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Trans-SEC scenario definition and framework report

Gornott, C., Hattermann, F., Nkonya, E., Herrmann, L., Graef, F., Tumbo, S. Kahimba, F., Mutabazi, K., Uckert, G., König, H. J., Lana, M., Schaffert, A., Germer, J., Asch, F., Silayo, V., Makindara, J., Lambert, C., Kinabo, J.

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14.07.2017

Milestones and Deliverables

D8.1.3 Report on the scenario framework (month 32) and up-date report on scenario implications on the outcomes of WP2–WP7 (month 32, 50) (**PIK, ZALF, IFPRI, SUA, IUW**, UHOH, ARI, DITSL, MVIWATA, TFC, ACT)

Content

1. Introduction and summary

What are climate change risks for bio-physical and socio-economic development in Tanzania up to 2030, 2050, or 2090? What will be the consequences of those changes for human well-being?

This document provides a definition of potential climate change scenarios and its consequences on bio-physical and economic conditions. The purpose of document is to give an overview of possible scenarios for Tanzania and the Trans-SEC case study sides (CSS). This includes different storylines of bio-physical and economic development changes. These storylines are used to assess the climate change risks for the bio-physical and economic conditions in Tanzania. The first part of the document gives a general overview of climatic change and its bio-physical consequences; in the second part, research field specific contents regarding the upgrading strategies (UPS) are given as result of the workshop of the annual Trans-Sec meeting and a survey to the UPS responsible persons. This part summarizes the knowledge of the sector specific Trans-SEC experts. Within the Trans-SEC group and beyond, this document can be used as guideline for the utilization of climate, bio-physical and socio-economic scenarios.

The scenarios will be used differently among WPs and tasks. However, criteria for storylines considered within the scenarios should be specific enough for the application in the whole food value chain and should allow many tasks to be adopted within. Furthermore, the scenarios should provide the opportunity to connect/ compare them with other scenario studies (e.g. ISI-MIP scenarios). For some WPs, the scenarios may corroborate own results, while in other cases, models can be directly applied with this scenarios.

In the following, the document will introduce a definition of all relevant terms. In the second part, the document gives an overview of the baseline scenario and two further scenarios to be discussed and confirmed. For each scenario, the document gives an overview of related elements, the possible impacts of climate change, and effects of bio-physical and economic conditions. The Third and fourth part shows the different climate scenarios and its application. In the last part, the document shows the effects of climate change within the food value chain/ UPS.

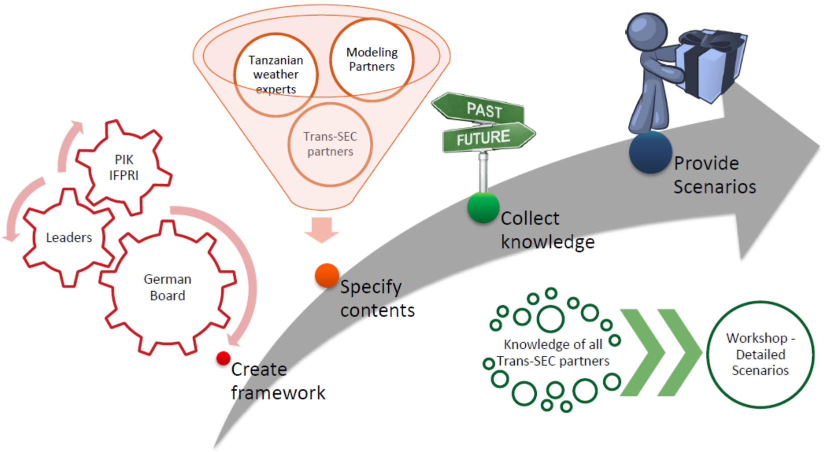

Fig. 1: Providing of the scenario data in four steps to the Trans-SEC members: (1) Create framework, (2) Specify contents, (3) Collect knowledge, and (4) provide data.

2. A baseline and two other scenarios

Due to changing climate pattern around the word, Tanzanian natural resources, livelihood, and economy will be influenced respectively. Generally, the climate has a strong impact of bio physical and socio economic conditions in Tanzania. Thus, an impact assessment of changing Tanzanian climate conditions is curtail for future assessments of physical and socio economic conditions. Therefore, climate scenarios with different possible futures can be used to map the rage of different pathways of climate change mitigation. These different pathways have different realizations of future climate change. Depending on the realization and the scenario, the expected changes are an increasing temperatures and regional changing precipitation patterns.

2.1. Definition

In the following, the relevant terms will be introduced.

(1) Driving forces of the scenarios:

The IPCC gives an overview of the major driving factors. These are:

  i. Population growth (fertility, health (HIV/AIDS, malaria, yellow fever))
  ii. Economy (economic growth, per capita income)
  iii. Technology (breeding, technological change)
  iv. Energy (renewable or fossil energy)
  v. Land-use (direct and indirect land-use change)
  vi. Agriculture (livestock, management practices, …)

(2) What are storylines and what are scenarios?

Scenario: a description of a potential future, based on storyline. **Storyline:** a narrative description of a scenario highlighting the main scenario characteristics, relationships between key driving forces, and the dynamics of the scenarios (source: IPCC).

The impacts of climate change have been transformed into storylines as such. By this, several climate change scenarios are grouped into few broader storylines. That means, storylines represent a pathway, like intensification of the economy, while scenarios are integrated in these storylines.

(3) What is risk assessment?

Risk is the product of a negative incident and the probability that these incident occurs. The assessment describes the damage of an occurring negative incident.

(4) Climate change Climate change in IPCC usage refers to a change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties for an extended period (decades or longer). It refers to any change in climate over time, whether due to natural variability or as a result of human activity.

(5) Bio-physical risks of climate change:

e.g. reduced water ability, reduced aquaculture production, biodiversity loss, deforestation, desertification, decreasing crop yield.

(6) Economic risks of climate change:

e.g. income loss, malnutrition and food security, adaptation and mitigation costs (cost benefit analyses), disparity of energy supply & demand (increasing carbon footprints).

(7) The temporal dimension of the scenario analysis are 10 (2025), 25 (2040) and 50 (2075) years (workshop during the Trans-SEC annual meeting 2014).

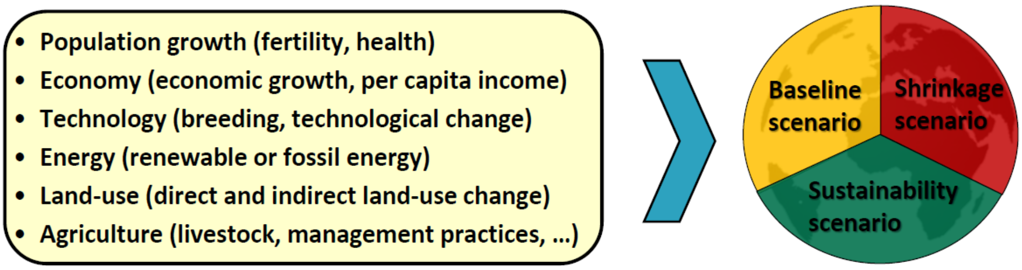

Fig. 2: Driving forces by changing climate conditions

2.2. Baseline scenario

The baseline is the continuation of current trends (hence not a still stand in absolute terms but a development using current trends). At this point, it is important if current trends are limited by natural circumstances (e.g. water demand for agriculture (irrigation) higher than available water).

Elements are:

- Slow economic growth (in particular in the agricultural sector)
- Low agricultural production (crop yields and livestock output)
- Losses during the food value chain (FVC): Waste and spoilage during food and crop production, storage, transport, and processing

Effects of climate change: increasing temperatures, increasing precipitation in the north (west) of Tanzania, constant precipitation in the south of Tanzania (no change): CMIP5 GCM - RCP8.5.

Effects on bio-physical conditions: Decreasing soil nutrients contents, soil degradation, nutrient immobility, low agricultural yields, deforestation, erosion

Effects on economic conditions: low food security and household income, malnutrition

2.3. Sustainability scenario

The sustainability scenario is a moderate development scenario. Some expansion is covered by it, though, sustainability criteria will qualify these activities, giving it a less accelerated speed, a more cautious reasoning and system optimization where also mid-term and long-term aspects count.

Elements are:

- The water use efficiency increases (a set of technologies)
- The concept of multiple water uses is respected (enough water for irrigation and to provide water)
- Wastewater treatment plants will be widely installed
- Extreme events (droughts, floods) could be moderate by adaptation
- Higher production based on higher yield and not on land-use change from deforestation
- Ban of deforestation maintains C storage (for forest area)
- Carbon stocks will be maintained and increased (e.g. by soil amendment, biochar, improved soil management, benefits from the biodiversity and ecosystem services)
- Nutrient cycles will be improved (e.g. applying manure in cropping, feeding crop by-products to livestock, applying mixed cropping with legume)
- Improving the post-harvest management (establishment of an storage system) to avoid famine
- Other forms of electricity generation will be increased (hydropower, wind, solar)
- Calorie demand for the increasing population will be met by the domestic production

Effects of climate change: small temperature increase, precipitation increase (e.g. CMIP5 GCM – RCP4.5). Additionally, we also test whole range of climate change scenarios to show the impact for a global shrinkage scenario and sustainable condition (best practice) in Tanzania at the CSS. → Are the CSS able to compensate the worse (extreme scenarios (RCP 8.5)) conditions?

Effects on bio-physical conditions: soil fertility increase, climate smart agriculture: (stable) crop yields and production (rainfed and irrigated) increase and the volatility of these yields decrease, CO_2 fertilization effects, reduction of greenhouse gas emissions, of biodiversity loss, and of water- & environment pollution by plant protection and fertilizer.

Effects on economic conditions: raising food security, increasing rural income, less losses during the FVC, decrease of malnutrition.

2.4. Shrinkage scenario

The shrinkage scenario reminds that things can also go worse (wrong?) - An overall decline (development mainly based on short-term economic advantages and heavily relies on investments).

Elements are:

- Water uptake from the river increases, returned water carries nutrients (N) and pesticide residues
- Soil degradation (nitrogen and phosphor loss , salt stress at arid soils)
- Unilateral and unbalanced nutrient management (leaching, Al-toxicity)
- Unappropriated plant protection (ground water pollution, residues in food)
- Environmental damage goes along with cuts in the livelihoods of most people
- More arable land from land-use change is used for production increase
- Irrigated cropping increases (intensification per unit land and expansion of total land area)
- The area of cash crops (e.g. for fuel) increases (money for investments comes from foreign enterprises and governments, decreasing of food security)
- Productivity of livestock farming increases

Effects of climate change: the range of uncertainty of climate change in SSA given by the current set of climate scenario runs pointing at shorter rainy season, more droughts, and less precipitation.

Effects on bio-physical conditions: soil fertility decrease, higher yield volatility, desertification takes place because of deforestation, brackish water hampers agricultural activities, erosion triggered by monoculture and diffuse pollution of water from intensive agriculture, land-use change (increasing acreage for arable crops), environmental damages due to intensification of plant protection (pesticides) and unilateral nutrient application.

Effects on economic conditions: decreasing food security and decreasing rural income because of high losses within the FVC, unbalanced property rights, exported cash crops (food, feed, fuel) by foreign enterprises.

3. Underling climate scenarios/ data base

The following scenarios are a selection of different pathways (from different other projects). The final selected database for the scenarios will be carried out by the discussion within the WPs and tasks.

RCP scenarios

The Task Group 'RCP Concentrations Calculation and Data' harmonised and consolidated greenhouse gas concentration and emission datasets for the pre-industrial control runs, 20th century, and the Representative Concentration Pathways (RCPs). The mixing ratios for the long-lived greenhouse gases provided below are the CMIP5 recommendation for Earth System Models in preparation of the IPCC Fifth Assessment Report.

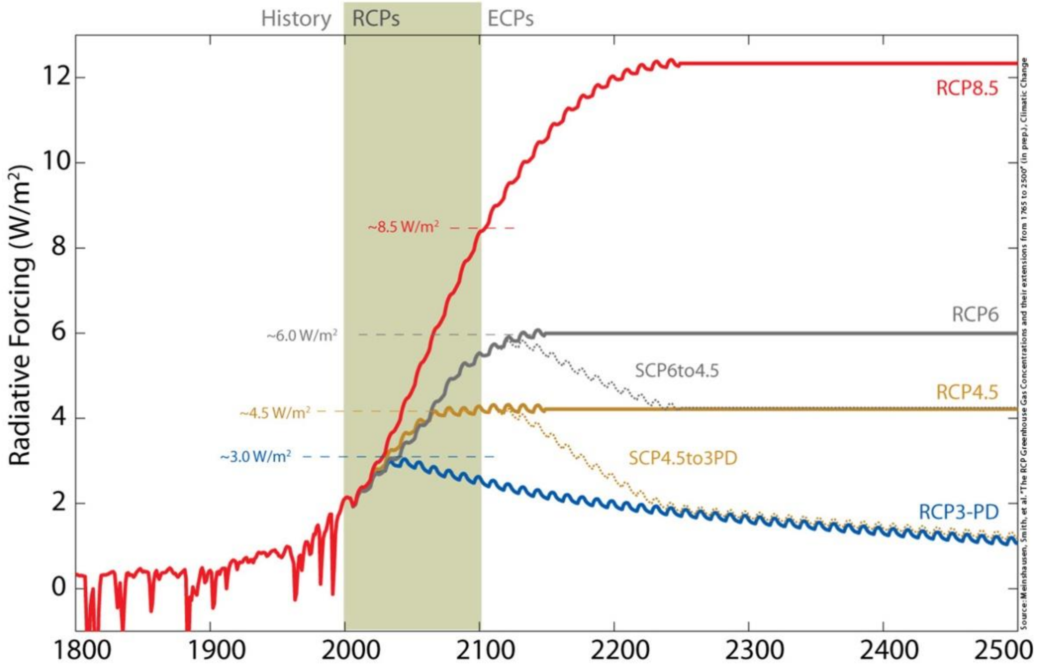

Fig 3: Global Anthropogenic Radiative Forcing for the high RCP8.5, the medium-high RCP6, the medium-low RCP4.5 and the low RCP3-PD. In addition, two supplementary extensions are shown, connecting RCP6.0 levels to RCP4.5 levels by 2250 (SCP6TO45) or RCP45 levels to RCP3PD concentrations and forcings (SCP45to3PD). No uncertainty ranges are shown and reported, as for creating the recommendation datasets for CMIP5, central estimates have been assumed closely in line with central estimates in IPCC AR4.

The RCPs describe a possible future of an increasing solar radiation [in W m-2] until 2100. This change in solar radiation is translated in regional temperature and precipitation signal by global circulation climate models (GCM). For SSA, there is a clear signal that the temperature will increase. Depending on the RCP, the region, and the climate projection, the increase is between 2°C and 8°C °C. The precipitation change is not that clear in comparison to the temperature. In the north eastern parts (e.g. Ethiopia, Kenya) an increasing precipitation is expected. Whereas in the southern parts of SSA (Mozambique, Zambia), declining precipitation amounts are expected. For Tanzania, the model mean shows only small changes in the precipitation amount.

