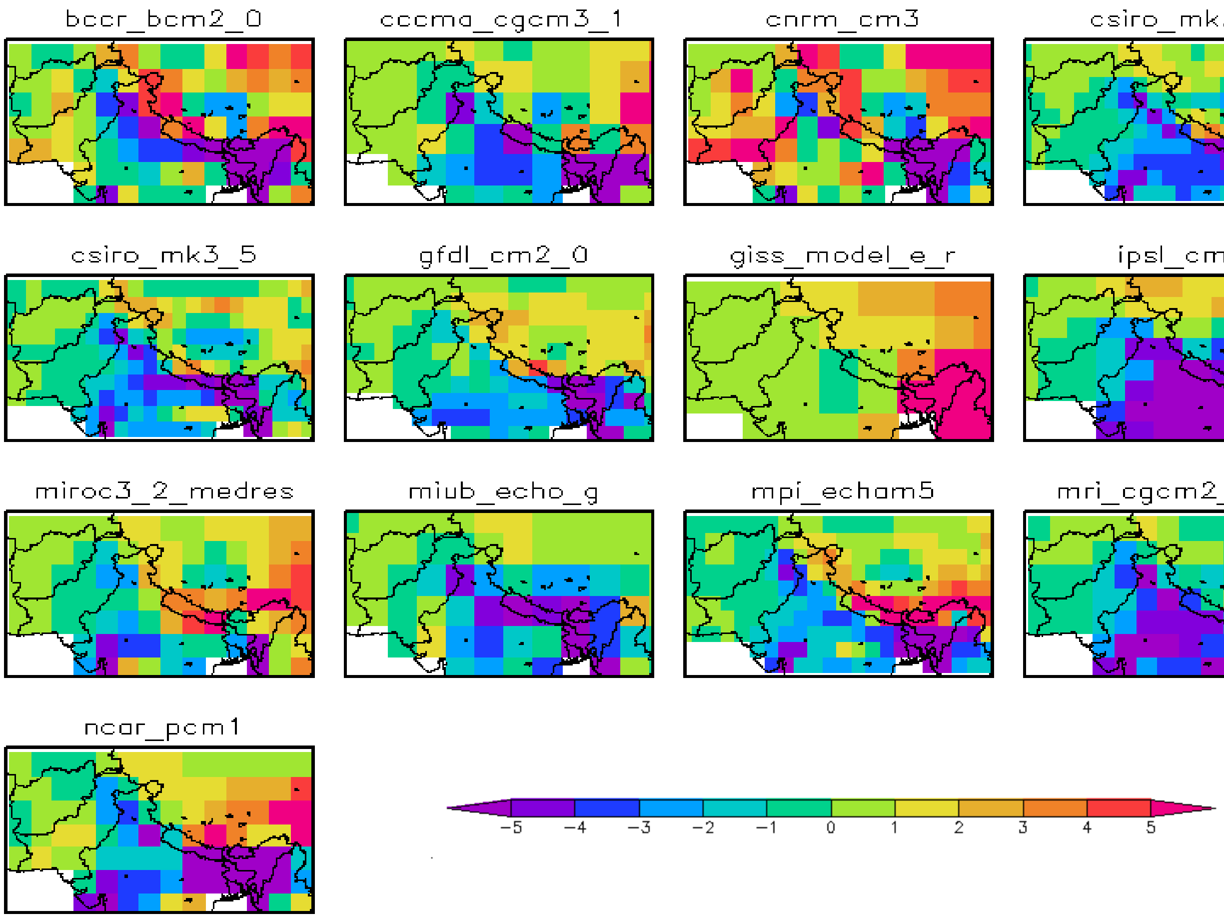
Monsoon Variability: Key Drivers

- ENSO
- Indian Ocean
- Eurasian Snow Cover
- North Atlantic
- Asian Brown Cloud Aerosols

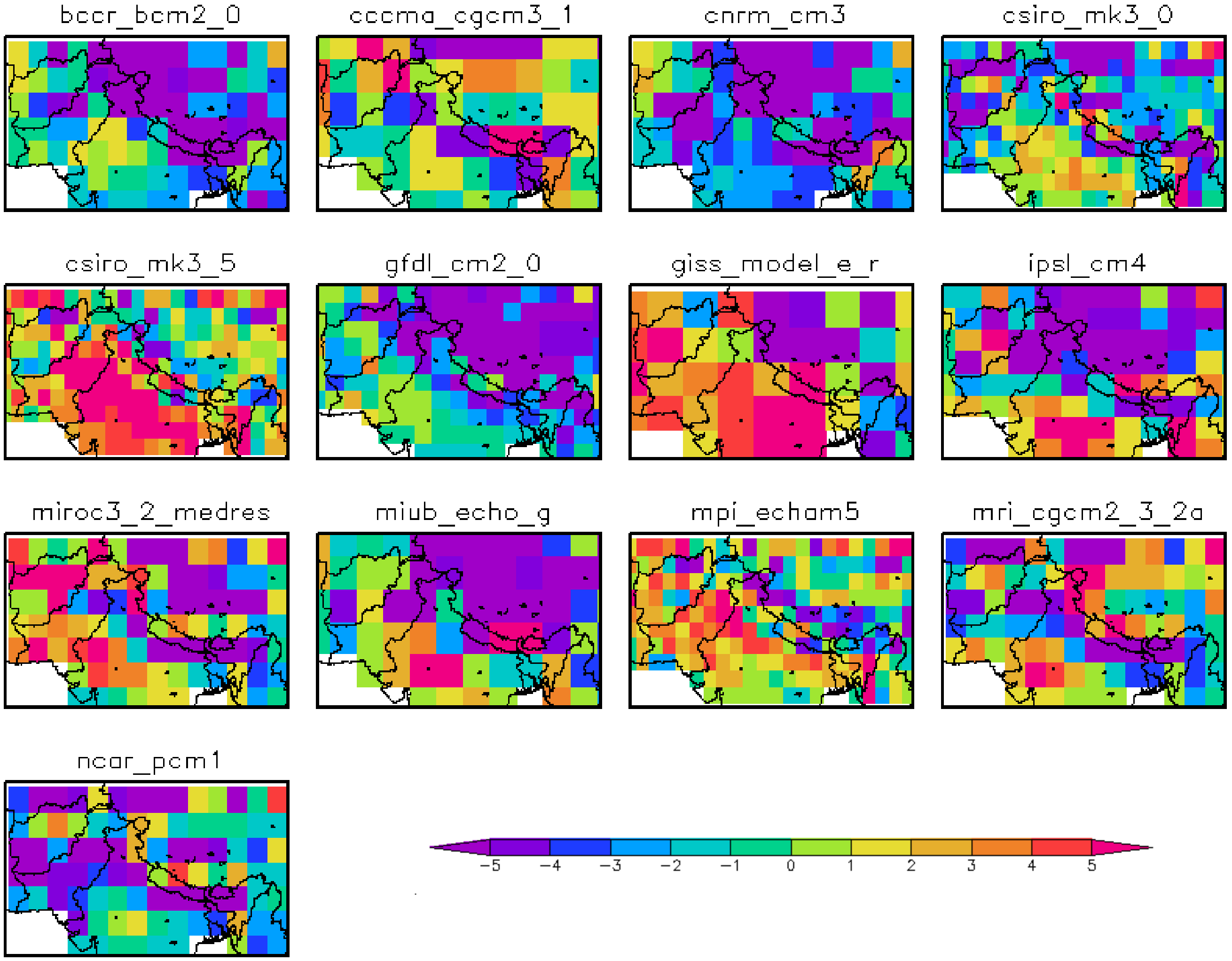
Model Evaluation

- Most models get the general atmospheric flows of the monsoon correct
- All models fail to capture spatio-temporal patterns of precipitation
- Most models fail to capture ENSO and/or IO teleconnections

