Climate Change Impact on Growing Seasons in the Ethiopian Highlands and the Surrounding Lowlands

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Introduction

1.1 Background

Climate change is a major development challenge in Ethiopia unless adaptation measures are implemented Ethiopia has seen droughts in the recent half century (Alebachew and Bewoket, 2011) caused by late onset and early cessation of seasonal rains and associated failure of the crop growing season. Hence, to optimally utilize the seasonal rainfall for agricultural production, additional knowledge is needed on how shifts may affect yields and the ability to predict the start, length and end of growing season is vital.

Moreover, improved forecasts of seasonal precipitation with high spatial resolution could potentially increase agricultural production and reduce production risks (Robertson et al. 2007). Therefore, to predict spatial and temporal precipitation, temperature and the connected growing seasons are crucial for livelihoods dependant on rain-fed agriculture.

2. Research design and Methodology

Location of the study area

1) The Ethiopian highlands with lat. 7-14^0 and long. 36-40^0
2) Eastern Ethiopia lowlands with lat. 3-14^0 and long. 40-48^0
3) Western Ethiopia lowlands with lat. 3-14^0 and long. 33-36^0
4) Southern Ethiopia with lat 3-7^0 and long. 36-40^0

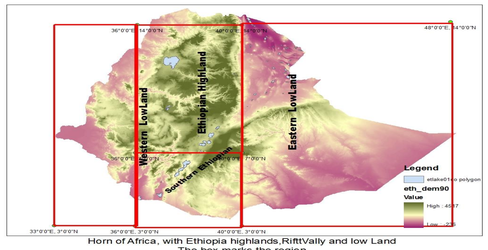
DATA TYPE, SOURCE AND COLLECTION MECHANISMS

Meteorological station in the Ethiopian highland are plentiful (>150), but some stations lack long and continuous records >30 yr. Stations data archived by NMA need to be interpolated using satellite and model to cover the gaps, so for this reason historical data on rainfall and temperature were extracted from gridded GPCC and CRU, respectively. http://pubs.usgs.gov/fs/2012/3053/

The GPCC v6 global precipitation re-analyses were used to describe rainfall variability and trends in the Ethiopian highlands and the surrounding lowlands , after annual cycle validation studies from 1981-2010 showed agreement with reference rain-gauge data from 42 stations in Eastern Amhara (r=0.99).
CRU TSv.3.22
GLDAS NOAH10_M.020-shf (r=0.90)
GLDAS NOAH10_M.020 (sensible heat flux) difference (P-E+1)

climate change models applied for this study are based on the output of model groups of CMIP5 data accessed on (http://cmip-pcmdi.llnl.gov/cmip5) or via Royals Netherlands Meteorological Institute (KNMI)
Step-wise criteria used to evaluate CMIP5 model outputs

To project the future PET of the Ethiopian we employed GLDAS NOAH10-M020 sensible heat flux as a reference to compare with CMIP5 rcp6 models data outputs for sensible heat flux for the Ethiopian highlands.
Following stepwise evaluation the models most likely appropriate to project the future sensible heat flux of Ethiopian highlands is HadGEM2-ES(r=0.94).



Horn of Africa, with Ethiopia highlands,RiftVally and low Land
The box marks the region
lat 33-48E and long 3-14N North-West Ethiopia

Methods used in the data analysis

No	Activity	Methods applied	Climate variables required/ acquired
1	Data collection gridded observed data Models simulated data Station data	GPCC V6 and CRU TS v3.32 gridded observation data from Climate Explorer website (climexp.knmi.nl) CMIP5 web page: http://cmip-cmdi.llnl.gov/cmip5 or via Climate Explorer website (climexp.knmi.nl) For soil moisture ecv_sm_contact@ipf.tuwien.ac.at http://ldas.gsfc.nasa.gov/ MERRA-Land http://podaac.jpl.nasa.gov/grace http://isdc.gfz-potsdam.de/grace NMA and secondary data document	Tmax, Tmin, tas, (Pr)precipitation, sensible and latent heat flux, soil moisture and PET
2	Clustering in to homogenous zones	EOF	GPCC V6-precipitation
3	Models validation	Stepwise evaluation	Pr, Tmax, shf, lhf, P-E and soil moisture
4	Analysis of climate change, climate variability and extremes	Statistical descriptors (mean, range, sd, percentiles) CV, SRA, PC, SCDI	Tmax, Tmin, tas, pr, onset, offset date and LGP, PET and soil moisture
5	Trend test	Regression-test	Tmax, Tmin, tas, pr, onset, offset date, LGP and PET
6	Onset Date, cessation date and length of growing period (LGP) of the past (1981-2010) and the future (2011-2040)	Soil moisture/ P- PET/lag+1	Soil moisture, PET, Tmax, Tmin, tas. shf, lhf and Rainfall
7	Assessing impact of climate change on length of growing season	CV, percentiles, correlation, sd	Soil moisture, PET, Tmax, Tmin, tas. Shf, Rainfall, Onset Date, cessation date and length of growing period (LGP)