Global Circulation Models (GCM) – CIMIP5

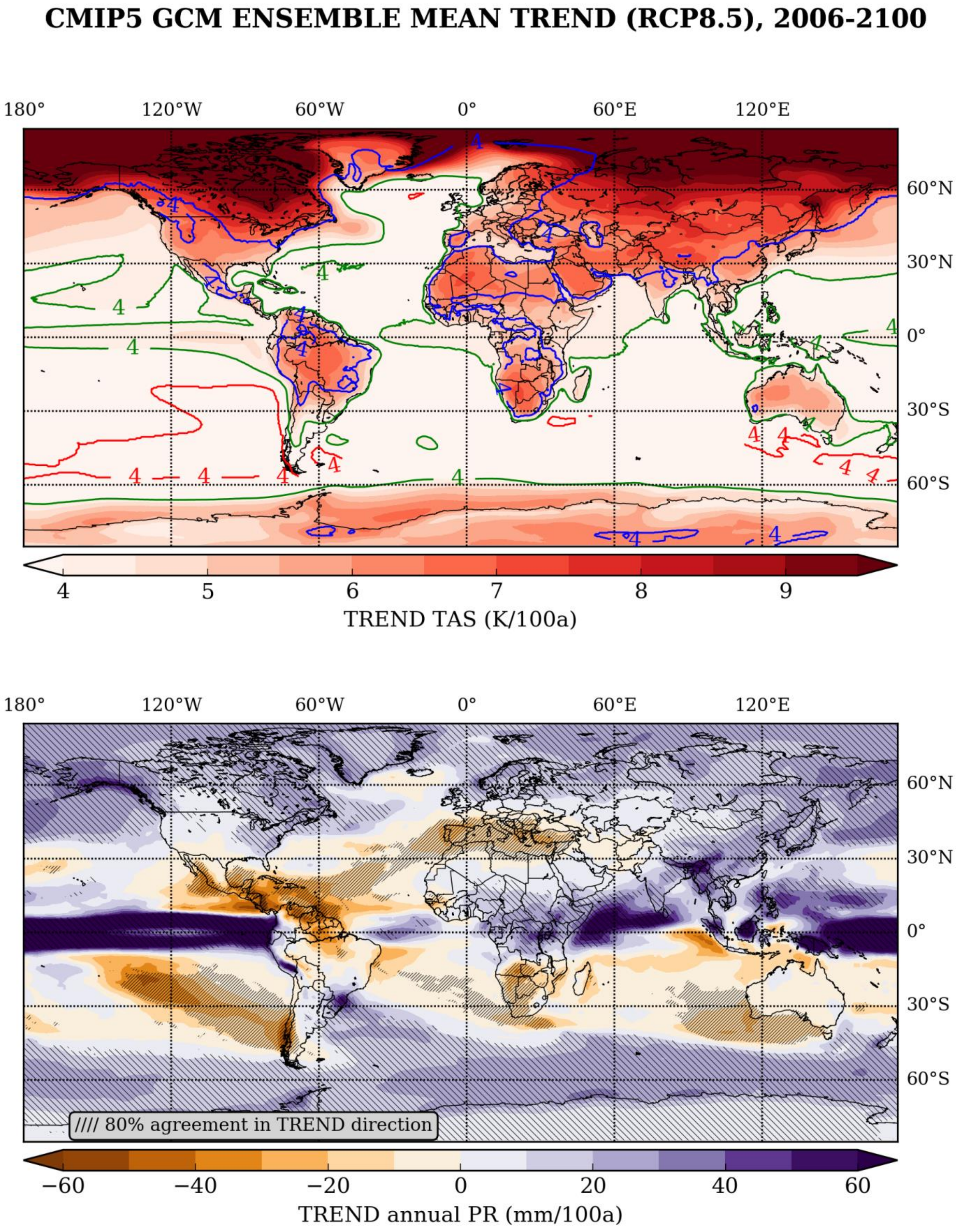

Fig. 4: Updated global RCP 8.5 climate scenarios (CMIP5). CIMIP5 GCM ensemble mean trend 2006 – 2100. Left: Temperature, Right precipitation.

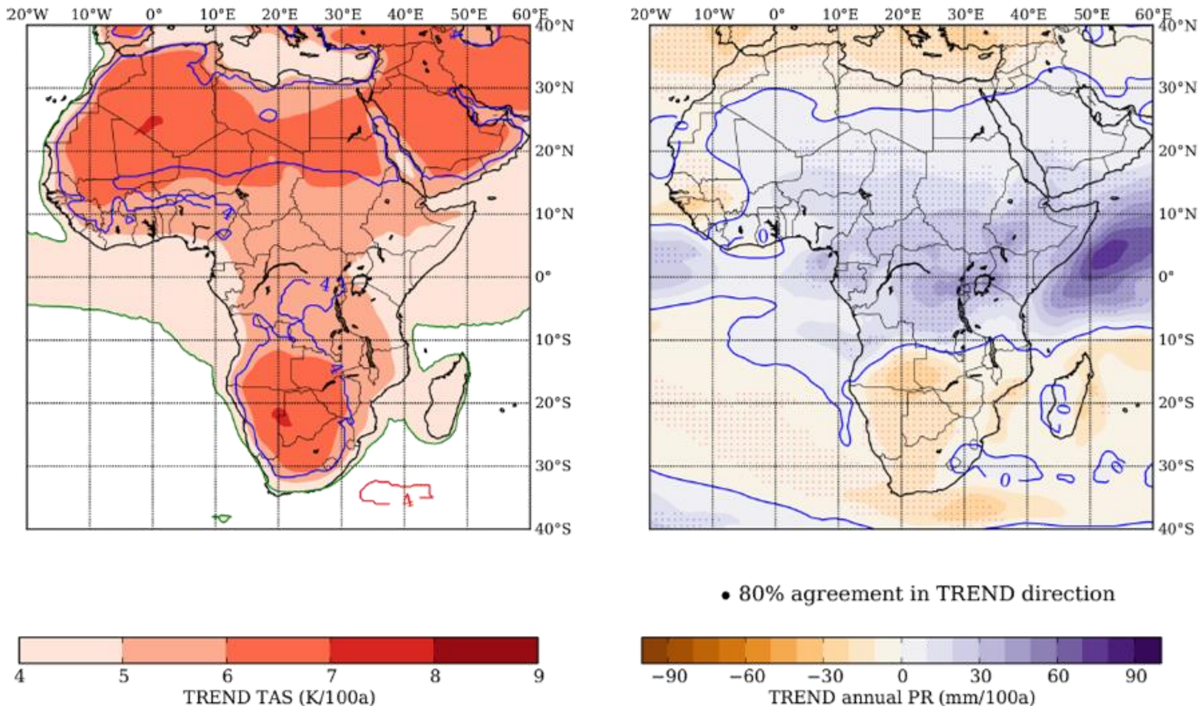

Fig. 5: RCP 8.5 climate scenarios (CMIP5) for Africa. CIMIP5 GCM ensemble mean trend 2006 – 2100. Left: Temperature, Right precipitation.

Regional Circulation Models – CORDEX

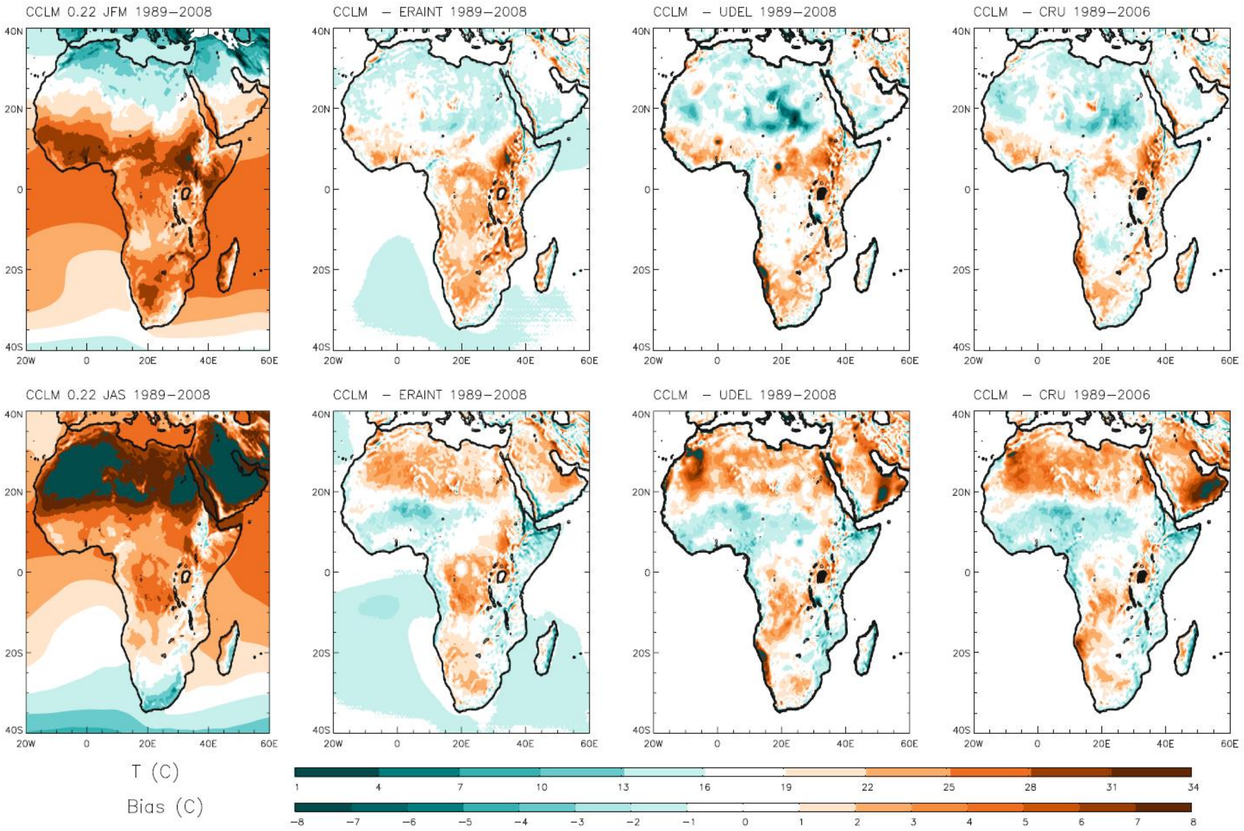

Fig. 6: Simulated seasonal mean 2-m temperature, for boreal and austral summer (top and bottom row, respectively), together with the model bias against ERA-Interim, the UDEL, and the CRU datasets (Panitz et al., 2014).

Global Climate Models (GCM) can provide reliable weather and climate information on scales of around 1000 by 1000km. They can cover vastly differing landscapes (from very mountainous to flat coastal plains for example) which might have highly varying potential for floods, droughts or other extreme events. Regional Climate Models (RCM) are applied over a limited area and driven by GCMs can provide information on much smaller scales supporting more detailed impact and adaptation assessment and planning. This is beneficial in many vulnerable regions of the world (http://www.cordex.org/).

The Figures 6–9 show the RCM results for Africa for the variables temperature (Fig. 6) and precipitation (Fig. 7–9). The maps show the differences in the individual RCM for different time periods.

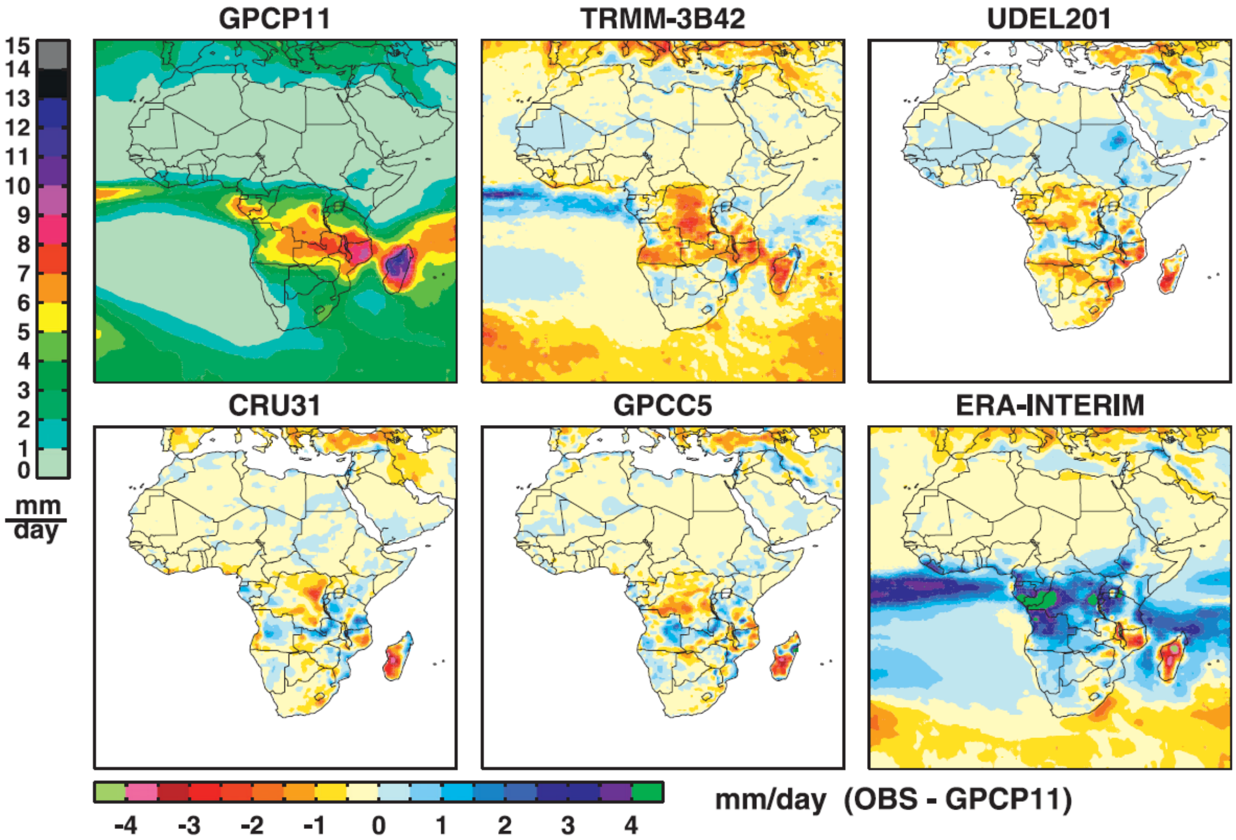

Fig. 7: GPCP mean JFM precipitation (1998–2008) and differences between other gridded precipitation products and GPCP according to Nikulin et al. (2012).

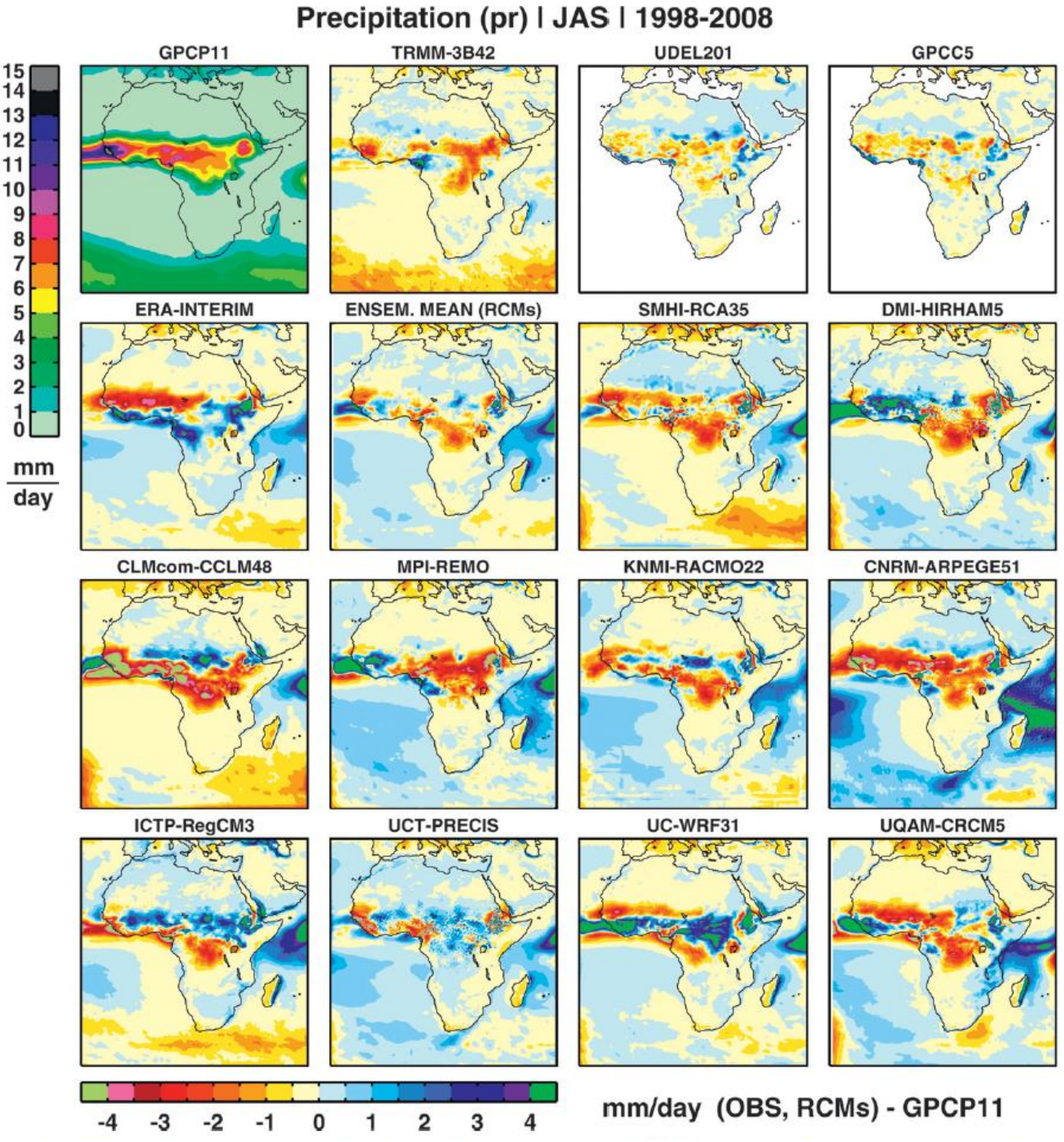

Fig. 8: GPCP mean JAS precipitation for 1998–2008 and differences compared to GPGP in the other gridded observations, the individual RCMs, and their ensemble average according to Nikulin et al. (2012).