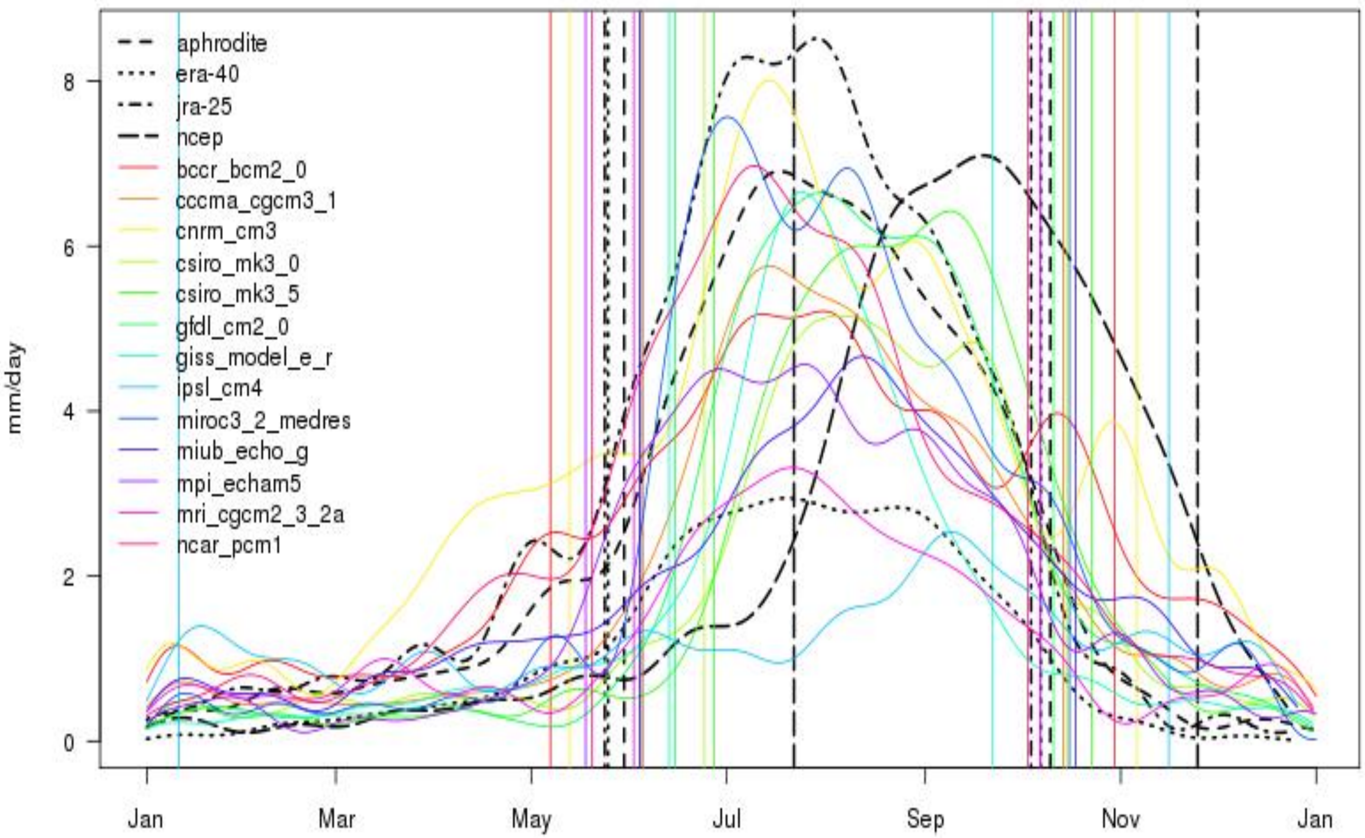
Model Precipitation Bias: Monsoon



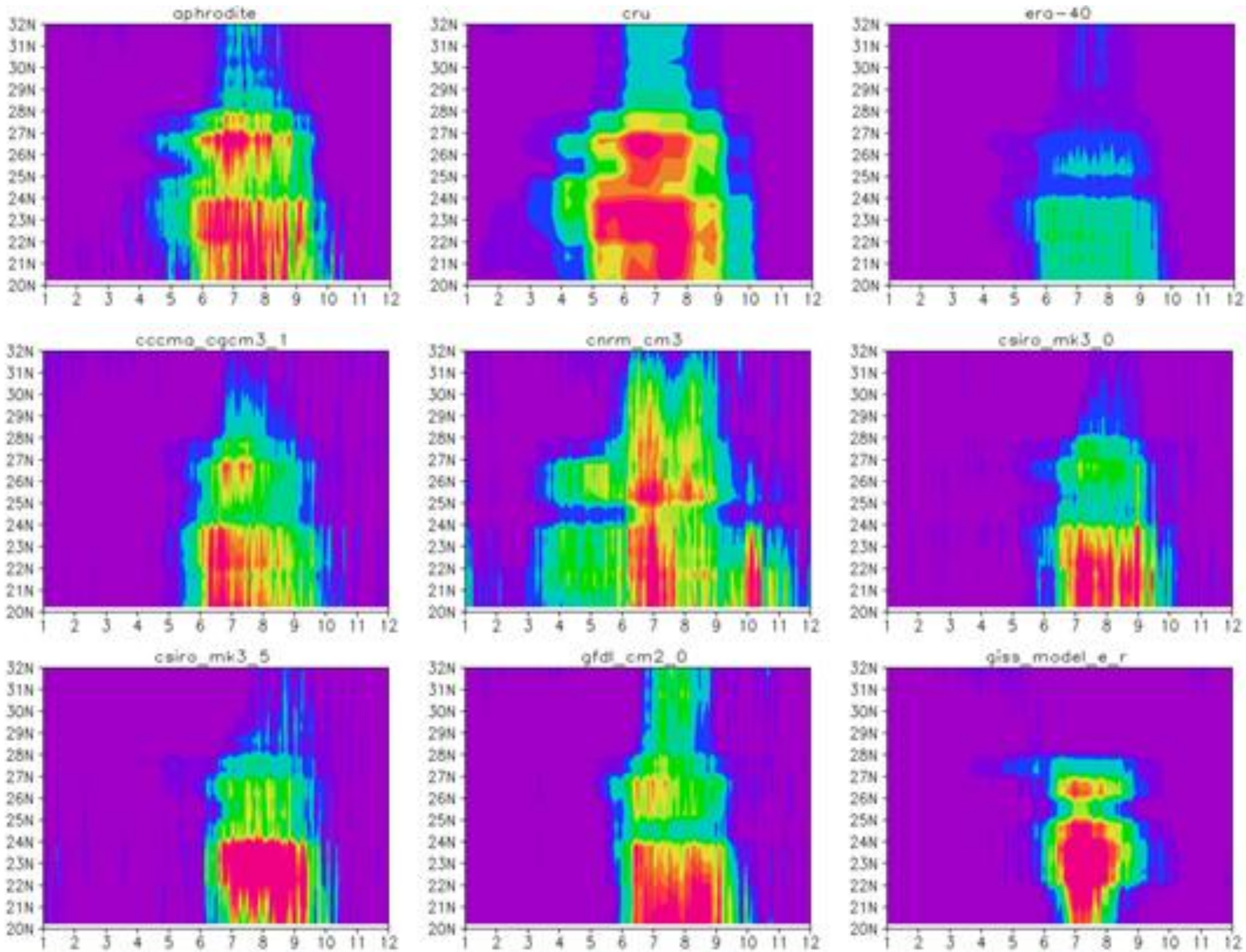
Model Temperature Bias: Monsoon



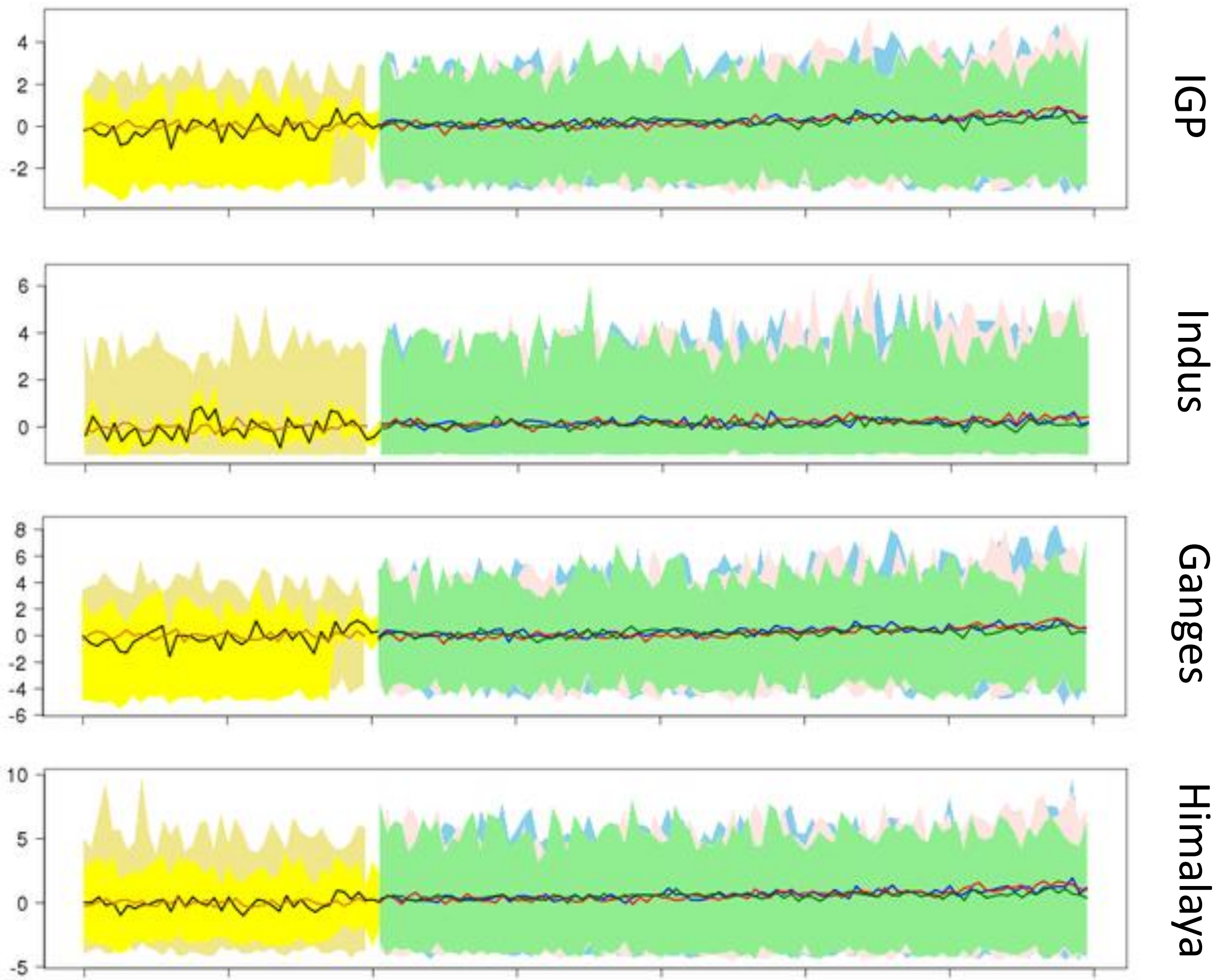
Model Monsoon Rainfall Evolution



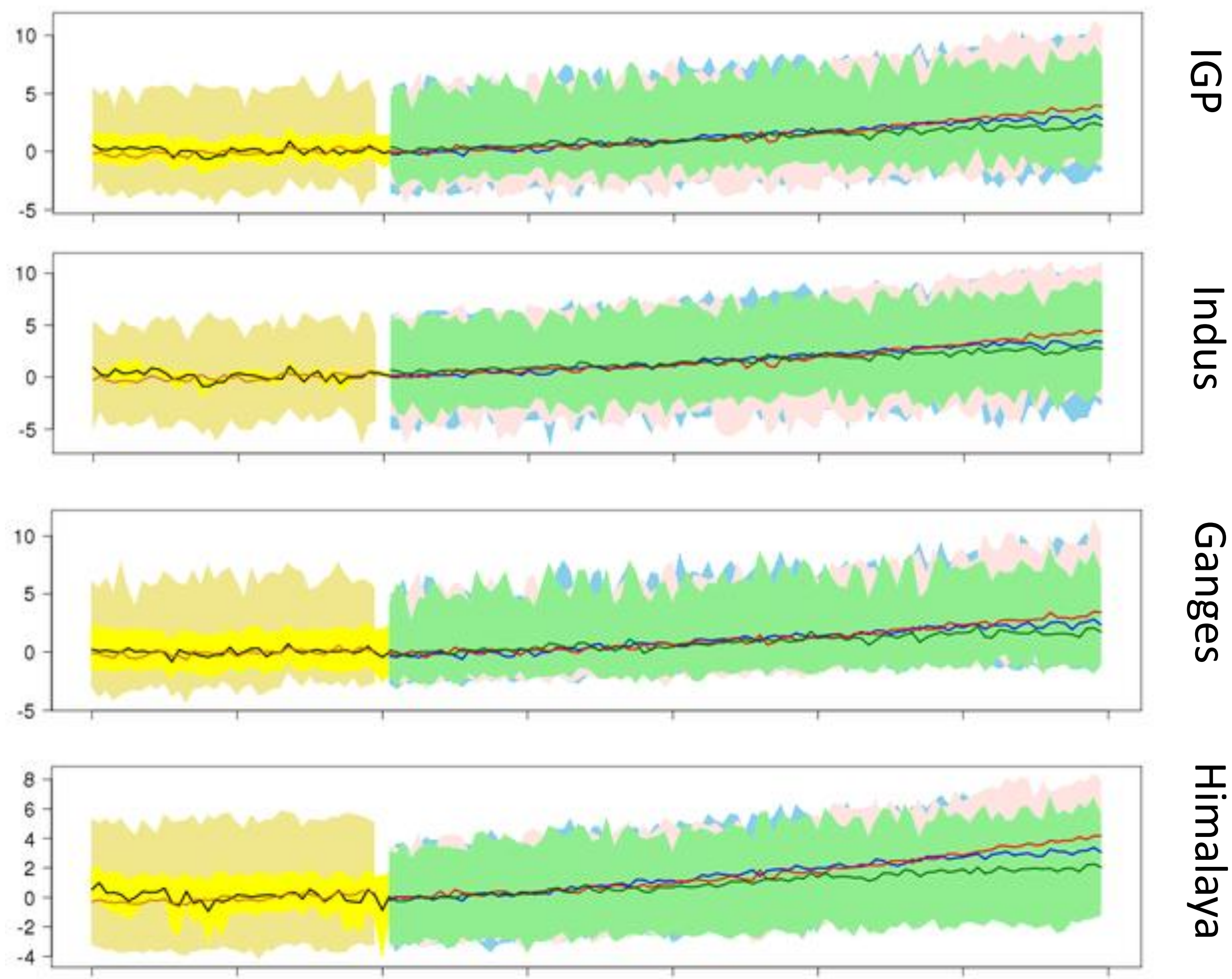
Model Monsoon Rainfall Evolution



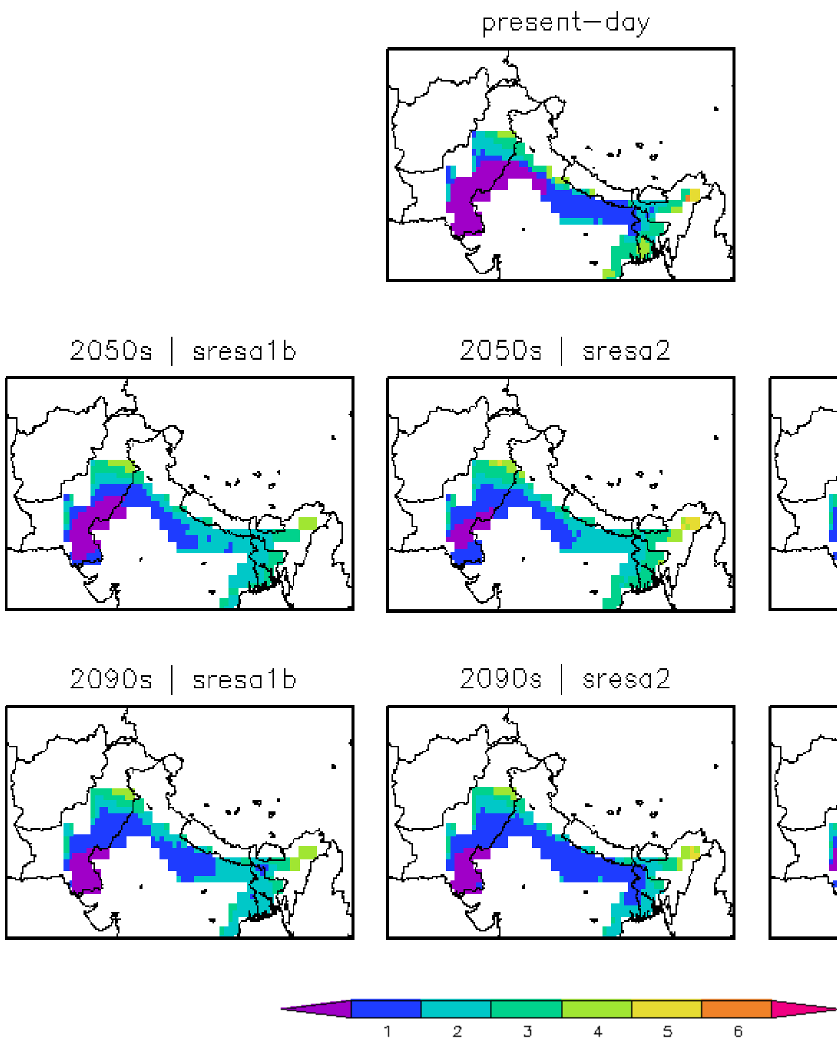
Climate Change Projections: PPT



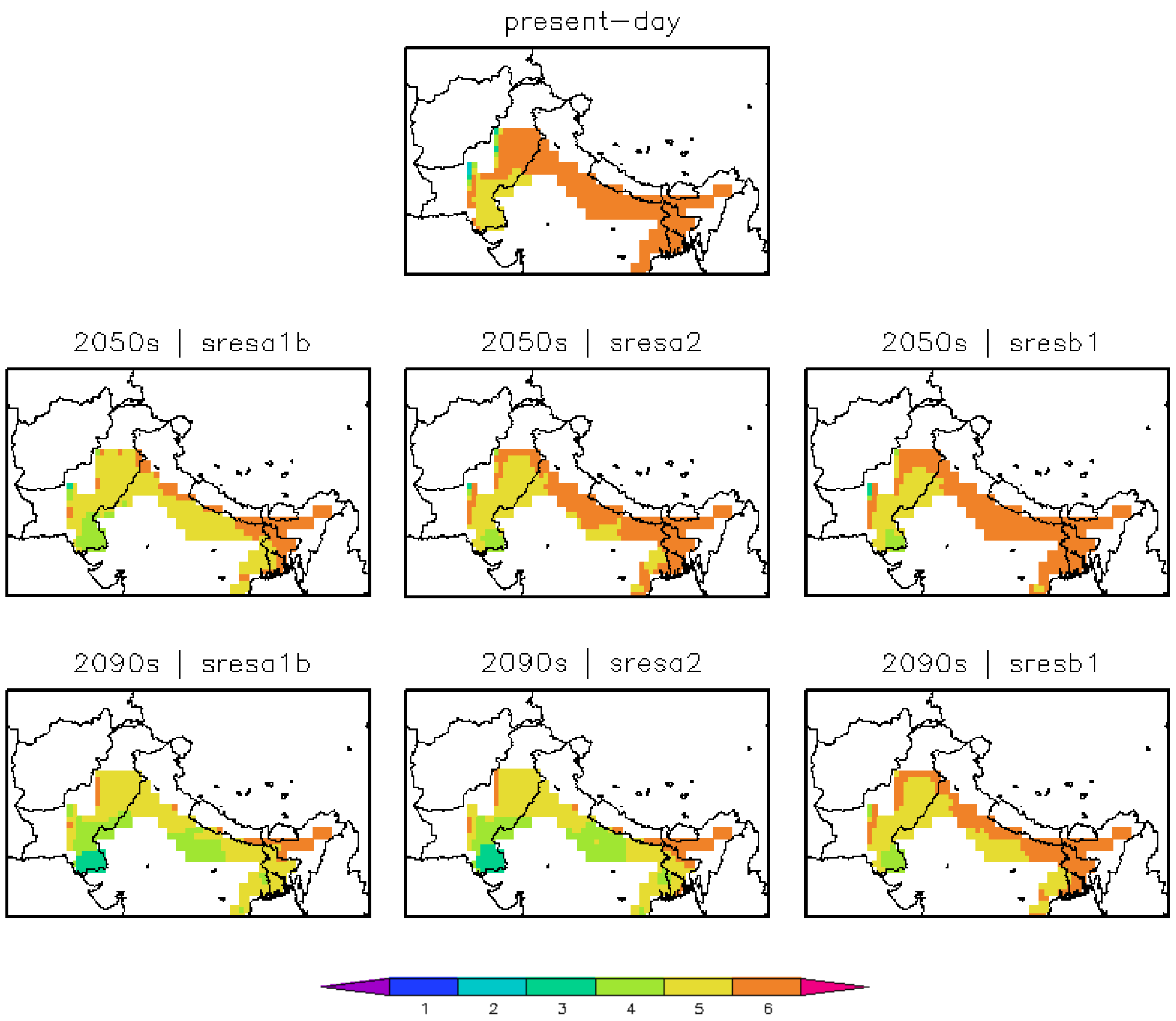
Climate Change Projections: Temp



Crop-climate Suitability: Rainfed Wheat



Crop-climate Suitability: Irrigated Wheat