Models performance evaluation

No	Cluster	Model	Rainfall stepwise evaluation			Temperature stepwise evaluation			
			GPCC -V6 (r)	GPCC-V6 peak	Pattern	CRU TS3.22(r)	CRUTS3.22 peaks	Pattern	Remark
1	Western lowlands of Ethiopia(WLE)	GISS-E2-H-P3	X	X	X	0.97	0.0	high	Tx-selected
		HadGEM2-ES	0.99	0.4	high	X	X	X	RF-selected
2	Eastern lowlands of Ethiopia (ELW)	bcc-csm1-1-m	X	X	X	0.99	-0.6	High	Tx-selected
		bcc-csm1-1-m	0.91	-0.3	High	X	X	X	RF-selected
3	South Ethiopia (SE)	bcc-csm1-1	X	X	X	0.89	-0.3	High	Tx-selected
		CSIRO-Mk3-6-0	0.98	0.95	High	X	X	X	RF-selected
4	Ethiopian highlands	CCSM4	X	X	X	0.98	-0.5	Highly	Tx-Selected
		HadGEM2-ES	0.97	-0.5	highly	X	X	X	RF -selected

3-Result and Discussion

Climate change comparison

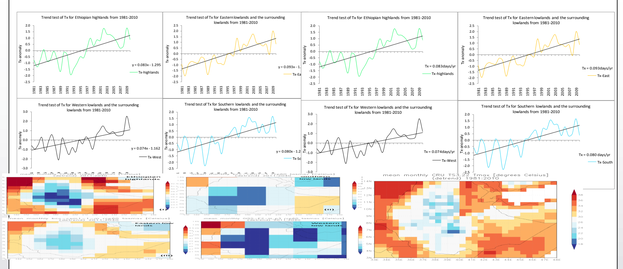
Comparing Temperature

Ethiopian highlands and surrounding lowlands average maximum temperature (0C) projection in thirty years time scale				
Region	Base line period (1981-2010)	2011-2040	2041-2070	2070-2100
Ethiopian highlands	26.4	25.8(-0.6)	26.4(-0.037)	27.1(+0.69)
South-Ethiopian lowlands	28.6	28.3(-0.3)	28.9(+0.3)	29.6(+1.0)
East-Ethiopian lowlands	32.4	32.4(+0.01)	32.9(+0.5)	33.5(+1.1)
West-Ethiopian lowlands	34.0	35.2(+1.2)	36.1(+2.1)	36.7(+2.7)

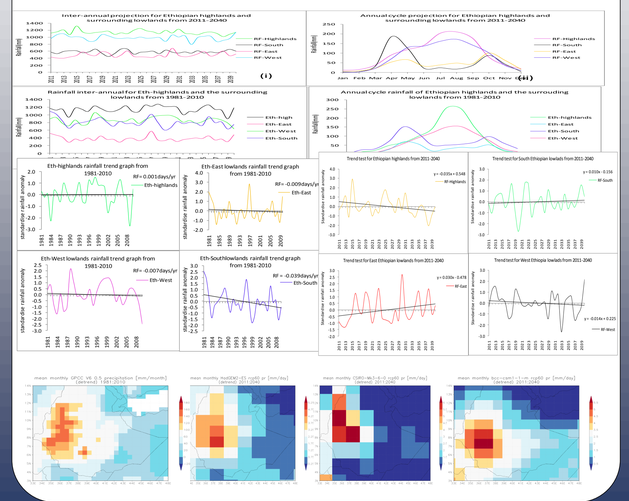
Region	Base line period (1981-2010)	Climatological period 2011-2040 (%)	2011-2040(%)	2070-2100 (%)
Ethiopian highlands	1144	1142(-0.2)	1181(3.2)	1195(4.4)
South-Ethiopian lowlands	809	579(-39.7)	594(-36.2)	672(-20.4)
East-Ethiopian lowlands	383	492(28.4)	544(42)	583(52.3)
West-Ethiopian lowlands	861	983(14.2)	945(9.8)	984(14.3)

Temperature maximum descriptive statistics for Ethiopian highlands and surrounding lowlands from 1981-2010								
Region	Minimum	Maximum	Range	Mean	Stdev	20th percentile	50th percentile	80th percentile
Eth-highlands	24.0	28.5	4.5	26.4	1.5	24.8	26.3	28.2
Eth-East	30.5	33.8	3.3	32.4	1.2	30.9	32.8	33.5
Eth-West	31.0	37.0	6.0	34.0	2.0	31.7	34.0	36.3
Eth-South	26.5	31.3	4.8	28.6	1.5	27.0	28.3	30.4

Tx-descriptive statistics for Ethiopian highlands and the surrounding lowlands from 2011-2040								
Region	Minimum	Maximum	Range	Mean	Stdev	20th percentile	50th percentile	80th percentile
Tx-highlands	25.4	26.4	1	25.767	0.24542	25.6	25.75	26
Tx-South	27.5	28.9	1.4	28.33	0.3515	27.92	28.4	28.6
Tx-East	31.9	32.9	1	32.413	0.28374	32.12	32.4	32.7
Tx-West	34.4	35.9	1.5	35.243	0.44154	34.8	35.3	35.78