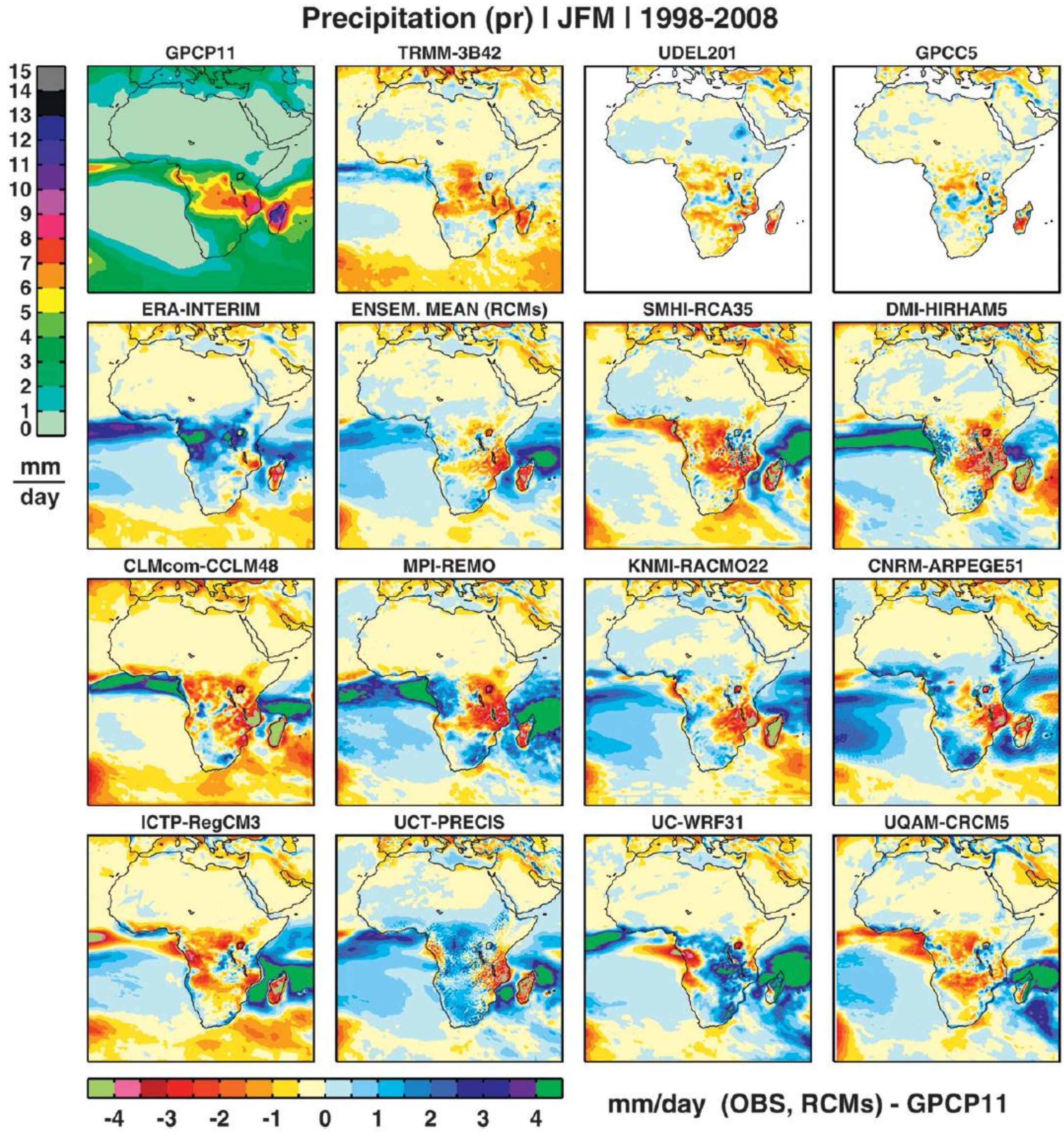

Fig. 9: As in Fig. 8, but for JFM according to Nikulin et al. (2012).

Inter-Sectoral Impact Model Intercomparison Project – ISI-MIP

Data for future climate scenarios are available from Inter-Sectoral Impact Model Intercomparison Project (ISI-MIP; isi-mip.org, Warszawski et al., 2014). These data are well accepted and also used for the Agricultural Model Intercomparison and Improvement Project (AgMIP; agmip.org; Müller et al., 2016). The scenario data based on Representative Concentration Pathways (RCPs) provided by the task group RCP Concentrations Calculation and Data of the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (IPCC 2015). As RCPs, we take the high-emission scenario RCP8.5, the medium-low-emission scenario RCP4.5 and the low-emission scenario RCP2.6 scenario (Moss et al., 2010; Riahi et al., 2011). The All RCP scenarios contain five different projections (GFDL-ESM2M, HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM.CHEM, and NorESM1-M). In total, we compared 15 different projections of three RCPs. Fig. 7 to 11 show the weather conditions and its changes in the crop growing season (the calculation of a representative growing season is also improved and implemented in the Web-GIS (see annex p. 44)

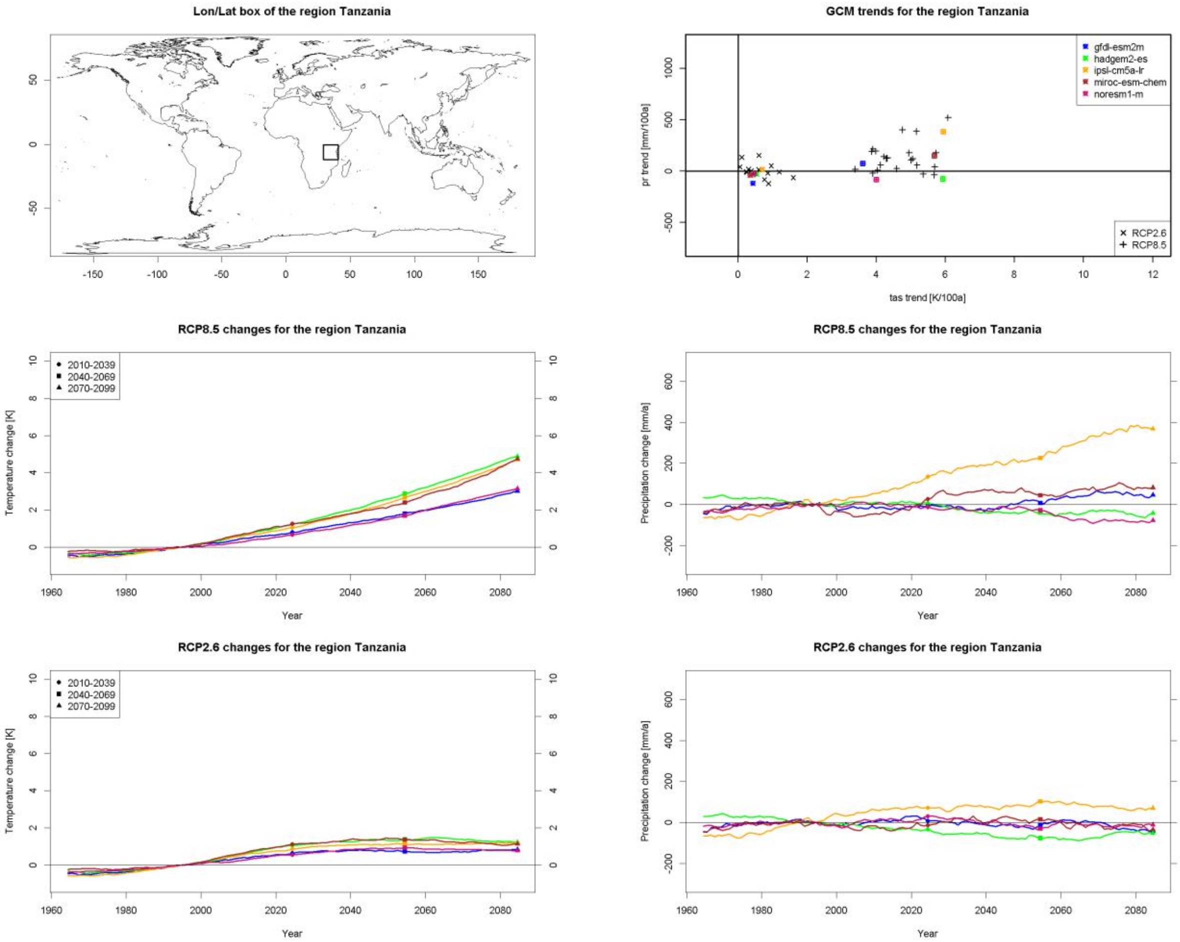

Fig. 10: ISI-MIP RCP climate scenarios (2.6 and 8.5) for entire Tanzania.

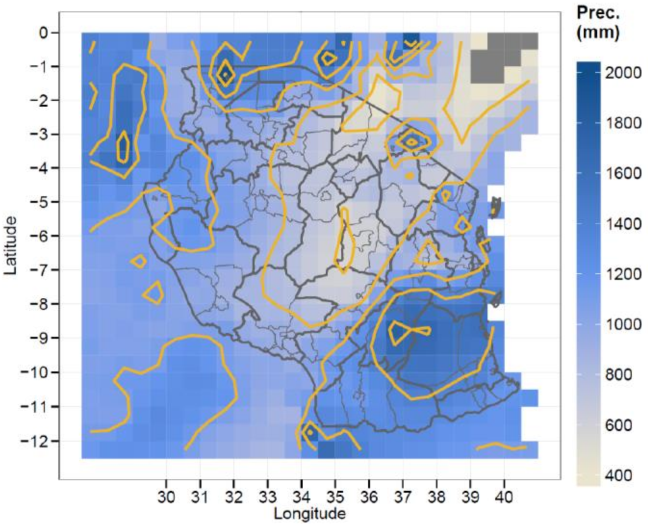

Fig. 11a: Precipitation in the growing season (1979-2012)

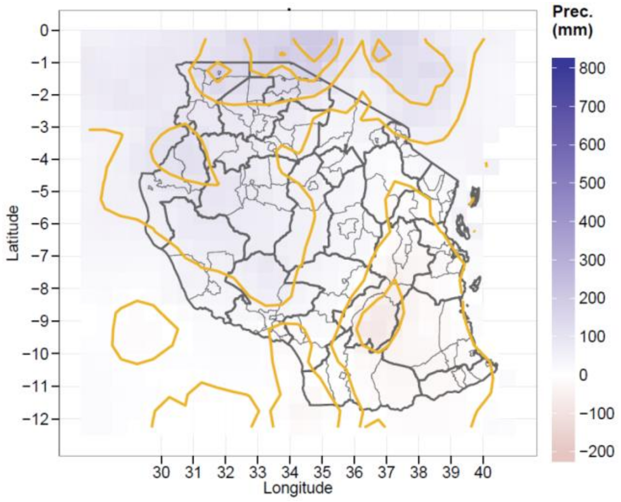

Fig. 11b: Precipitation change in the growing season RCP 8.5 – 2030 to 2000

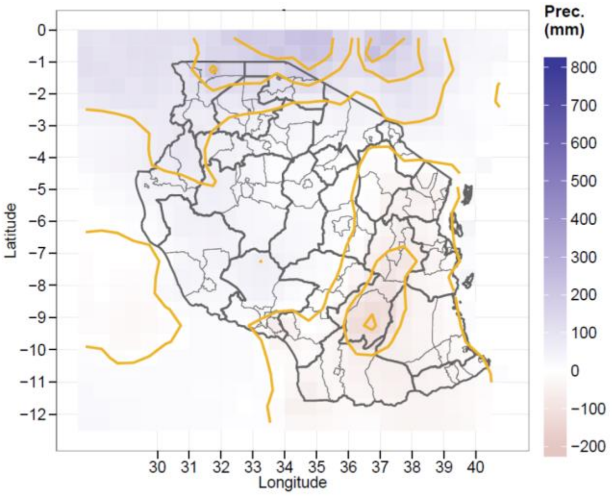

Fig. 11c: Precipitation change in the growing season RCP 8.5 – 2050 to 2000

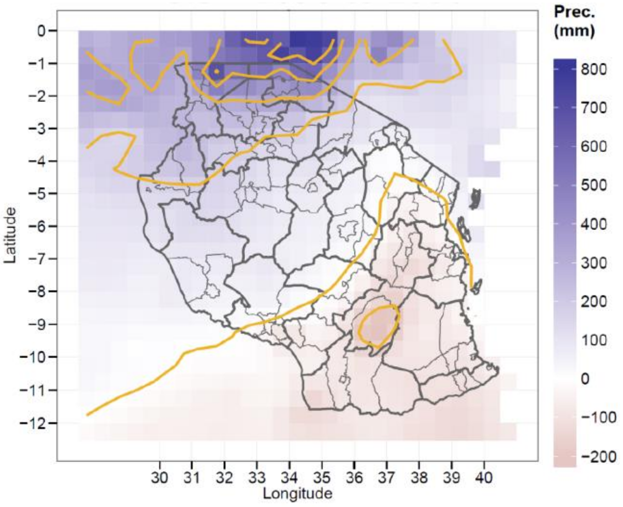

Fig. 11d: Precipitation change in the growing season RCP 8.5 – 2090 to 2000

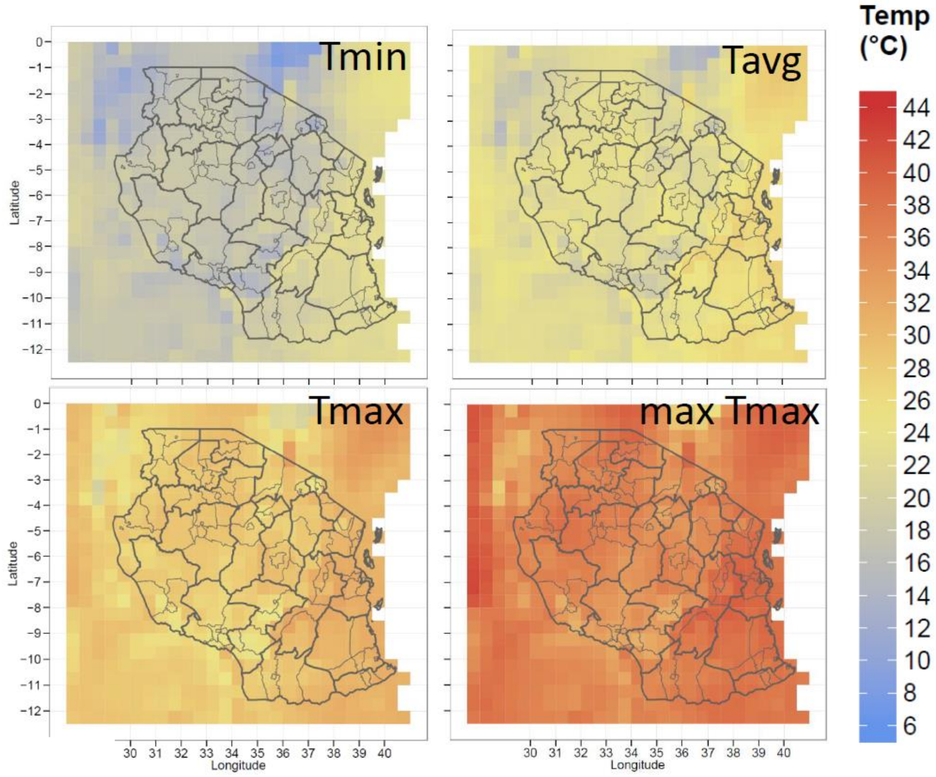

Fig. 12: Temperature in the growing season (1979-2012)