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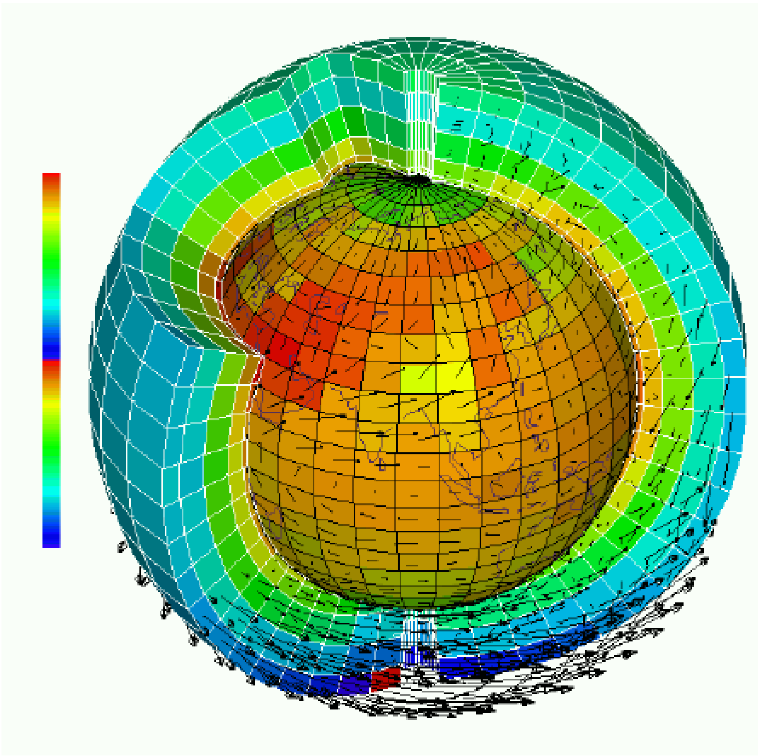
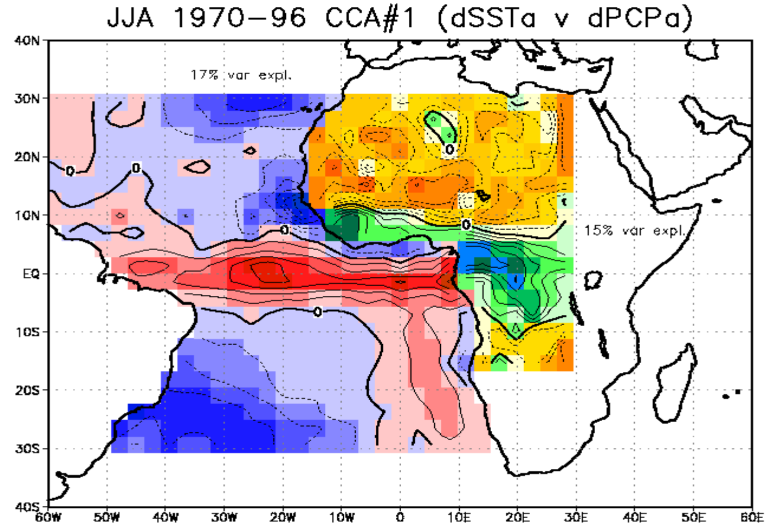
CMIP5:
21 modelling groups
40+ models



Primary Group	Country	Model	Primary contact
CAWCR	Australia	ACCESS	Tony Hirst
BCC	China	BCC-CSM1.1	Tongwen Wu
GCESS	China	BNU-ESM	Duoying Ji
CCCMA	Canada	CanESM2, CanCM4, CanAM4	Greg Flato
CCSM	USA	CESM1, CCSM4	Jim Hurrell
RSMAS	USA	CCSM4(RSMAS)	Ben Kirtman
CMCC	Italy	CMCC-CESM, CM, & CMS	S. Gualdi, C. Cagnazzo
CNRM/CERFACS	France	CNRM-CM5	D. Salas-Mélia, L.Terray