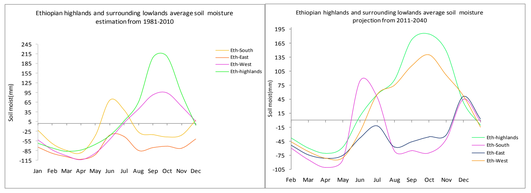
Comparing Rainfall



Comparing growing seasons

Ethiopian highlands and surrounding lowlands average annual cycle soil moisture(lag+1) from 1981-2010												
Region	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Eth-highlands	-62	-76	-87	-83	-65	-38	7	67	203	207	92	-6
Eth-South	-21	-64	-85	-91	-36	72	42	-28	-36	-43	-37	10
Eth-East	-74	-93	-104	-112	-97	-37	-41	-85	-76	-71	-77	-49
Eth-West	-52	-83	-101	-113	-92	-49	1	45	88	94	51	5

Region	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Eth-highlands	-38	-60	-71	-58	9	56	86	172	185	149	39	-12
Eth-South	-60	-85	-101	-85	84	49	-66	-65	-70	-42	45	-2
Eth-East	-54	-74	-81	-75	-38	-12	-57	-47	-36	-32	51	2
Eth-West	-46	-67	-82	-81	-24	55	75	116	140	96	53	-15



Conclusion

This study presents analysis on the comparison of climate change and climate variability and their impact on growing seasons of the past and the future between the Ethiopian highlands and the surrounding lowlands.

Historical observation data from CRUTS 3.22 (temperature) and GPCC V6 (rainfall) and from CMIP5 models groups to predict the future temperature and precipitation CCSM4 and HadGEM2-AS for Ethiopian highlands, bcc csm1-1 and CSIRO-MK3-6-0 for South Ethiopian, bcc-csm1-1-m for Eastern Ethiopia and GISS-E2-H-P3 and HadGEM2-AS for western Ethiopian lowlands respectively data simulation were used as inputs after they have been justified and achieving the most criteria.

The findings of the study shows in Ethiopia there is consistent increasing of max temperature which is in agreement with regression trend analysis also.

The comparison and evaluation of the temperature variability carried out using only maximum temperature (Tx) as Tx is anticipated to occur as the result of climate change shows West-Ethiopia lowland is the hottest region and highly variable, next the East-Ethiopia lowlands and the coldest region the Ethiopian highland and next the South-Ethiopian and the hottest months are April-June all over the country. The spatial distribution of the country Tx temperature looks influenced by the topographic features where the highlands depicted min Tx and the lowlands max Tx.

During the past the Ethiopian highlands were the region with good potential of rainfall, while the East-Ethiopian lowland has a critical rainfall deficit that could not support the livelihood using rain-fed agriculture only. The rest two regions received rainfall to subsist the agricultural crop production at a normal season this is expected to be consistent in the future also.

The seasonal distribution shows the Ethiopian highlands has the maximum JJAS rainfall potential next Ethiopian-West lowlands during the same season. The Ethiopian-South cluster revealed maximum MAM seasonal rainfall and short period SON season rainfall and the vice-versa bi-modal rainfall nature but with poor seasonal rainfall amounts in the Ethiopian-East lowlands.

The regression trend analysis shows decreasing trend in the two potential rainfall regions; the Ethiopian highlands and West-Ethiopian lowlands and increasing trend in the Ethiopian East and South rate of change of rainfall where the rate of changes in the regions are very close to zero.

In the future comparing to the past, however insignificant the Ethiopian-East and South lowlands depicted change of trend from decreasing to increasing but the Ethiopian-West lowlands shows consistent decreasing trend of change.

The spatial distribution of rainfall in Ethiopia is mainly influenced by the movement and position of the weather bearing systems ITCZ and determines the amount of rainfall and the length of the rainy period. I n general, the spatial distribution is in agreement with time series analysis both in the past and in the future, i.e. the Ethiopian highlands with max potential rainfall and next the Western lowlands and the Southern cluster but the Eastern-lowlands will continue to be rainfall deficit areas.

The comparison of length of growing seasons based of the three major soil types sandy, loam and clay) depicted the Ethiopian highlands has suitable growing season with (>4 months/JJAS/) both in the past and in the future.

In the Ethiopian-south cluster the result depicts LGP maximum 2 months /April –May/for sandy soil areas both in the past and in the future while in the remaining two soil has no growing and in the second growing season of the area it is expected only one month /October/ growing season for sandy soil areas shows there was no growing season in the past for all soil types and for loam and clay soil types in the future.

The Ethiopian –East lowlands that mainly comprise the Afar and Somali regions are to face rainfall deficit consequently there are no seasons that could support the rain-fed agriculture both in the past and in the future (except one month on October).

In the Ethiopian-West lowlands sandy soil area the average maximum LGP 4 months /June-September/ and in the future maximum LGP 6 months / May-October/ in sandy soil areas and in loam soil areas maximum LGP 3 months /August-October/ but no growing seasons for loam and clay soil areas in the past and for clay soil areas in the future.

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