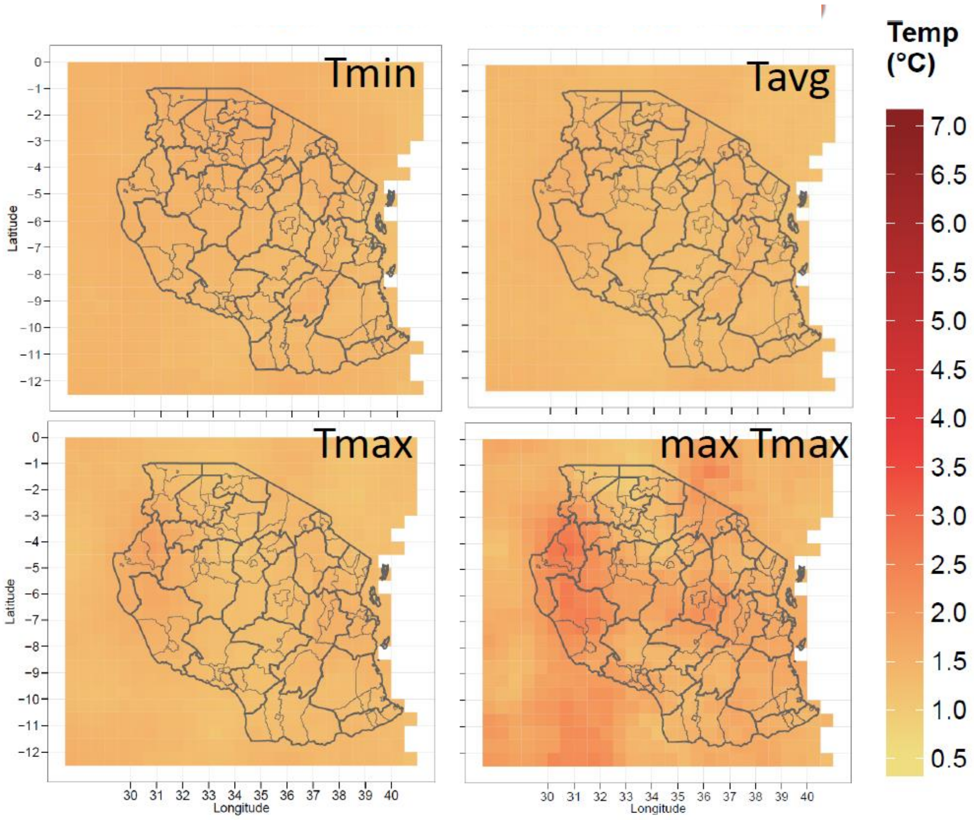

Fig. 13: Temperature change in the growing season RCP 8.5 – 2030 to 2000

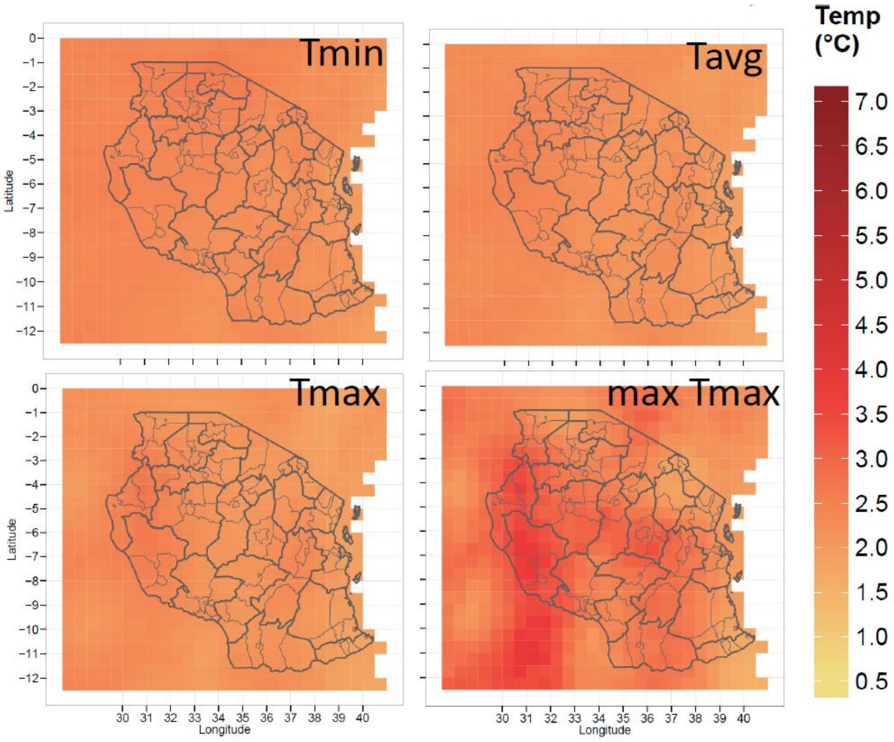

Fig. 14: Temperature change in the growing season RCP 8.5 – 2050 to 2000

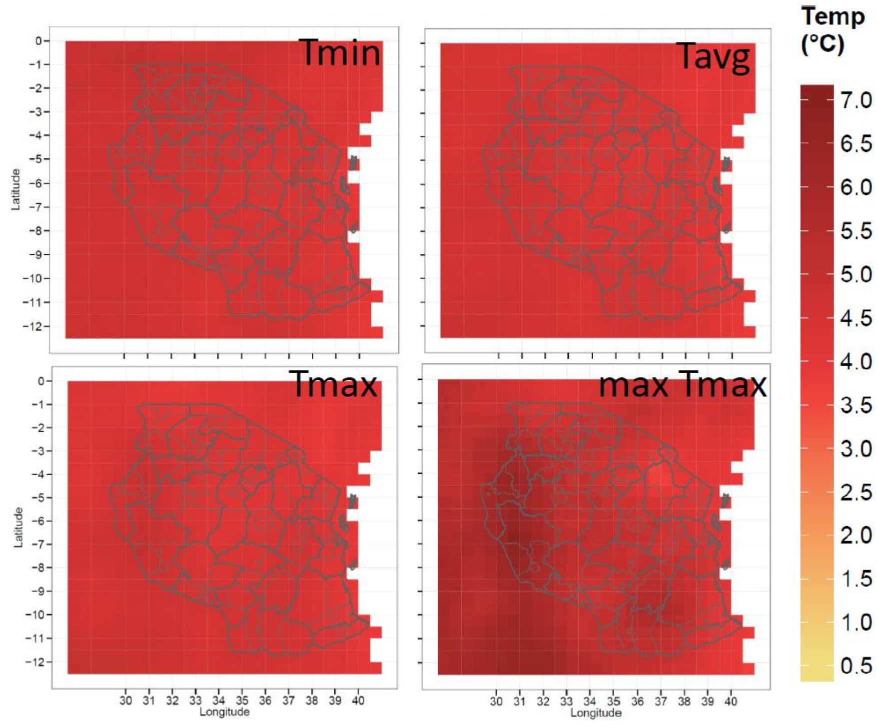

Fig. 15: Temperature change in the growing season RCP 8.5 – 2090 to 2000

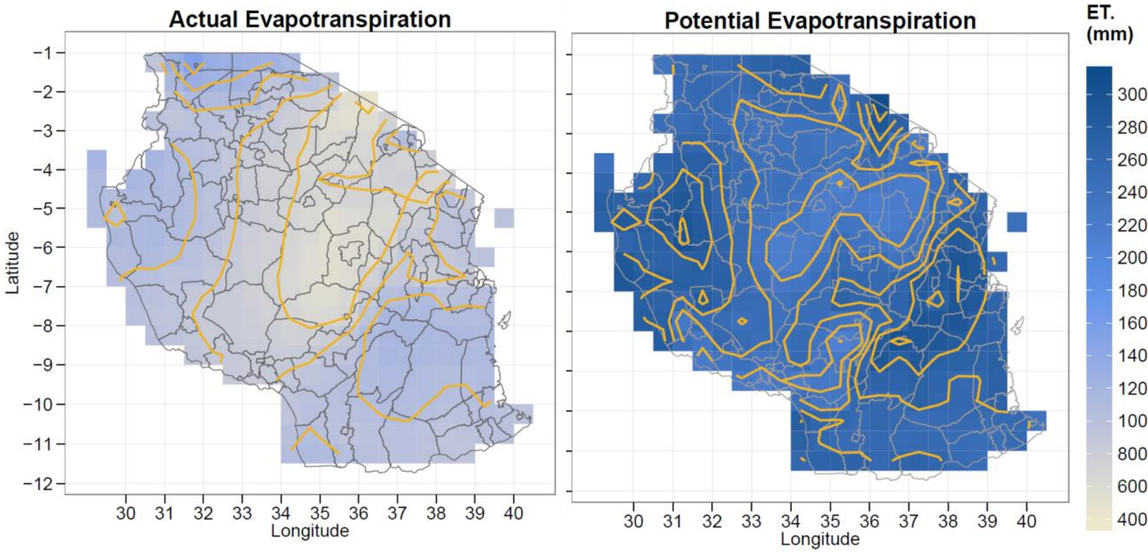

Fig. 16: Evapotranspiration in the growing season calculated by SWIM.

4. Use of the data

The climate scenario data are used for several applications. After two workshops on how to use and interpret the data, several Trans-SEC partners (but also of the wider GlobE network) requested the data for different regions and time periods (see Fig.). The data are processed individually for each request. The latest development is the automatic data providence service in the web-GIS. This tool allows users to select a region, seasonality (e.g. the growing season), and a time period. After choosing these criteria, the data are automatically processed and is made available for the user.

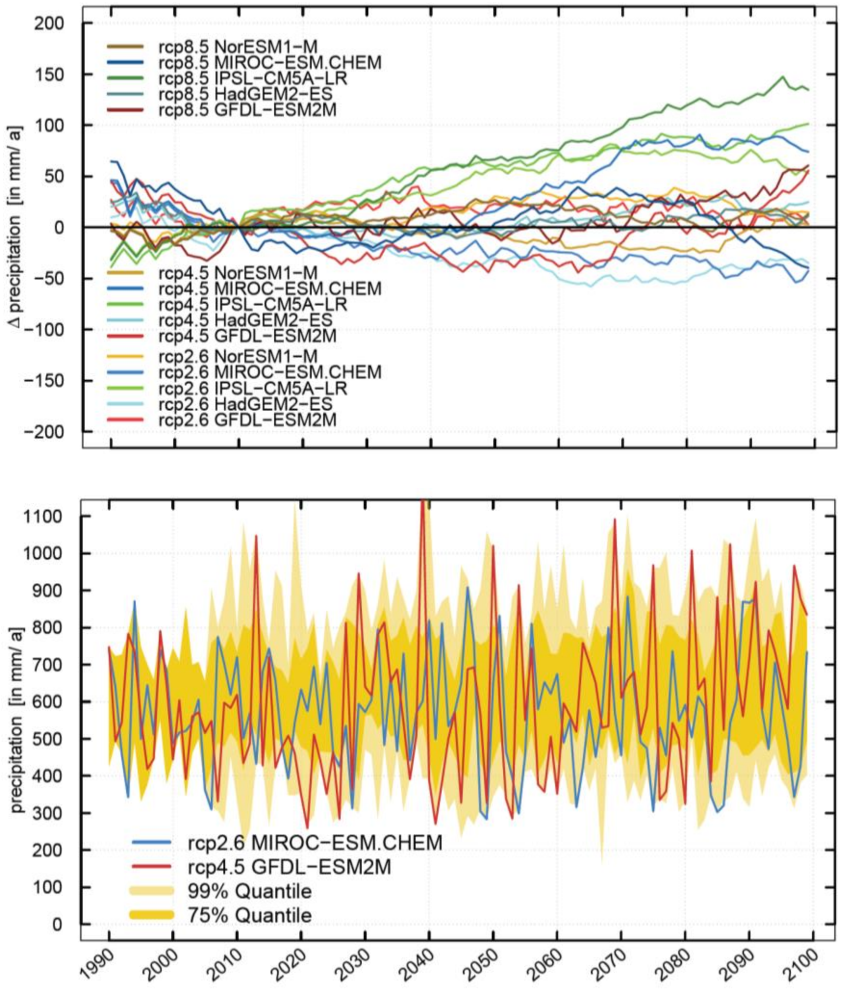

Fig. 17: ISI-MIP RCP climate scenarios (2.6, 4.5, 8.5) for Dodoma. Top: 30 years average of the precipitation change. Bottom: Annual variability of the absolute precipitation.

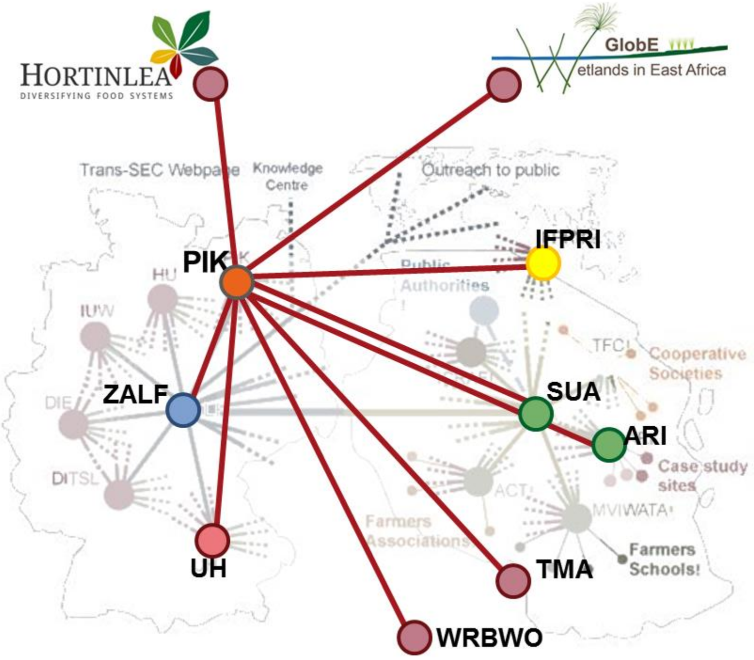

Fig. 18: Example of the network for the provided scenario data.

5. Bio-physical risk assessment

The future food production system must integrate the global challenges of climate change, an increasing world population with land intensive food demand, and the scarcely expandable arable land (Foley et al., 2011). Notably in Sub Saharan Africa (SSA), these challenges endanger increasingly the supply of sufficient food and thus, food security (Godfray et al., 2010, Liu, 2008). Since fertile arable land is only limited expandable, the yield per hectare must increase for a sufficient food supply. Statistical and process-based crop models can contribute to understand the factors, which are required for yield enhancements. While process-based models can assess yields treated by different agronomic management practices, statistical models capture also socio-economic impacts on actual farm yields.

In particular in SSA, the crop yield projections go along with high model uncertainty about future weather impacts on yields (Müller et al., 2011). Due to changing climate conditions in SSA, weather related cropping conditions might lead to decreasing maize yields in the future (Schlenker and Lobell, 2010). This will hamper crop yield enhancements in Tanzania (Rowhani et al., 2011) and increase the vulnerability in regard of poverty (Ahmed et al., 2011). Maize (*Zea mays* L.) is the most widely planted arable crop and the most important food crop in Tanzania. Despite, Tanzanian maize yields are only 1.3t ha^{-1} on average between 2003 and 2010 (MAFC, 2013).

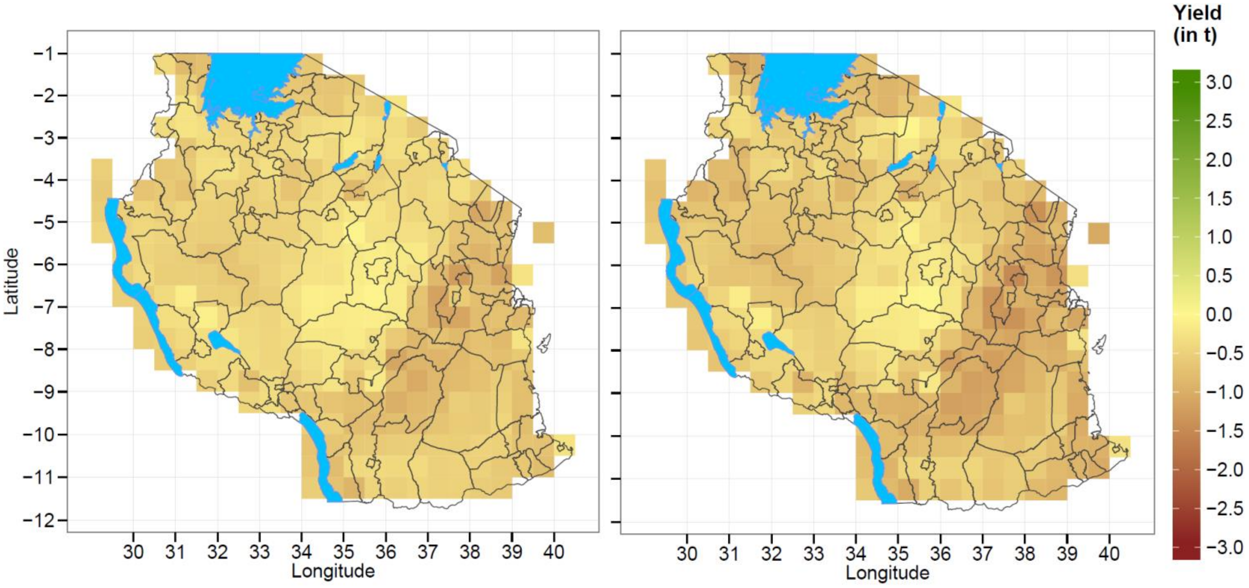

Fig. 19: Absolute yield changes (in t/ha) of under changing climate (RCP 8.5) for 2020-2040 and 2040-2060.