CSIRO/QCCCE	Australia	CSIRO-Mk3.6	Leon Rotstayn
EC-EARTH	Europe	EC-EARTH	Wilco Hazeleger
MPI-M	Germany	ECHAM6/MPIOM-HR & LR	M. Giorgetta, S. Legutke
?	China	FGOALS-G2.0, S2.0 & gl	Tianjun Zhou
GFDL	USA	GFDL-HIRAM-C360, C180, CM2.1, CM3, ESM2G, ESM2M	R. Stouffer, T. Delworth, B. Wyman, L. Horowitz
MOHC	UK	HadCM3, CM3Q, GEM2-AO, GEM2-ES	Mat Collins, Chris Jones
NMR/KMA	Korea / UK	HadGEM2-AO	Hyo-Shin Lee
INM	Russia	inmcm4	Evgeny Volodin
IPSL	France	IPSL-CM5A-LR, CM5A-MR, CM5B	Jean-Louis Dufresne
MIROC	Japan	MIROC5, 4m, 4h, ESM, ESM-CHEM	M. Watanabe, S. Emori, M. Ishii, M. Kimoto, A. Abe, M. Kawamiya, T. Nozawa
MRI	Japan	MRI-AM20km, AM60-km, CGM3, ESM1	Shoji Kusunoki
NorClim	Norway	NorESM	Trond Iversen / Mats Bentsen
NASA/GISS	USA	GISS-E2-H, GISS-E2-H-CC, GISS-E2-R, GISS-E2CS-H, GISS-E2CS-R	Gavin Schmidt
NASA/GSFC	USA	?	Max Suarez



Models used in seasonal prediction are useful for tracing errors in climate models because the models can be evaluated against real, historical events.

Figure above shows error in model precip which is associated with an SST error ***Goddard & Mason***, *Climate Dynamics, 2002*