It should be kept in mind that the planted varieties are not adjusted over time. Because of increasing temperatures the heat units until maturity are achieved earlier. Due to this, the evaporation increases, however, the transpiration will be decrease because of the shortening of the growing season.

To investigate whether our process-based model is able to capture the impacts of fertilization and weather condition, we compare the modeled yields with different crop field trials' treatments. All these trial yields are water-and-nutrient-limited yields, because they are achieved without irrigation and with a limited nutrient supply. For our analyses, we apply the process-based model with the same fertilization and the weather conditions of the trial year. As fertilization levels, we consider (i) actual farm yield with no fertilization, (ii) crop trial yields with no fertilization, (iii) average crop trial yields with 120kg N ha-1 and 40kg P2O5 ha-1, and (iv) the 95% yield percentile of the 120kg N ha-1 and 40kg P2O5 ha-1 treatment. Trial yields and modeled yields show similar yield levels across the different fertilization treatments and across the Tanzanian agro-ecological zones (Fig. 13). The unfertilized trial yields (ii) are slightly higher than the actual yields (i). The iii and iv yields are clearly higher in all zones. However, the modeled 95Q yields in the semi-arid highlands and the sub-humid zones are lower than the observed. For the semi-arid regions, no trials for potential yields exist. Since the potential yields are the 95Q trial yields, there is a higher risk of outlier within the upper tail. To reduce the risk of outliers, we take the 95% yield percentile and not the highest yield as iv yields. This is similar to the approach of Mueller et al. (2012) and Neumann et al. (2010).

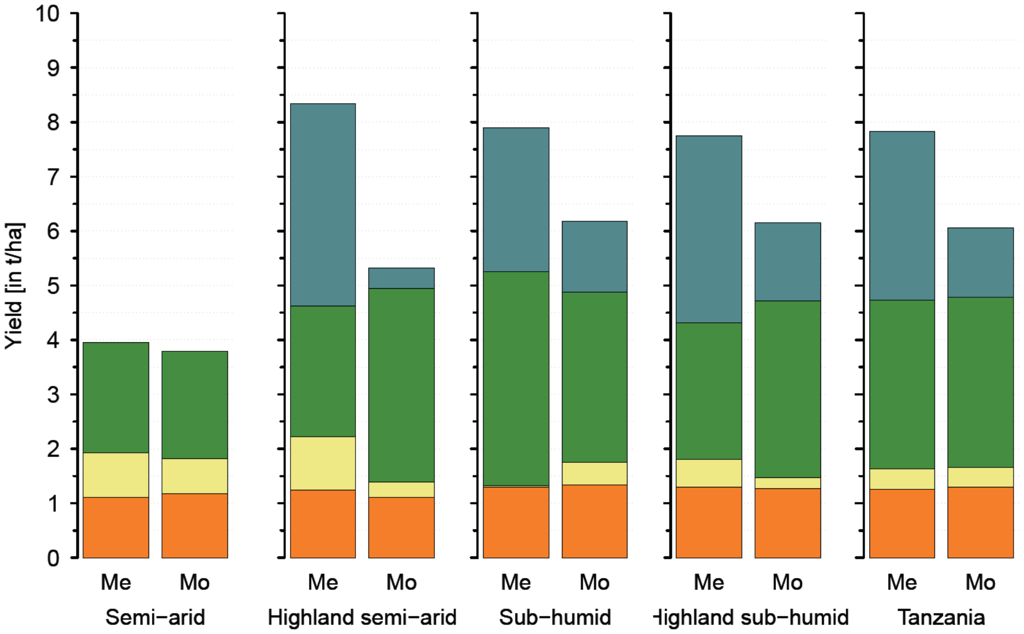

Fig. 20: Observed (Me) and Modeled (Me) yield levels within the yield gap concept. Potential, water limited, water & nutrient limited, and the actual yields for the different agro-ecological zones (semi-arid, sub-humid, for the highlands respectively, and for entire Tanzania). Note: Since the observed trial conditions always under rainfed and different but limited nutrient supply, we also adjust respectively the conditions in our model.

Moreover, we compare different modeled, water-and-nutrient-limited yields with observed yields of the different fertilizer supply trial treatments. This enables us to investigate whether our process-based model is able to capture the impacts of fertilizer supply for yield projections beyond the observed conditions. Fig. 3 shows that the process-based model is able to reproduce (r = 0.84***) the yields of different fertilization treatments for the spatially and temporal aggregated scale (filled points). The temporal aggregated yields cover the observed yield (triangles) by r = 0.28***. On individual trial scale (squares), the modeled yields scatter higher around the corresponding observed yields (0.22***). A reason for the lower coverage of unaggregated trial yields could be that the cropping conditions (e.g., crop varieties, planting and harvesting dates) of the trial are not fully documented. We apply the process-based model with the same fertilization and the weather conditions of the trial year. As fertilization levels, we consider no (0 kg N, 0 kg P2O5), medium (60 kg N, 20 kg P2O5), and high (120 kg N, 40 kg P2O5 ha–1) fertilization according to the trial treatments. Since crop models calculate for identical circumstances the same yield (for trial treatments it is not necessarily the case), the treatments for the same year, site, and fertilization are aggregated.

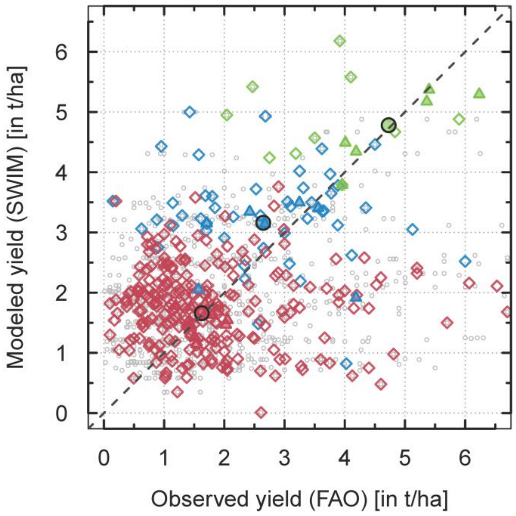

Fig. 21: Observed and process-based modeled yield for different nutrient supply levels on different years and trial locations within Tanzania. The triangles are the temporal aggregated trials; the squares are the spatial aggregated trials. The temporal and spatial aggregated trials are the filled points. The treatment of 0kg N and 0 kg P2O5 is covered by the red color, the 60kg N and 20 kg P2O5 treatment is covered by the blue color, and the 120kg N and 40 kg P2O5 is colored in green. The small grey points are the full dataset, which based on 1170 yield observation for 484 trial sites and 10 years.

Weather-related yield losses endanger food security and inhibit the establishment of a resilient farming system for more than 30 million people working in the agricultural sector of Tanzania. If these losses were quantified, this information could be used for risk transfer instruments to stabilize smallholder farmers' incomes and enhance their food security in Tanzania. Yield losses – here defined as yield anomaly below the mean yield level – which are attributable to weather impacts, are problematic for smallholder farmers. Our separation of maize yield loss factors shows dissimilar shares of weather-related (27%) and non-weather-related (73%) yield losses for Tanzania on average. Across districts, weather-related yield variability varies between 4% (in sub-humid south–east Tanzania) and 57% (in the semi-arid central and north–west, see Fig. 3). In total, the average and maximum weather-related yield losses are 0.11 and 0.41 t ha–1 and the non-weather-related yield losses are 0.34 and 1.70 t ha^{-1}, respectively.

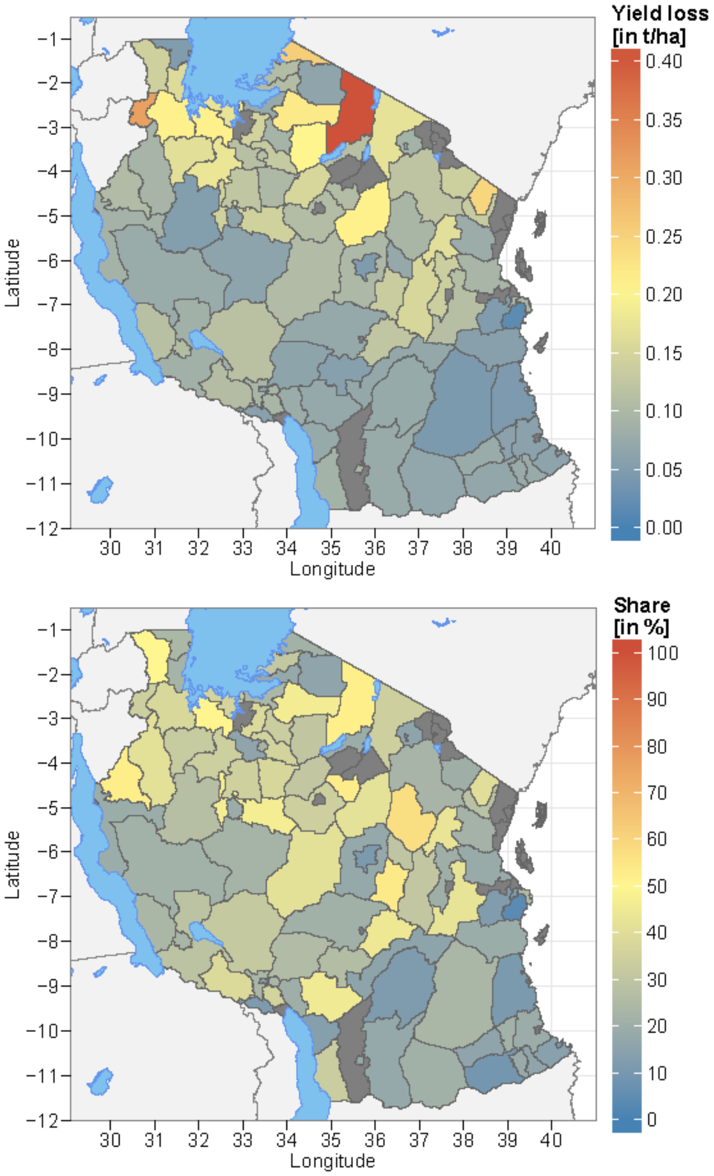

Fig. 22. Weather-related yield losses in t ha–1 p.a. (top), the share of weather-related yield losses in comparison to the total yield losses in % (bottom).

6. Effects of food value chain at different levels

6.1. How affect the scenarios the UPS and *vice versa*?

If an UPS has a positive impact on food security under the climate change shrinkage scenario, this could be interpreted as potential adaption strategy. If the UPS even affects the scenarios in a positive way, it could be interpreted as potential mitigation strategy. The linkage and interaction between UPS and scenarios should be discussed in the following.

Rainwater harvesting (RWH) as a technique aims at storing water in case of decreased rainfall, but even more importantly for making water available at times of need. This is important even under unchanged or increasing rainfall (the most climate projections show an increasing precipitation for east Africa), as the general problem in most regions (including some CSS) is not the overall amount of rainfall, but rather the temporal distribution. If water could be saved, or soil water be increased to cover dry spells within the rainy season and assure water availability in sensitive cropping periods, this could ensure much higher yields. In addition, RWH can also serve as retention for excess water during high intensity rainfall, possibly reducing flooding and erosion risks. However, this depends very much on the infrastructure etc.

Fertilizer Micro-dosing: Increasing precipitation and rising temperatures result in higher nitrification and leaching rates (efficiency of the UPS?).

Optimized weeding program: No interaction between UPS and the scenarios are expected. Positive yield effect, reduced leaching, and reduced nutrient requirements?

Profitable and market oriented storage: Changing climate conditions require for an adaption of the storage management. The climate change will shift global and regional supply chains because of changing cropping patterns/ rotations and diets. These require for an adjustment of the supply chain and the storage systems.

Horizontal and vertical coordination: Shifting global, regional and local demands and supplies could affect the climate conditions. This shifting depends on further diets and production systems.
Improved cooking stoves: Less deforestation

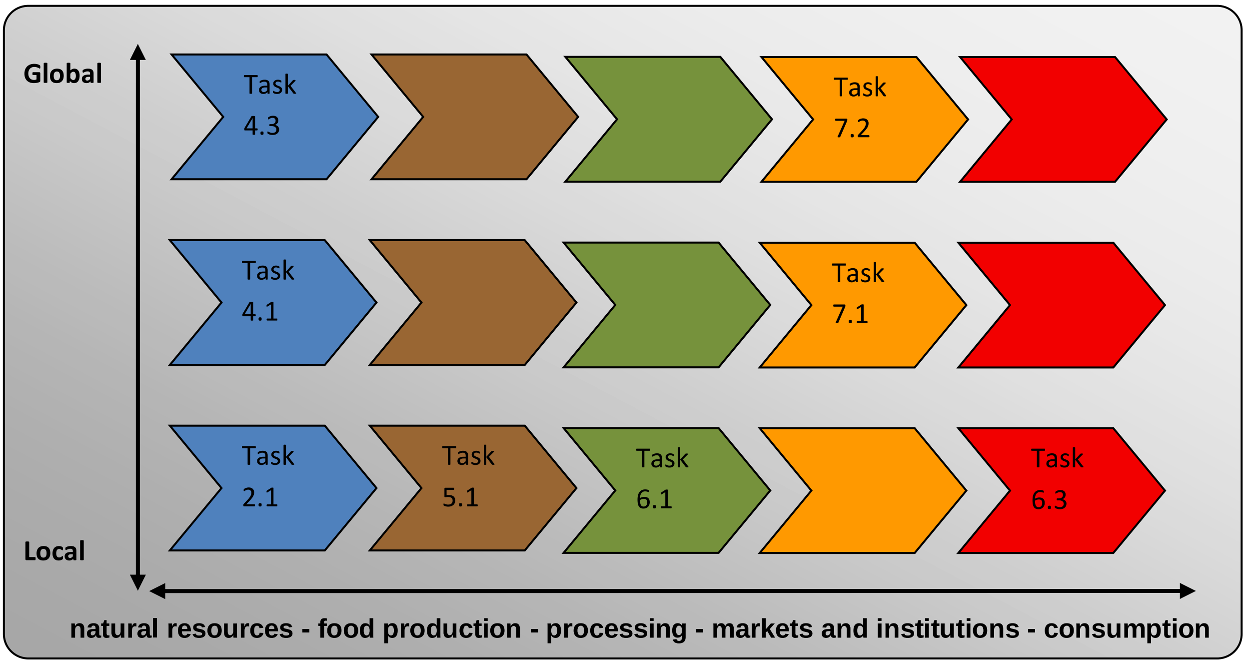

Fig. 23: Schematic overview of the spatial working scale of the different tasks.

6.2. Integration of the UPS at different spatial scales where they affect the scenarios

The spatial scale of the UPS application is important for the scenario downscaling. The UPS are utilized at different spatial scales (e.g. the UPS marked access or market information systems are only useful at a broader spatial scale). UPS on higher spatial scale will have an interaction/ feedback to the scenarios.

UPS	**Relevance**	
	Semi-arid	Sub-humid
1 Rainwater harvesting	4.5	2.0
1 Fertiliser micro-dosing	4.0	4.0
1 Optimised weeding	4.5	4.5
2 Byproducts for bioenergy (pyroliser for charcoal making)	2.8	2.8
3 Improved processing	4.0	4.0
4 Improved wood supply	5.0	4.0
5 Improved stoves	1.0	1.0
6 New product development	5.0	4.0
7 Optimised market oriented storage	5.0	5.0
8 Poultry-crop integration	5.0	5.0
9 Market access system (m-IMAS)	-	1.5
10 Kitchen garden training	4.0	3.0
10 HH nutrition education	1.5	1.5

1 = very low, 2 = low, 3 = medium, 4 = high, 5 very high

For a successful UPS implementation, it is important to secure a resilient UPS usability also under changing climatic conditions. Hence, the UPS vulnerable to climate change should be as low as possible. To identify the vulnerability of the UPS in regards of climate change, we combined a climate scenario data analysis with expert interviews. Climate change vulnerability is function of exposure degree and the exposed elements the (IPCC, 2015). The exposure degree is evaluated by the UPS responsible experts. The exposed elements are the UPS, which require inputs in form of (1) know how & education, (2) investment costs & external inputs, (3) labor requirements, (4) physical capital (buildings, streets), and (5) natural capital (water, soil). These input requirements are evaluated within ScalA-FS analyzes.

As climate data, we use scenarios of the Inter-Sectoral Impact Model Inter-comparison Project – ISI-MIP (Warszawski et al., 2014). The scenario data bases on Representative Concentration Pathways (RCPs) provided by the task group RCP Concentrations Calculation and Data of the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (IPCC 2015). As RCPs, we take the high-emission scenario RCP8.5, the medium-low-emission scenario RCP4.5 and the low-emission scenario RCP2.6 scenario with the corresponding five realizations (GFDL-ESM2M, HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM.CHEM, and NorESM1-M). In total, we compared 15 different realizations of 3 RCPs.