too warm in the tropics = too wet in the tropics and too dry in the Sahel

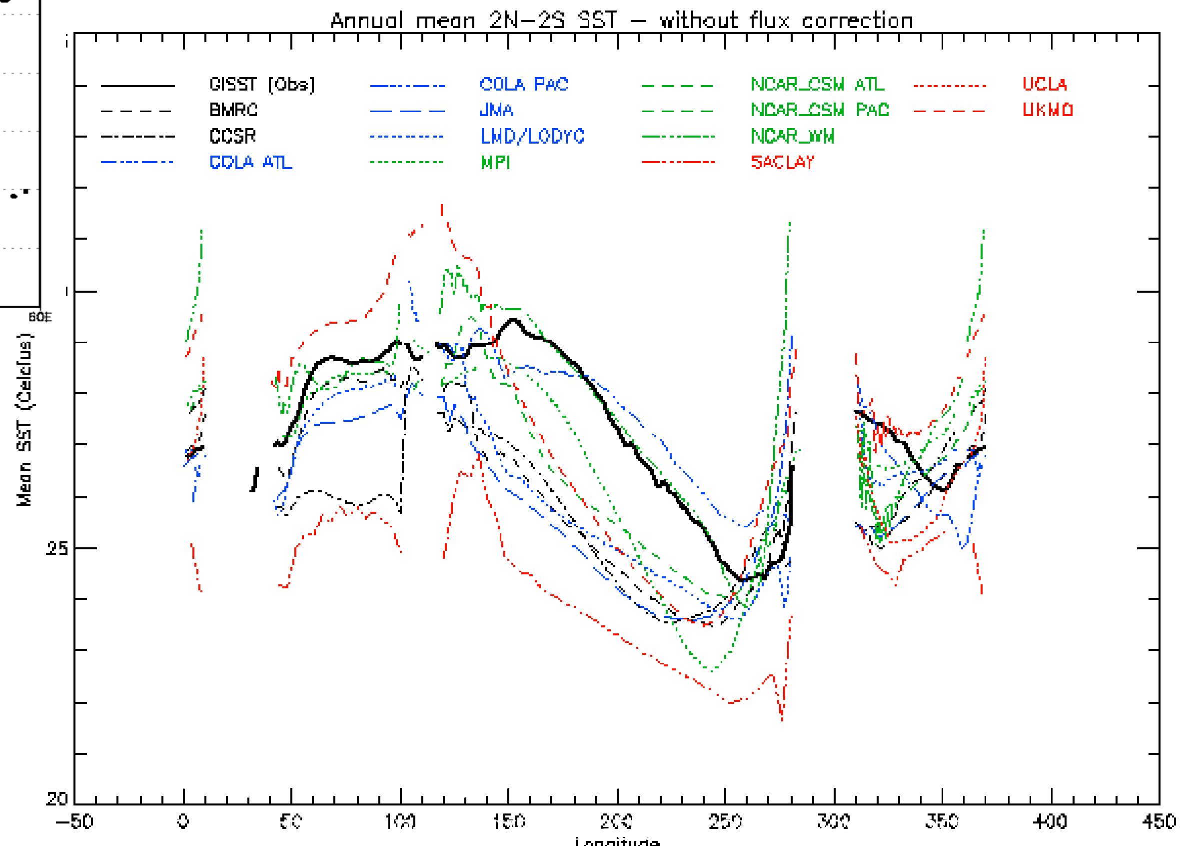
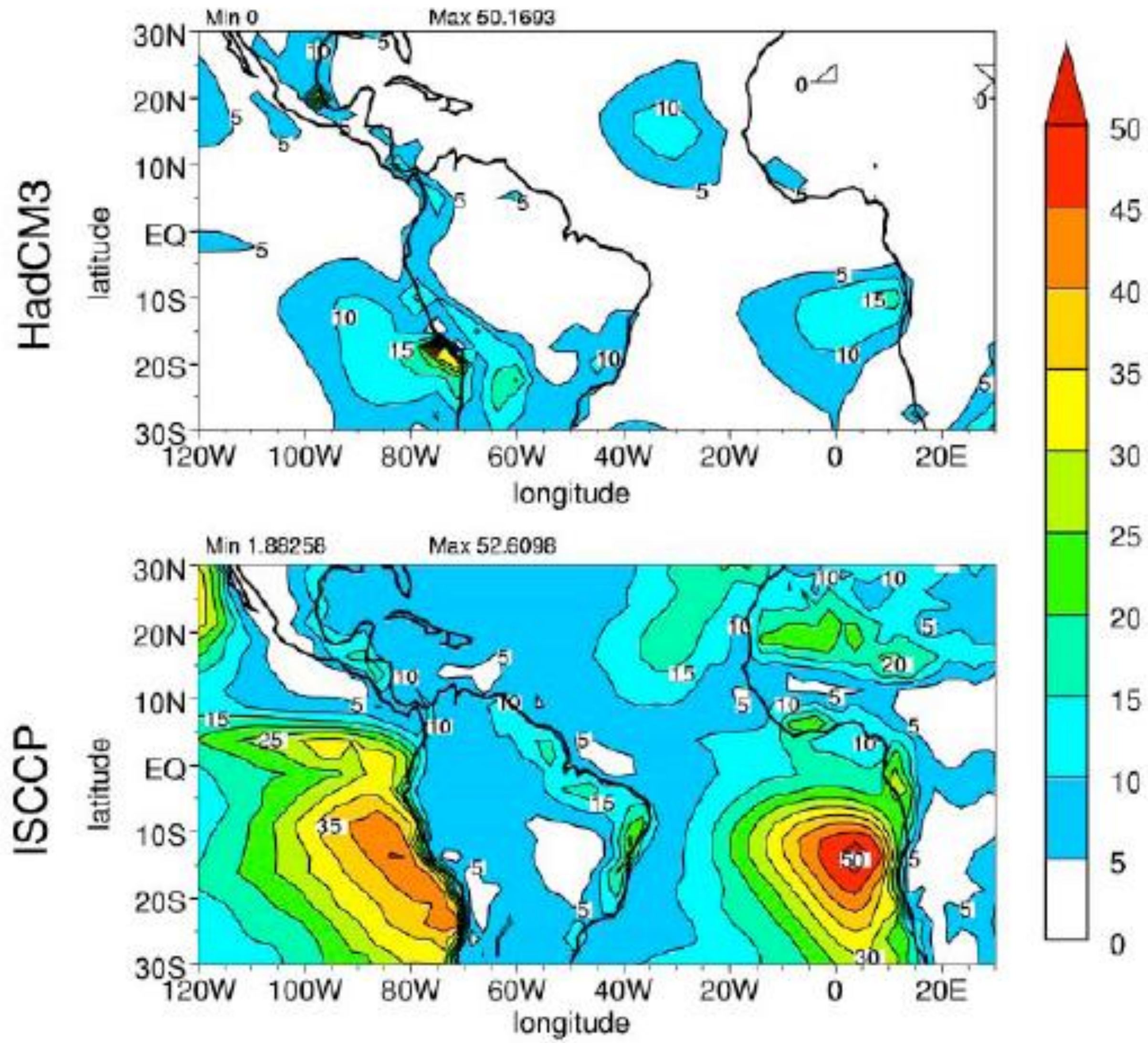
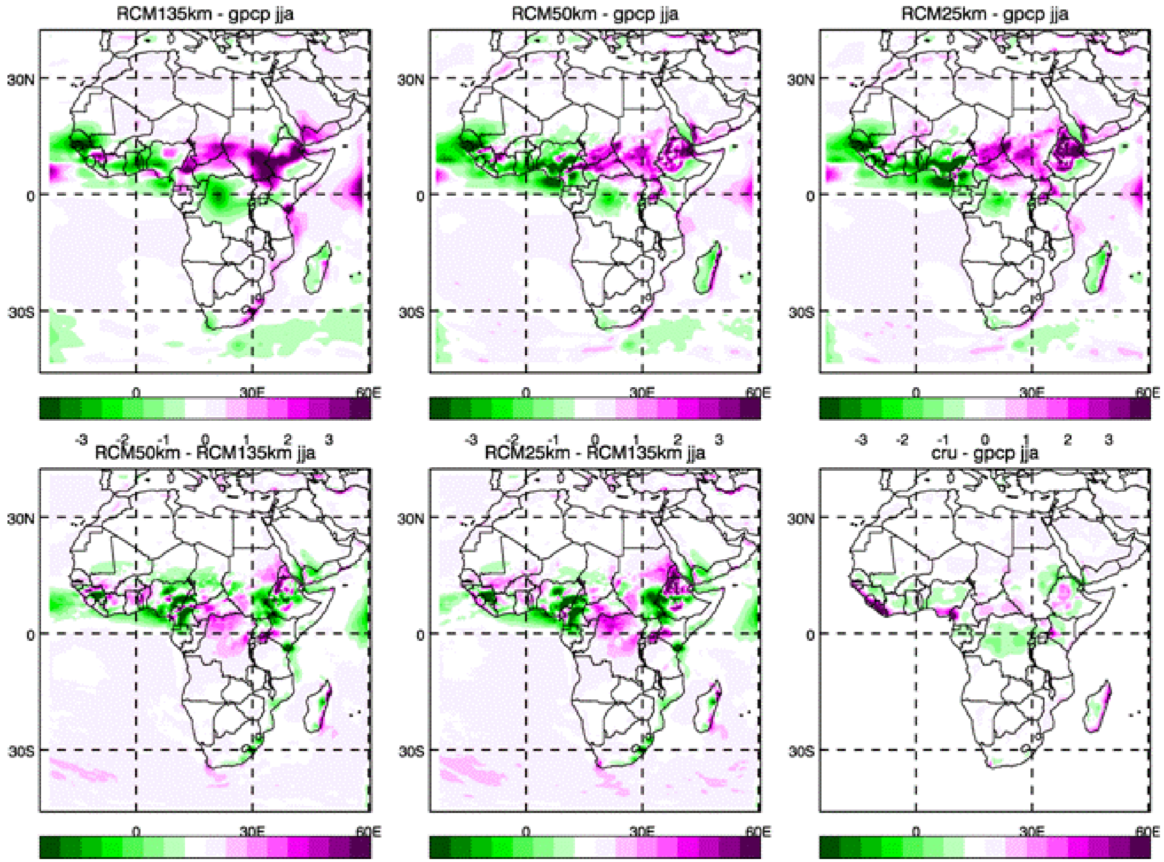


Figure above shows SST values for observed (black) and several coupled models across the equatorial oceans. In the Atlantic, all models have an SST gradient from east to west (warm to cooler). The observed is opposite. The SST error can be traced to stratus clouds in the subtropics – see next slide