Based on the climate scenario analysis, we conduct interviews with the UPS responsible experts to evaluate the effects of the projected climate on the corresponding UPS. The experts addressed the effects of climate change on the UPSs and the relevance of these climate changes in regard of the UPS. Based on this information, we calculated an exposure degree for the corresponding UPS. Finally, the exposure degree and the exposed elements are used to calculate the UPS vulnerability in regard of climate change.

The climate scenario analyses shows as result that the temperature increases in all scenarios and realizations across entire Tanzania. The effect of precipitations shows different signs. While in the north of Tanzania, precipitation increases in most of the realizations, a precipitation decrease is projected in the southern parts of Tanzania. In the center of Tanzania (where our CSS are located), the precipitation signal varies between a moderate decreases to a moderate increase.

Tab. 2 shows that the vulnerability in regard of climate change differs substantially between the UPS. The vulnerability levels have a range between 0 and 100. While 100 can be interpreted as very high climate change vulnerability of the UPS, 0 can be interpreted as no climate change vulnerability. The highest climate vulnerabilities have the UPS *optimized market oriented storage*, *poultry-crop integration*, and *improved wood supply*. All the UPS are rated with high climate sensitivity/ relevancies and have a high input demand.

Tab. 2: Vulnerability of the UPS.

UPS	**Vulnerability**	
	Semi-arid	Sub-humid
1 Rainwater harvesting	59	27
1 Fertiliser micro-dosing	56	57
1 Optimised weeding	50	50
2 Byproducts for bioenergy (pyroliser for charcoal making)		41
3 Improved processing	60	62
4 Improved wood supply	58	
5 Improved stoves	10	10
6 New product development	70	
7 Optimised market oriented storage	46	46
8 Poultry-crop integration		66
9 Market access system (m-IMAS)		14
10 Kitchen garden training	28	21
10 HH nutrition education	13	13

15 = very low, 30 = low, 45 = medium, 60 = high, 75 very high

Tab. 3: Focal crops: Maize (intercropped with pigeon pea), Sesame (stand alone) in Ilakala&Changarawe // Millet, Sunflower (both intercropped with groundnuts) in Ilolo & Idifu

UPS	Ilakala	Changarawe	Ilolo	Idifu	UPS responsible	Local responsible for monitoring
1 Rainwater harvesting & Fertiliser microdosing & Optimised weeding	✓	✓	✓	✓	Jörn Germer, Folkard Asch Ludger Herrmann Frederick Kahimba, E. Swai, Bashir M. +	Paul (Kilosa) Emanuel (Dodoma) Nuru Mgale (Dod.)
2 Byproducts for bioenergy (pyroliser for charcoal making)	✓				Simon Munder, Sebastian, Valerian Silayo,	Obedi (Kilosa)
3 Improved processing	✓ **maize sheller**	✓ **maize sheller**	✓ **millet thresher**	✓ **millet thresher**	Valerian Silayo, Charles, Mwinuka, Claude, +	Bashir (Kilosa) Devotah (Dodoma) Felista (Dodoma)
4 Improved wood supply			✓		Götz Uckert Anthony Kimaro	Majige (Dodoma)
5 Improved stoves	✓	✓	✓	✓	Götz Uckert, Ogossi, +	Obedi (Kilosa) Majige (Dodoma)
6 New product development			✓ **sunflower oil pressing**	✓ **sunflower oil pressing**	Charles, Mwinuka, Claude, Khamaldin Valerian Silayo, +	Devotah (Dodoma) Felista (Dodoma)
7 Optimised market oriented storage	✓	✓	✓	✓	Charles, Valerian, Khamaldin, Mwinuka, Claude, +	Rashidi (Kilosa) Devotah (Dodoma)
8 Poultry-crop integration		✓			Said Mbaga, Charles, Mwinuka, Claude, +	Phlorentin (Kilosa)
9 Market access system (m-IMAS)	✓	✓			Khamaldin, Claude, +	Bashir (Kilosa)
10 HH nutrition education & Kitchen garden training	✓	✓	✓	✓	Hadijah, Christine Lambert, Joyce Kinabo, +	Rashidi (Kilosa) Nuru Mgale (Dod.)
UPS groups (total)	**7**	**7**	**7**	**6**		

Tab. 4: Impacts of changing climatic conditions on UPS (answers of the UPS responsible persons).

Scenario UPS	**Useful in case of Temperature increase?**	**Useful in case of precipitation increase?**	**Useful in case of precipitation decrease?**	**Useful in case of shift in seasonality?** (e.g. earlier, later, shorter, or longer rainy seasons)	**Useful in case of longer drought periods?**	**Relevance of the UPS in regard to climate change**
Rainwater harvesting (tied ridges, infiltration pits)	Temperature increase means at the same time ET increase, consequently the importance of the technique is rising with increasing temperature, also because soil water is decreasing soil and near canopy temperature.	Overall importance decreasing with increasing precipitation, but still there are possibilities for extended vegetation period.	Increasing importance is obvious, especially if decreasing precipitation is related to higher intensity events.	Don't know what shift means exactly here: Length of season or later begin or???	Definitely due to higher water stocks.	

Fertilizer micro-dosing	No direct relations.	Effect depends more on rainfall distribution at the beginning of the season rather than total rainfall.	My guess is that importance is increasing, since with shorter rainy seasons the importance of early growth gets more important.		Marginally due to higher water use efficiency.	
Optimized weeding	Depending how optimized is defined. We can decrease soil surface temperature if we introduce selective weeding. But as far as I understood Jörn that is not what he had in mind.	With increasing precipitation the optimal weeding strategy is different, due to higher concurrence effects.	See left. Optimal weeding depends on rainfall amount (and distribution).		Definitely, since plant cover and thus ET can be managed.	
Rainwater harvesting (tied ridges, infiltration pits)	Higher temperatures increaes evapotranspiration rates and hence reduces soil mosture stored in the soil. Use of tied ridges and inftration will help to trap more moisture and hence compensate for moisture lost through increased Temperature	Too much precipitation in flat cultivation caused water logging. Presence of tied ridges can assist to drain excess moisture leaving the didge top aerated. Hence plant can continue surviving in ridges even under heavy P compared to in flat cultivation	For low P both tied ridges and infiltration pits will trap the little rain falling on the ground and cnserve it for plant waer uptake at later times	May have no effect	The UPS will be advantageous in case of increased dryspells as the trapped moisture will be avilable for the crops during dry spells	high relevance
Fertilizer micro-dosing	Normal fertilizer application at higher temperatures affects fertilizer performance due to lack of moistgue to dissolve the fertilizer. Fertilizer may also 'burn' crops. Application of fertilizer in small doses will minimize the negative effects of T increase	Useful with increased rainfall because rainfall will assure maximum dissolution and hence uptake of the fertilizer by plants	the UPS will be useful as even with little rain farmers will be assured of good crop growth perfornance due to the microdose	it can still be useful as it is not affected by change in seasonality	Will be less efficient in case of extended drought	high relevance
Optimized weeding	Usefull as only small portion of the field is exposed during weeding. The rest is left covered by vegetation hence cooling the ground, and minimizing soil evaporation	Very useful as good rains are also associated with increased weed growth	Moderate useful as low rains are also associated with slower weed growth	No difference	High efficient as it will avoid competition for lesser amount of soil moisture between crops and weeds during the time of extended droughts	Hign relevance
Byproducts for bioenergy	No effect	No effect	No effect	No effect	No effect	High emission mitigation potential due to indirect reduction of deforestation and direct cleaner combustion
Byproducts for bioenergy	The byproducts will dry fast to attain the desired moisture content for pyrolysis	There shall be increase in crop yield parallel with increase of biomass materials.	It will negatively affect availability of biomass materials	No obvious effect	Reduced availability of biomass materials	Medium relevance

Improved processing	Increase in temperature will lead to fast removal of moisture to the level that is conducive for procesing, e.g., for maize shelling and sorghum/millet threshing	Increase of precipitation at the time of harvesting may necessitate further drying before processing could be done.	Reduced precipitation will reduce yield and hence affect the processing businesses as there will not be enough materials to process.	The peak processing period will also be shifted	Same as for reduced precipitation	High relevance
Improved wood supply	if adapted tree species	more reliable installaltion of the UPS	if adapted tree species	if adapted tree species	if adapted tree species	High relevance
Improved stoves	generally YES: due to reducing the pressure on natural resources	generally YES: due to reducing the pressure on natural resources	generally YES: due to reducing the pressure on natural resources	generally YES: due to reducing the pressure on natural resources	generally YES: due to reducing the pressure on natural resources	High relevance
New product development	Higher temperature will results into proper drying of crops in the field (i.e. maize, millet and groundnuts). Hence facilitate deveopment of dry products.	Increase in precipitation will lead to increase in yield hence more raw materials for new product development. However, increase in precicipitation will lead to increase in mositure hence preparation of dried products will be in danger due to mould.	Low precipitation will lead to low yields hence no suprlus raw materials for new products development as the production will be used for subsistence	Shift in seasonality will affect marketing of the products because timing is required for introducing new products in the markets. If late, then competition will be high, if early, the demand may be too low.	If longer dry periods are expereinced, iy may be a challenge for yields/new products to be developed/or opportunity for the new products to be consumed in the dry seasons	Market and demand shifts may occur due to seasonality changes
Optimized market oriented storage	If temperature increases, it is beneficial to storage since stored products will attain optimum moisture level for proper storage.	If precipitaion increases, drying of the crops will take longer time and sometimes additional dryinf faciliy will be required. Incidences of mould in stored crop will be high and crop loss may results	Low precipitation will have no effects on storage.	Shifting in seasonality may lead to either increase or decrease in demand for storage facility depending on the yields produced.	For longer drought periods, demand for storage is required especially for the staple crops i.e. maize and millet.	In case of climate change effects, demand for storage will increase. However, if temperatures are high and affect yields, then demand for storage will be low and UPS may seem irrelevant
Poultry-crop integration	Increase in temperature may affect yield and hence reduce the amount of crops to be diverted to poulrty feeds	Increase in precipitation may lead to increase in crops, hence a bigger proportion will be diverted to poultry feeds. However, it may lead to outbreak of poultry diseases	Decrease in precipitation is better for poultry keeping, but may be detrimental to crop yields	Shift in seasonality may affect crop production. However, it may also increase chances of outbreak of poultry diseases. However, it may also influence demand for crops and chicken as well.	Longer dought will affect crop yields as well as availability of feeds to poulty.	In case of climate change effects, it may be an opportunity to produce and keep poultry when other areas are not producing. However, in case of production, it may affect yields and availability of poultry feeds.

New product development	This depends on how increased Temperature will affect the supply of sunflower as a raw material for sunflower valued added products. The law of supply and demand would hold and signaled in prices - low supply means higher prices and vice versa	Increased precipitation will have impacts through improved supply which can lower the price of value added sunflower products. However, it can still be beneficial given expected higher effective demand as a result of population and income growth and urbanization	Decreasing ppt will lower supply and rise prices	This depends on how the crop development will be impacted with such seasonal shifts that will affect the supply	With longer droughts supply will be low, hence price hikes. Very unlikely that lost production will be offset by price increase	Very relevant as it create wealth through value addition on whatever output realized
Optimized market oriented storage	If production is affected farmers will produce less surplus for storage. High temperature can held proper drying of grains	Useful as increased production means that there will be surplus to store	May be less useful in case of limited/no storable surplus	Can be affected through effect on the production	Can be useful in storing whatever grains available my minimizing post-harvest losses	Very relevant to ensure economic storage
Poultry-crop integration	Temperature dynamics can alter the poultry disease dynamics and phystical stress. These can affect production and reproduction of birds. In case crop sector is affected feeds will be expensive eating from farmers' margins	There could be disease dynamics for rural chicken with increasing temperature - this can limit production and reproduction. High rainfall would render feed avalable	Can be possitive in case of some poultry diseases and pests are halted. But there could decrease in supply of feed hence raising prices	Not certainly clear on how this might affected. It can also change the polutry disease and pests patterns from those used to farmers	Very useful, as poultry can help smooth consumption	Very relevant
Market access system (m-IMAS)	Very useful, as farmers can sell/market whatever they manage to produce and buy whatever they want to with less transaction costs	Very useful, as farmers can sell/market whatever they manage to produce and buy whatever they want to with less transaction costs	Very useful, as farmers can sell/market whatever they manage to produce and buy whatever they want to with less transaction costs	Very useful, as farmers can sell/market whatever they manage to produce and buy whatever they want to with less transaction costs	Very useful, as farmers can sell/market whatever they manage to produce and buy whatever they want to with less transaction costs	Very relevant
Poultry-crop integration	No effects	No effects	N effects	Can provide income throughout the year hence a buffer during pre-harvest period	Poultry less prone to prolonged drought. Hence a good buffer and climate shock aversing strategy	Highly relevant
HH nutrition education	Little enhancing importance of the UPS. Enables the household to adapt nutrition to the different food supply in a climate with higher temperatures	No effect	Little enhancing importance of the UPS. Enables the household to adapt nutrition to the different food supply in a climate with lower pricipitation	No effect	UPS has an limited binifit	low relevance
Kitchen garden training	Enhancing importance of the UPS. In kitchengardens the evapotranspiration due to higher temperatures can be limited (pocket gardens, shading)	Improves the success of the UPS due to a better yield form the kitchen garden	Enhancing importance of the UPS. Waste water use in kitchengardens reduces the negative impact on vegetabel production due to lower precipitation	No effect	Due to the use of waste water for the kitchen garden, the supply of vegetables could be safed	moderate relevance

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Supplemental information

Climate-smart and "climate-dump" activities:

The concept of climate-smart agriculture (CSA) is defined by FAO and should contribute to sustainable development goals. CSA integrates the economic, social and environmental dimensions of sustainable development to support food security under climate change. The FAO defines three main pillars for CSA:

(1) sustainably increasing agricultural productivity and incomes;
(2) adapting and building resilience to climate change;
(3) reducing and/or removing greenhouse gases emissions, where possible.

The concept of CSA is not a specific agricultural technology or practice. CSA promotes suitable agricultural production technologies and practices to protect natural resources and requires site-specific assessments.

History

The document has been started by Christoph Gornott, Fred Hattermann and Christoph Müller (PIK). In a first step, the conceptual framework of the document was discussed with Ephraim Nkonya (IFPRI), WP-leader Ludger Herrmann, and the project leaders Stefan Sieber and Frieder Graef. As second step, the document was shared with the German Trans-SEC Board. The German Board also sent comments to the conceptional framework. In a third step, the contents of the document where discussed by the modelling partners in work package (WP) 4 considering specific contents of their research field. All comments were considered in the follow up version of the document. As the last step, we want to share the document with the whole Trans-SEC community and discuss it within a workshop at the annual Trans-SEC meeting in Morogoro in September 12, 2014.

Regional specific answers of the UPS responsible persons for the CSS:

Value chain componet	Scenario UPS\	Useful in case of T↑?	Useful in case of P↑?	Useful in case of P↓?	Useful in case of shift in seasonality?	Useful in case of longer drought periods?	Relevance of the UPS in regard to climate change
For rainwater harvesting (tied ridges, infiltration pits)	**Ilakala**						
	Changarawe	No effect of water harvesting and fertilizer since lowland if the sites are used that were shown to us.	Drainage more important than water harvesting				
	Ilolo	For Illolo and Idifu it is more the differences within the villages rather than between the villages that count. We have soils that range from sandy to clayey with consequences for nutrient and water stocks.					
	Idifu						
Byproducts for bioenergy	**Ilakala**	None	None	None	None	None	None
	Changarawe	None	None	None	None	None	None
	Ilolo	None	None	None	None	None	None
	Idifu	None	None	None	None	None	None
UPS "Improved wood supply - tree planting"	**Ilakala**	development like in Dodoma region is possible	additional role for UPS: water erosion control	development like in Dodoma region is possible, i.a. high groundwater levels may balance this			High relevance
	Changarawe						High relevance
	Ilolo	kind of desertification already in place	additional role for UPS: water erosion control	limiting tree growth rates: will challenge the economical incentives for planters		no success of the UPS if no possibility of watering the tree seedlings	Very high relevance
	Idifu						Very high relevance
Byproducts for bioenergy	**Ilakala**		Does not differ from Changarawe				Medium relevance

	Changarawe		See Ilakala				Medium relevance
	Ilolo		The UPS is applicable for maize cobs which are not of significant use				
	Idifu		See Ilolo				
Improved processing	**Ilakala**		Significant for maize production	Significant for maize production	Same effect as for the rest of the CSS	Low frequency of occurrence	High relevance
	Changarawe		Significant for maize production	Significant for maize production	See Ilakala	Low frequency of occurrence	High relevance
	Ilolo		Significant for millet/sorghum and sunflower production	Significant for millet/sorghum and sunflower production	See Ilakala	High frequency of occurrence	High relevance
	Idifu		significant for millet/sorghum production	significant for millet/sorghum production	See Ilakala	High frequency of occurrence	High relevance
New product development	**Ilakala**	NA	NA	NA	NA	NA	High relevance
	Changarawe	NA	NA	NA	NA	NA	High relevance
	Ilolo	Can be successful due to proximity to Mvumi market centre	Can be successful due to proximity to Mvumi market centre	Can be successful due to proximity to Mvumi market centre	Can be successful due to proximity to Mvumi market centre	Can be successful due to proximity to Mvumi market centre	Very high relevance
	Idifu	It is remote, the UPS can have limited benefit from local market access	It is remote, the UPS can have limited benefit from local market access	It is remote, the UPS can have limited benefit from local market access	It is remote, the UPS can have limited benefit from local market access	It is remote, the UPS can have limited benefit from local market access	Very high relevance
Optimized storage	**Ilakala**	It can benefit the community as they chose it	It can benefit the community as they chose it	It can benefit the community as they chose it	It can benefit the community as they chose it	It can benefit the community as they chose it	very relevant
	Changarawe	NA					
	Ilolo	NA					
	Idifu	NA					
Poultry-crop integration	**Ilakala**	NA					

	Changarawe	Very useful under conditions affecting the production and reproduction. Just impelemented in one village	Very useful under conditions affecting the production and reproduction. Just impelemented in one village	Very useful under conditions affecting the production and reproduction. Just impelemented in one village	Very useful under conditions affecting the production and reproduction. Just impelemented in one village	Very useful under conditions affecting the production and reproduction. Just impelemented in one village	Very relevant
	Ilolo	NA					
	Idifu	NA					
	Ilakala	Equally useful across the case study sites	Equally useful across the case study sites	Equally useful across the case study sites	Equally useful across the case study sites	Equally useful across the case study sites	Very relevant
	Changarawe	Equally useful across the case study sites	Equally useful across the case study sites	Equally useful across the case study sites	Equally useful across the case study sites	Equally useful across the case study sites	Very relevant
	Ilolo	Equally useful across the case study sites	Equally useful across the case study sites	Equally useful across the case study sites	Equally useful across the case study sites	Equally useful across the case study sites	Very relevant
	Idifu	Equally useful across the case study sites	Equally useful across the case study sites	Equally useful across the case study sites	Equally useful across the case study sites	Equally useful across the case study sites	Very relevant

HH nutrition education	**Ilakala**						minimal
	Changarawe						minimal
	Ilolo			Low relevance of climate changes to this UPS in all CSS.			minimal
	Idifu						minimal

Kitchen garden training	**Ilakala**	greater effects of the UPS	little or no difference	greater effects of the UPS	no difference	greater effects of the UPS	moderate
	Changarawe	greater effects of the UPS	little or no difference	greater effects of the UPS	no difference	greater effects of the UPS	moderate
	Ilolo	greater effects of the UPS	greater effects of the UPS	greater effect sof the UPS	no difference	greater effects of the UPS	high
	Idifu	greater effects of the UPS	greater effects of the UPS	greater effects of the UPS	no difference	greater effects of the UPS	high

Household survey regarding climate change and UPS implementation

Conducted: August 2015

Climate change impacts on Trans-SEC upgrading strategies –
Connection of scenario framework and impact assessment

Corresponding authors: Christoph Gornott, Fred Hattermann
Contribution to the survey: Hannes König, Frider Gräf
Responsible for the survey in the CSS villages (Corresponding persons): Hannes König, Götz Uckert

Case study villages: Ilakala, Changarawe, Ilolo, Idifu

Instructions:

The questions focus on long term climate trends **(trends = long term shifts of patterns (climate))**. These trends include shifts (later, earlier), elongation, and shortening in saisonality and changes in frequency and strength of extreme events (heavy rains, drought, hail).

The questions below should only focus on observed climate changes in precipitation (rainfall) patterns. Temperature or other climate variables are not relevant.

Two climate change effects are relevant:

1.) Saisonality (shifts, elongation, shortening)
2.) Extreme events (frequency and strength)

Pease check while questioning: It is only relevant, if the people observe trends in precipitation (i.e. long term shifts of patterns = climate); single unusual events (=weather) are not relevant.

Possible Answers for the open questions of the UPS

e.g.: Q: How are the UPS affected?
A: Because of stronger rain events, runoff and erosion will increase, this will hamper the UPS tied ridges.
A: Poultry-crop integration: Increase in precipitation may lead to increase in crops, hence a bigger proportion will be diverted to poultry feeds. However, it may lead to outbreak of poultry diseases.
A: Waste water use in kitchen gardens reduces the negative impact on vegetable production due to lower precipitation

01.09.2015 **NR-UPS**

Climate change impacts on Trans-SEC upgrading strategies –

Connection of scenario framework and impact assessment

Corresponding authors: Christoph Gornott, Fred Hattermann
Case study villages: Ilakala, Changarawe, Ilolo, Idifu

Instructions:

The questions focus on long term climate trends **(trends = long term shifts of patterns (climate))**. These trends include shifts (later, earlier), elongation, and shortening in saisonality and changes in frequency and strength of extreme events (heavy rains, drought, hail).

The questions below should only focus on observed climate changes in precipitation (rainfall) patterns. Temperature or other climate variables are not relevant.

Two climate change effects are relevant:

1.) Saisonality (shifts, elongation, shortening)
2.) Extreme events (frequency and strength)

Pease check while questioning: It is only relevant, if the people observe trends in precipitation (i.e. long term shifts of patterns = climate); single unusual events (=weather) are not relevant.

Possible Answers for the open questions of the UPS

e.g.: Q: How are the UPS affected?
A: Because of stronger rain events, runoff and erosion will increase, this will hamper the UPS tied ridges.
A: Poultry-crop integration: Increase in precipitation may lead to increase in crops, hence a bigger proportion will be diverted to poultry feeds. However, it may lead to outbreak of poultry diseases.
A: Waste water use in kitchen gardens reduces the negative impact on vegetable production due to lower precipitation

Normally Vuli starts on October heavily but now a days,3 years ago, Vuli starts October but very shallow that is not enough to support plant growth, so it may be heavily on December then they plant on December/January.

Normally Masika starts on March and now a days it starts in same period but in poor distribution and reduced amount, also ends earlier. So people plant on Jun when the Vuli is going to end, and connects with Masika as it has short duration now!

The distribution of rain is so poor, it may rain very heavily to cause flood and stop for long period to…………

Multiple choice questions: More answers are possible!

Topic: Rainfall and water availability

1) Short rains (Vuli)

1.1) Time of the rainy season

a) Did you recognize changes in short rain times during the past 10 years?

☐ - The short rains start later in the year.
☐ - The short rains start earlier in the year.
☐ - The end of the short rains rainy season is later.
☒ - The end of the short rains rainy season is earlier.
☐ - The duration of the short rains is longer.
☒ - The duration of the short rains is shorter.

b) Does this affect the UPS____ *(please fill UPS name)***?**

☒ - Yes
☐ - No

c) What is the main effect on the UPS?

It is too short to support plant growth to maturity

1.2) Amount of rainfall

a) Did you recognize changes in amount of rain per event in short rains during the past 10 years?

☒ - There are less rainy days in the short rains.
☐ - The amount per rain event (rain per day/ per hour) increases.
☐ - There are more rainy days in the short rains.
☒ - The amount per rain event (rain per day/ per hour) decreases.

b) Does this affect the UPS____ *(please fill UPS name)***?**

☒ - Yes
☐ - No

c) What is the main effect on the UPS?

Shortage of moisture for production.

Disturb the planting scaduale.

Multiple choice questions: More answers are possible!

Topic: Rainfall and water availability

2 Long rains (Masika):

1.1) Time of the rainy season

a) Did you recognize changes in long rain times during the past 10 years?

☐ - The long rains start later in the year .
☐ - The long rains start earlier in the year.
☐ - The end of the long rains rainy season is later.
☒ - The end of the long rains rainy season is earlier.
☐ - The duration of the long rains is longer.
☒ - The duration of the long rains is shorter.

b) Does this affect the UPS______________________________ *(please fill UPS name)***?**

☐ - Yes
☒ - No

c) What is the main effect on the UPS?

Because of long rains (duration) from Vuli they start planting earlier and plant be supported by the remained moisture from Vuli

1.2) Amount of rainfall

a) Did you recognize changes in amount of rain per event in long rains during the past 10 years?

☒ - There are less rainy days in the long rains.
☐ - The amount per rain event (rain per day/ per hour) increases.
☐ - There are more rainy days in the long rains.
☒ - The amount per rain event (rain per day/ per hour) decreases.

b) Does this affect the UPS______________________________ *(please fill UPS name)***?**

☒ - Yes
☐ - No

c) What is the main effect on the UPS?

Less moisture.

Sometime it may lead to floods.

Changarawe NR

Multiple choice questions: More answers are possible!

Topic: Rainfall and water availability

3 Dry spells: (both Vuli & Masika, normally in February are longer.)

1.1) Time of the dry spells

a) Did you recognize changes of dry spell times during the past 10 years?

☐ - The dry spells occur later in the year.
☒ - The dry spells occur earlier in the year.
☒ - The duration of the dry spells is longer.
☐ - The duration of the dry spells is shorter.
☒ - The frequency of the dry spells is higher (more often).
☐ - The frequency of the dry spells is lower (rarely).

b) Does this affect the UPS____ *(please fill UPS name)***?**

☒ - Yes
☐ - No

c) What is the main effect on the UPS?

Affect yield especially Maize.

RWH

Changes you have observed in 10 years.

i- Vuli (Short rains)

→In previous years, short rains were enough even to plant and growth cowpea, maize, paddy.
→In previous years, Vuli started on November and/or December and/or January and February was the dryer months.
→In recent years (eg 2014) Vuli starts on October, use …
→Now days, people ………due to changes in season and rain distribution.

ii- Masika (long rains)

→It starts on March. The condition has less change but the difference of previous years and recent is that Masika is not as long as in previous years. Also in the Masika in previous years, rains were enough but now it may rain today and it will rain again after 2-3 weeks' time. In addition the average of rains previously was higher compared to recent years.

- Is the changes in rainfall pattern and amount have any changes in Masika season on production?
  Man: no change in production → why? In March even if this ... change in rainfall pattern and amount, the condition is cooler hence reducing dry spell
  Woman: no change in production.
- Dry spell has prolonged. The rains may stop on early May. Until November in the previous the rains will go until the end of May or even early June.
- How does the changes in climate affect UPS implementation?
  Ans:
  Lady: for thoes in hilly …., they much depend on Masika but for those in valley areas, they start planting using Vuli rains and the crops will grow through Masika.
  Man:

RWH

Multiple choice questions: More answers are possible! llakala

Topic: Rainfall and water availability

1) Short rains (Vuli)

1.1) Time of the rainy season

a) Did you recognize changes in short rain times during the past 10 years?

☐ - The short rains start later in the year.

☒ - The short rains start earlier in the year.

☐ - The end of the short rains rainy season is later.
☐ - The end of the short rains rainy season is earlier.
☐ - The duration of the short rains is longer.
☐ - The duration of the short rains is shorter.

b) Does this affect the UPS____ *(please fill UPS name)***?**

☒ - Yes
☐ - No

c) What is the main effect on the UPS?

1.2) Amount of rainfall

a) Did you recognize changes in amount of rain per event in short rains during the past 10 years?

☒ - There are less rainy days in the short rains.
☐ - The amount per rain event (rain per day/ per hour) increases.
☐ - There are more rainy days in the short rains.
☒ - The amount per rain event (rain per day/ per hour) decreases.

b) Does this affect the UPS____ *(please fill UPS name)***?**

☒ - Yes
☐ - No

c) What is the main effect on the UPS?

RWH

Multiple choice questions: More answers are possible! llakala

Topic: Rainfall and water availability

2 Long rains (Masika):

1.1) Time of the rainy season

a) Did you recognize changes in long rain times during the past 10 years?

☒ - The long rains start later in the year. (not much- very small change)
☐ - The long rains start earlier in the year.
☐ - The end of the long rains rainy season is later.
☒ - The end of the long rains rainy season is earlier.

☐ - The duration of the long rains is longer.

☒ - The duration of the long rains is shorter.

b) Does this affect the UPS____ *(please fill UPS name)***?**

☐ - Yes

☒ - No

c) What is the main effect on the UPS?

They used to receive heavy (very) so reduced amount …. not .. the effect year.

…… the day spell is prolonged, it doesn't affect ….

1.2) Amount of rainfall

a) Did you recognize changes in amount of rain per event in long rains during the past 10 years?

☐ - There are less rainy days in the long rains.
☐ - The amount per rain event (rain per day/ per hour) increases.
☐ - There are more rainy days in the long rains.
☐ - The amount per rain event (rain per day/ per hour) decreases.

b) Does this affect the UPS____ *(please fill UPS name)***?**

☐ - Yes
☐ - No

c) What is the main effect on the UPS?

25.08.2015

There is there is a lot of changes in rainfall patterns on 10 years.

→ Normally

- Rains starts late November/early December.
- Rains ends on April.
- Dry spell …. the season in feb.
- It may come on Nov and stops (within two weeks)/ until Jan(the distribution is very irregular)

→ the rain season duration have become too short (* no much change in the time when the rain starts but the end of the season in March unsteady of April.)

→ there is changes in amount of rainfall (now days it may rain so heavily at very short period like two days in the beginning of the rain season, there after the amount of rain decrease sustainably up the end of the season.)

→ there is positive effect; like when people start using the improved stoves, the speed of cutting trees will be reduced.

Llakale
NR

Vuli has changed in 10 years

Support crop growth up to maturity/ harvest (eg: paddy/ Maize/Cowpeas)

→Started in November- January.

→Dry spell in February

→Then connects into Masika in March.

*Nowadays Vuli start early with poor distribution of rain events (long intervals of dry spell in the season that the plant can not source).

*The amount of rain is decreased largely, normally it start- heavily then the amount decrease. Nowadays they stop cultivating maize and paddy and go for cowpeas and …… that needs little rains.

- Dry season has become longer because the season ends earlier in May unlike the past years (and they no longer.)
  Receive (mrua za maembe) in Agust.
  → It affects production depends on the location of the … . There is diggenett perception within the group.
- For those farms located in the low lands- favored by Vuli.
- Who have farms in the uplands they are favored by Masika.
- Finger millet can be grown anytime (Vuli or Masika) whether uplands /lowland. But Maize depends a lot on rains.
  → It's difficult to set priority (because of these differences.) with the group.
  → the decision on mal will base on the crop (other crop will grow in Vuli other Masika) location base.

- Masika has used to be very heavy but now days the amount is decreased.
- The dry spell within the season is longer.

Multiple choice questions: More answers are possible!

Topic: Rainfall and water availability

1) Short rains (Vuli)

1.1) Time of the rainy season

a) Did you recognize changes in short rain times during the past 10 years?

☐ - The short rains start later in the year.
☐ - The short rains start earlier in the year.
☐ - The end of the short rains rainy season is later.
☐ - The end of the short rains rainy season is earlier.
☐ - The duration of the short rains is longer.
☐ - The duration of the short rains is shorter.

b) Does this affect the UPS______________________________ *(please fill UPS name)***?**

☐ - Yes
☐ - No

c) What is the main effect on the UPS?

1.2) Amount of rainfall

a) Did you recognize changes in amount of rain per event in short rains during the past 10 years?

☐ - There are less rainy days in the short rains.
☐ - The amount per rain event (rain per day/ per hour) increases.
☐ - There are more rainy days in the short rains.
☐ - The amount per rain event (rain per day/ per hour) decreases.

b) Does this affect the UPS______________________________ *(please fill UPS name)***?**

☐ - Yes
☐ - No

c) What is the main effect on the UPS?

Multiple choice questions: More answers are possible!

Topic: Rainfall and water availability

2 Long rains (Masika):

1.1) Time of the rainy season

a) Did you recognize changes in long rain times during the past 10 years?

☐ - The long rains start later in the year .
☐ - The long rains start earlier in the year.
☐ - The end of the long rains rainy season is later.
☐ - The end of the long rains rainy season is earlier.
☐ - The duration of the long rains is longer.
☐ - The duration of the long rains is shorter.

b) Does this affect the UPS____ *(please fill UPS name)***?**

☐ - Yes
☐ - No

c) What is the main effect on the UPS?

____

____

____

____

1.2) Amount of rainfall

a) Did you recognize changes in amount of rain per event in long rains during the past 10 years?