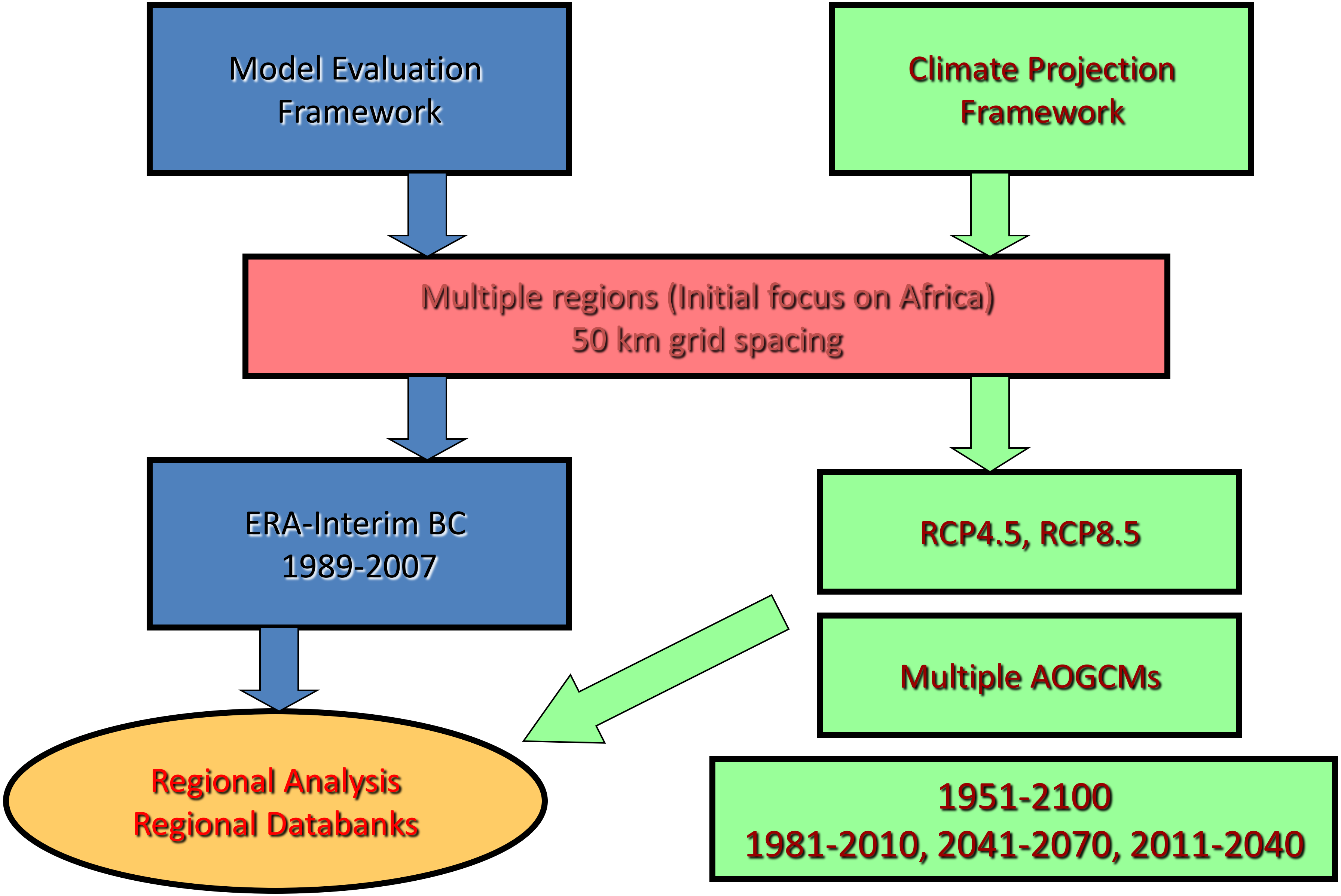
HadCM3 errors in simulating marine stratocumulus

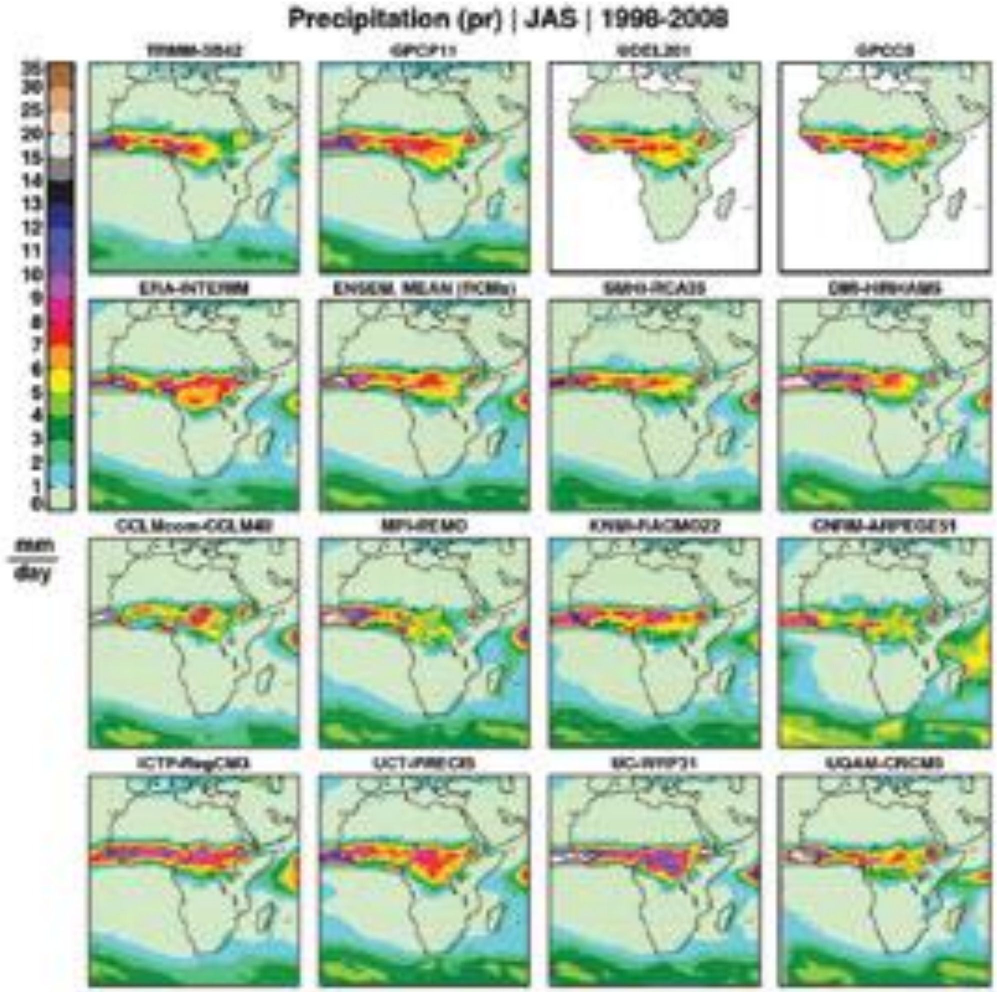




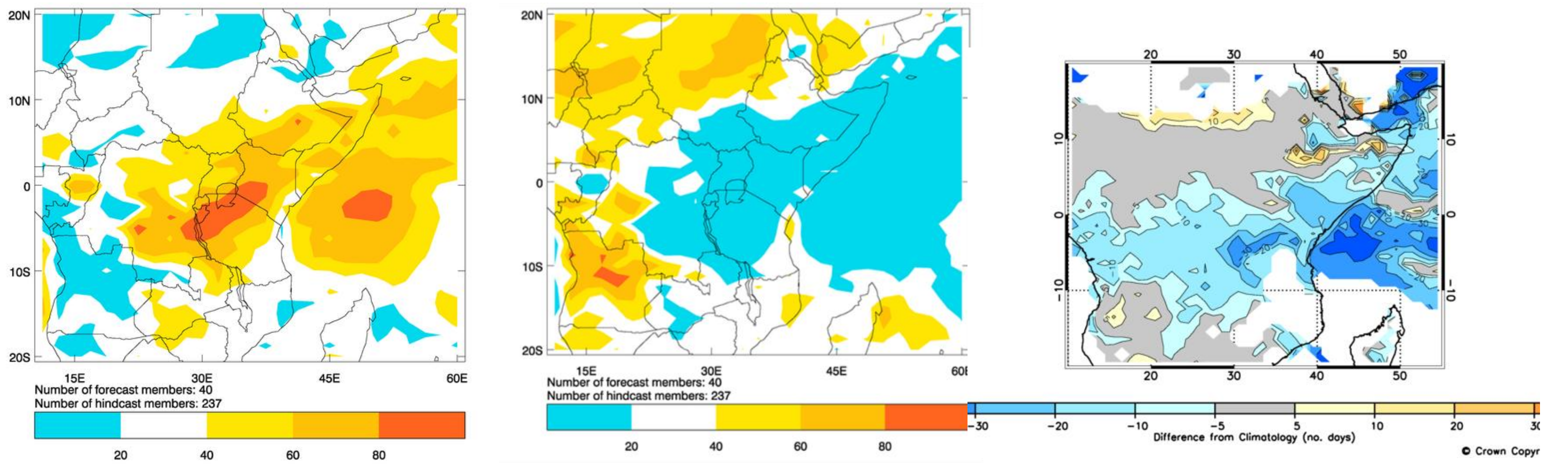
Top: Average (1990-2006) June-August precipitation biases (mm/day) from GPCP for regional model simulations at 135km, 50km, and 25km horizontal resolutions. Bottom: differences between precipitation obtained with 50km and 25km resolution with those obtained at 135km resolution and (right) observational uncertainties approximated by the differences in the CRU and GPCP datasets.

CORDEX Phase I experiment design





CORDEX Precipitation July-September climatology
Met Office CSRP

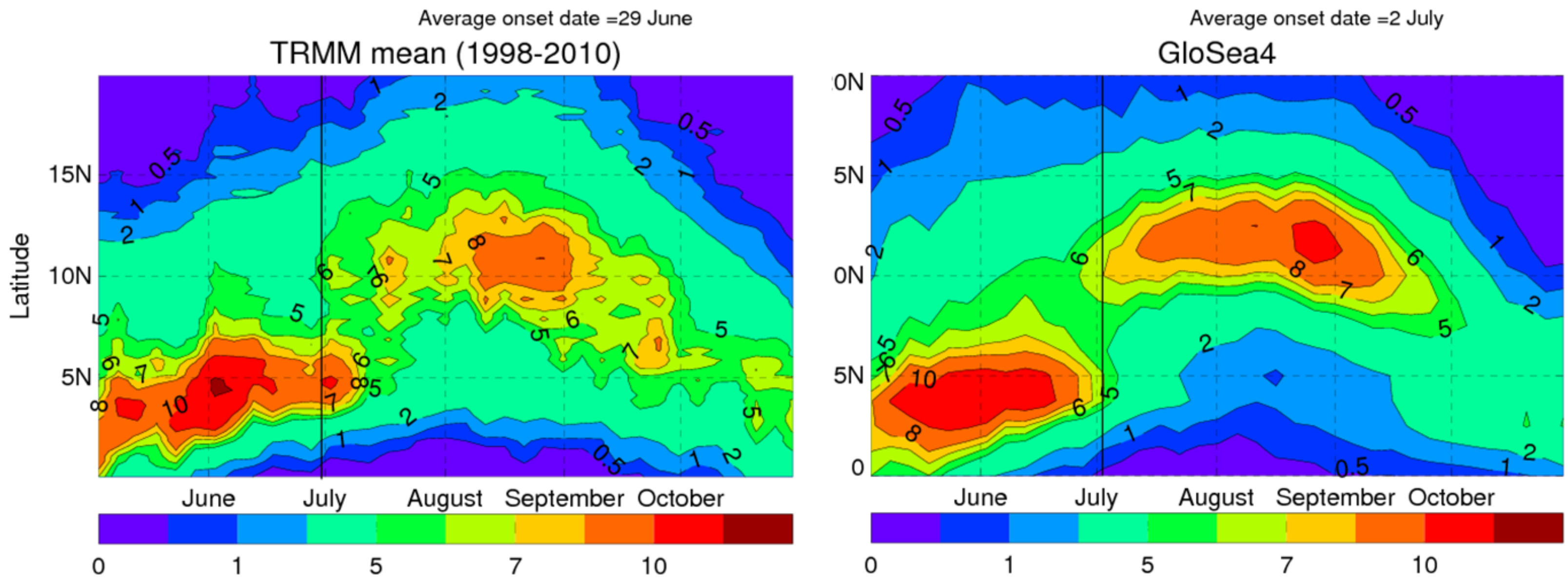


Forecast probabilities issued in August 2011 for early (left) and late (middle) onset of the East Africa October to December rain.

A three category definition of early/average/late onset is used such that the a priori probability of each is 33%. Thus yellow-red colours indicate a predicted enhanced probability (>40%) of the category and blue colours indicate a diminished probability (<20%). Observed onset date in days difference from the climate average. Blue shading = early onset, red shading = late onset.

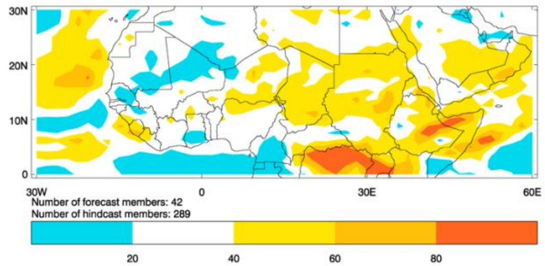
Observations are from the CPC FEWS-NET daily precipitation estimates dataset (climatology = 1995-2010).

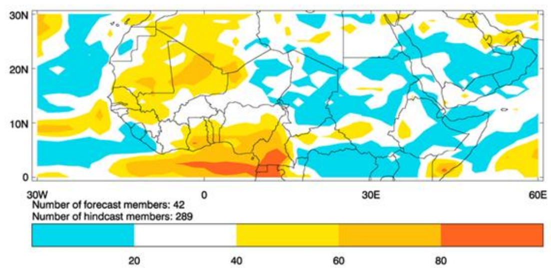
Met Office Experimental Onset Forecasts
Courtesy Michael Vellinga

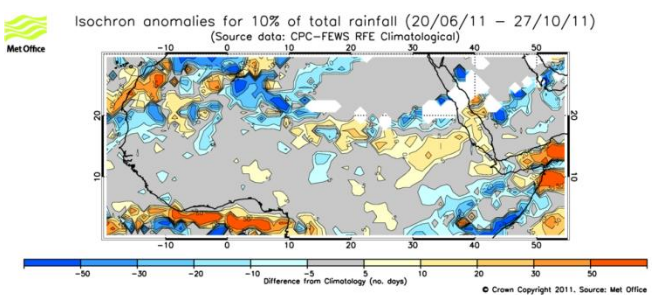


Evolution of the WAM as observed by TRMM measurements, 1998-2010 (left) and in the GA3.0-based GloSea4 seasonal hindcast climatology.

Met Office Experimental Onset Forecasts
Courtesy Michael Vellinga







Forecast probabilities issued in June 2011 for early (top) and late (middle) onset of the West Africa season (July-September).

A three category definition of early/average/late onset is used such that the a priori probability of each is 33%. Thus yellow-red colours indicate a predicted enhanced probability (>40%) of the category and blue colours indicate a diminished probability (<20%). Bottom: observed onset date in days difference from the climate average. Blue shading = early onset, red shading = late onset.

Observations are from the CPC FEWS-NET daily precipitation estimates dataset (climatology = 1995-2010).

Met Office Experimental Onset Forecasts
Courtesy Michael Vellinga

Facing up to the demands of resolution, complexity and uncertainty in Earth System Modelling: Is there a choice?