☐ - There are less rainy days in the long rains.
☐ - The amount per rain event (rain per day/ per hour) increases.
☐ - There are more rainy days in the long rains.
☐ - The amount per rain event (rain per day/ per hour) decreases.

b) Does this affect the UPS____ *(please fill UPS name)***?**

☐ - Yes
☐ - No

c) What is the main effect on the UPS?

____

____

____

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Multiple choice questions: More answers are possible!

Topic: Rainfall and water availability

3 Dry spells:

1.1) Time of the dry spells

a) Did you recognize changes of dry spell times during the past 10 years?

☐ - The dry spells occur later in the year.
☐ - The dry spells occur earlier in the year.
☐ - The duration of the dry spells is longer.
☐ - The duration of the dry spells is shorter.
☐ - The frequency of the dry spells is higher (more often).
☐ - The frequency of the dry spells is lower (rarely).

b) Does this affect the UPS____ *(please fill UPS name)***?**

☐ - Yes
☐ - No

c) What is the main effect on the UPS?

Defining the onset and cessation of the rainy season for Tanzania

Web-GIS

1 Introduction and methods

1.1 Overview

In various parts in Sub Saharan Africa, the onset of the rainy season is crucial for the crop development in the first development stages after sowing (Omotosho et al. 2000). After sowing, insufficient crop water conditions increase the risk of crop failure. In particular in years with late rainy season onsets, the crop yields response very sensitive (Sivakumar 1990). In Tanzania, the growing season is strongly influenced through the yearly amount and intra-annual distribution of precipitation. Within Tanzania, the yearly amount of precipitation and the rainy season onset and cessation are quite heterogeneous (see Trans-SEC – Weather analysis for Tanzania and FAO 2015). Accordingly, farmers have to adapt their management on the regional rainy season circumstances.

The rainy season onset can be defined by various methods. The method used by Omotosho et al. (2000) based on an analysis of the atmospheric conditions (temperature and upper winds in the inter-tropical discontinuity). Vrieling et al. (2013) calculate the onset and the variability of the rainy season by the Normalized Differenced Vegetation Index (NDVI) from remote sensing time series data. For a region in Kenya around the Lake Victoria, Mugalavai et al. (2008) take the modeled soil water content as onset and cessation definition criteria for an average soil. Another opportunity is the direct use of precipitation records (P). This has the advantage that (i) mostly, precipitation has a higher density of weather stations (in comparison to e.g. solar radiation), (ii) precipitation has a clear intra-annual variation in Sub Saharan Africa (in contradistinction to temperature), and (iii) precipitation is as easy observable climate variable (also observable without measuring instruments) the direct decision basis for agricultural practices of farmers. Thus, assessments of the rainy season onset and cessation based on precipitation records are a powerful and low data demanding opportunity. For the implementation on rainy season onsets, various definitions exist, which based on fulfilled restrictions. These restrictions are mostly very similar, but the criteria of the restrictions differ substantially among the regions.

1.2 Rainy season criteria

To define the rainy season onset, a large range of definitions using different restriction criteria exist in the literature. Odekunle (2006) recommends the number of rainy days rather than the amount of precipitation for the calculation of the rainy season onset and cessation in Nigeria. In Average (across the years), the precipitation amount archives a similar result as the number of rainy days. However, considering inter-annual variability, the number of rainy days leads to more plausible results. To identify the rainy season onset and cessation, Odekunle (2006) use the perceptual, 5 days running average cumulative precipitation curve. From this curve, he takes graphically the first point of a positive curvature as onset and the last point of the negative curvature as cessation. For Australia, Cook and Heerdegen (2001) describe the spatial variation of the rainy season duration and onset based on probability[1] of a 10 day dry spell. For their analysis, they calculate the probability by a 10 days running average. The onset is defined as far as the probability is below 0.5.

A comparatively simple approach is use by Waha et al. (2012) for their global crop yield model LPJmL. Depending on the region, the sowing of annual crops is limited either by temperature or precipitation. In the region Tanzania, the sowing date is limited by the precipitation. The algorithm for a precipitation limited region defines the precipitation around the month with the largest sum of monthly precipitation-to-potential-evapotranspiration ratios of four consecutive months as main rainy season. The first precipitation day ($P_d \geq 1\,\mathrm{mm}$) within the main rainy season is defined as onset of the rainy season and is equally the sowing date.

For the period from 1978 to 2002, Kniveton et al. (2008) show a trend of later occurring rainy season onsets for Africa. However, their results strongly depend on the onset restrictions. As restriction, they use an definition after Stern et al. (1982), which is frequently use for Africa in agro-climatological applications: "(i) the start of the wet season is not considered until after a particular date, d; (ii) the potential start date is defined as the first occurrence of at least l mm totaled over k consecutive days; and (iii) the potential start could be a false start if a dry spell of n or more days in the next m days occurs afterwards. The variables d, k, l, m, and n can be defined locally according to user requirements."

Moeletsi and Walker (2012) and Reason et al. (2005) use a similar definition for South Africa. Moeletsi and Walker (2012) use as criteria for the restriction "the last day in which rainfall of 25 mm or above has been

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[1] However, they do not describe the method behind the word *probability.* As method is a simple cross section analysis across the years, a Bayesian probability, or an estimator by Maximum-Likelihood possible. However, since the method is not further described, I expect they take the simplest.

accumulated over the previous 10 days and at least 20 mm accumulated in the subsequent 20 days." Reason et al. (2005) take the "date of the first two pentads with at least 25 mm of rainfall, provided this is followed by four pentads within which at least 20 mm of rainfall occurs."

For Ethiopia, Segele and Lamb (2005) compare the rainy season onset and cessation with different methods (e.g. upper winds and precipitation restrictions) and different criteria for the precipitation restrictions. As onset criteria, they take, for instance, a precipitation sum of > 20 mm within three days and without a dry spell (< 0.1 mm precipitation) longer than 8 days within the following 30 days. The cessation is defined as date where 20 or more following days occur with precipitation less than 0.1 mm. Therefore, Segele and Lamb (2005) test different definitions of both rainy days (0.1, 5, 10 $\mathrm{mm\,d^{-1}}$) and dry spells (three contiguous dry days ($< 0.1\,\mathrm{mm\,d^{-1}}$), five contiguous days with less than 5 mm rain on any day ($< 5\,\mathrm{mm\,d^{-1}}$), or five contiguous days on which rain do not exceed $10\,\mathrm{mm\,d^{-1}}$).

1.3 Definition

The most common method of onset definitions for Africa is an algorithm based on fulfilled precipitation restrictions (see Stern et al. 1982). The simplest restriction takes the first day (expressed in days of the year (doy)) with more than 1 mm precipitation (P) as onset of the rainy season (Waha et al. 2012):

$$\mathrm{doy}_{onset} = \mathrm{doy}_d \quad \{\ P_d \geq 1 \tag{1}$$

Equation (Eg.) 1 can be expanded by more restrictions (e.g. to prevent that in following 25 days after onset no dry spell occurs[2]) and specified by changed restriction criteria (e.g. $10\,\mathrm{mm\,d^{-1}}$ instead of $1\,\mathrm{mm\,d^{-1}}$). Based on the literature and various tested restriction criteria, we use the following approach to calculate the date for onset of the rainy season:

$$\mathrm{doy}_{onset} = \mathrm{doy}_d \quad \begin{cases} P_d \geq 1 \\ \sum_{d=1}^{5} P_d \geq 10 \\ \sum_{d=6}^{30} P_d \geq 1 \\ \mathrm{doy}_{onset-1} < \mathrm{doy}_{cessation-1} \end{cases} \tag{3}$$

For the cessation, we calculate the date by the Eq. 4. The last restriction make sure that onset and cessations (Eq. 3 and 4) alternate.

$$\mathrm{doy}_{cessation} = \mathrm{doy}_d \quad \begin{cases} \sum_{d=1}^{20} P_d < 10 \\ \mathrm{doy}_{onset-1} > \mathrm{doy}_{cessation-1} \end{cases} \tag{4}$$

To consider the short and long rains, a further restriction is used. These restriction investigates whether the following 90 days after the end of the rainy season have summed more than 20 mm precipitation. In that case, a second rainy season (with the same onset restrictions) is considered. In particular, whether the onset and cessation dates are averaged by years, the consideration of more than one rainy season is important. Otherwise the onset date will be delayed and the cessation will be calculated premature due to this aggregation.

2 Results and discussion

Fig. 1 shows the observed average distribution of precipitation for different weather stations. On the bottom of each plot are the onset and cessation dates calculated by Eq. 3 and 4. In the case of only one rainy season (see above for the definition), the symbols ($\triangle, +$) are black, for two or more rainy seasons, the symbols are gray. The plots based on the average of the years from 1970-2006, thus black and gray symbols are in the plots. For the regions around Dodoma and Songea, a clear cut between dry and rainy season is observable, while for Bukoba and Mwanza, the rainy season occurs over the whole year with changing intensities.

Fig. 2 shows the variation of the onset dates over the years. To test whether there is a shift of the onset dates within the observed period, a trend analysis is shown for the onset dates. Therefore, we utilize the Mann-Kendall

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[2] Since the crops are able to survive for short periods without sufficient water supply, but longer dry spells (ds) are critical for the crop development, the days without precipitation (dwp)

$$dwp < 10 \quad \begin{cases} dwp = \sum_{d=1}^{D} ds_d \end{cases} \quad \begin{cases} \text{if } P_d \neq 0, & ds_d = 1 \\ \text{if } P_d = 0, & ds_d = 0 \end{cases} \quad . \tag{2}$$

can be useful variable. This variable takes into account the plant requirements, while the approach of a precipitation amount within a specific period considers only the amount within one period, but not distribution.

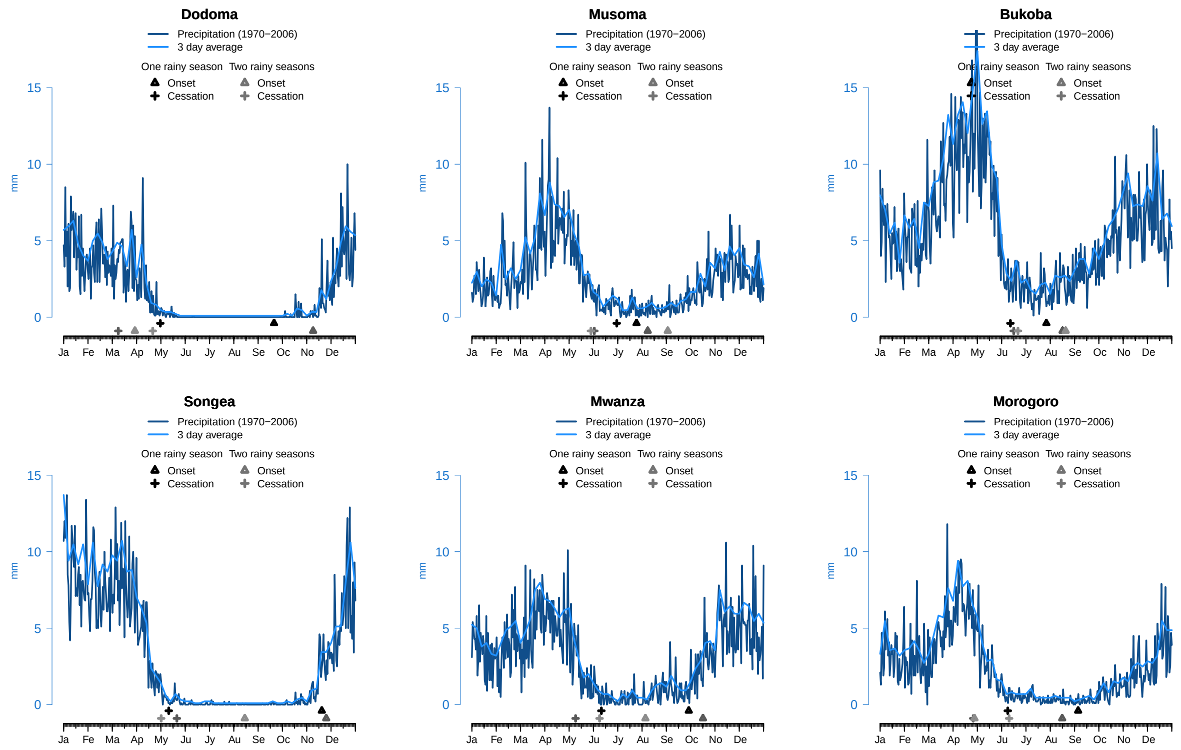

Figure 1: Onset and cessation dates for the rainy season for different weather stations (bottom). The blue line shows the average intra-annual precipitation distribution.

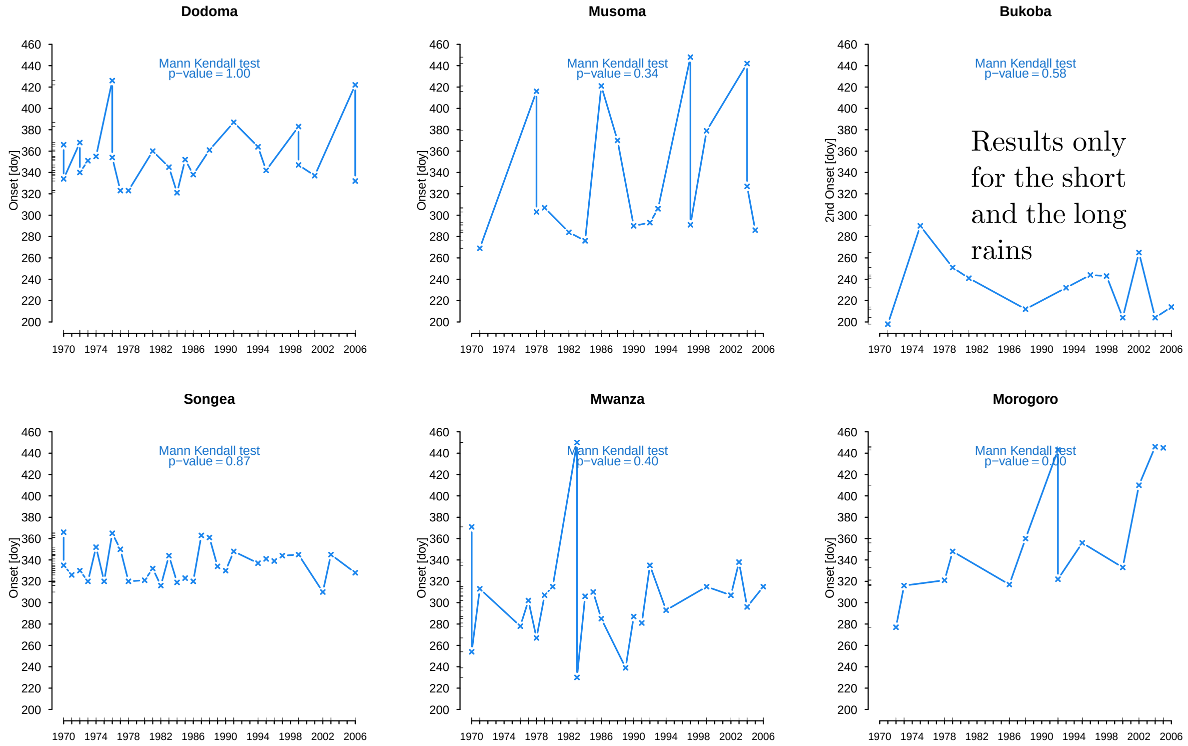

Figure 2: Onset doy's (days of the year) variation over the years. The doy 365 is December 31^{st}, the doy 366 is January 1^{st}. The Mann Kendall test shows whether there exists a significant trend over the time. A p-value below 0.05 means there is a significant trend, above 0.05 there is no significant trend in the time series.

test to check whether the time series has a significant trend. If the p-value of this test is $p \leq 0.05$, the time series contains a trend; if $p > 0.05$, no trend is observable. For onsets around December and January (of the following year), the averaging of the doy's leads to a technical problem, because June is the average of the December and January. Therefore, we split the year at the 200th doy. All days below doy 200 are shown as extension of the year (doy+365). For all tested 16 weather stations (not all shown in the figure), only Morogoro has a significant trend for the onset for one rainy season per year. In the case of two or more rainy seasons, no weather station has any trend. Since the Morogoro trend only based on 13 observations (in the other years are two rainy seasons) and the Morogoro dataset is compounded by two datasets, the trend might be an error.
Fig. 3 shows the calculated average onset dates for entire Tanzania. The calculation based on reanalysis weather data (WFDEI 1979-2012). In the maps are clear regional patterns for the onset and cessation dates. These patterns are (more or less) in line with the onset and cessation dates from the remote sensing data observed by Vrieling et al. (2013) and the estimated precipitation data from the FAO (2015).

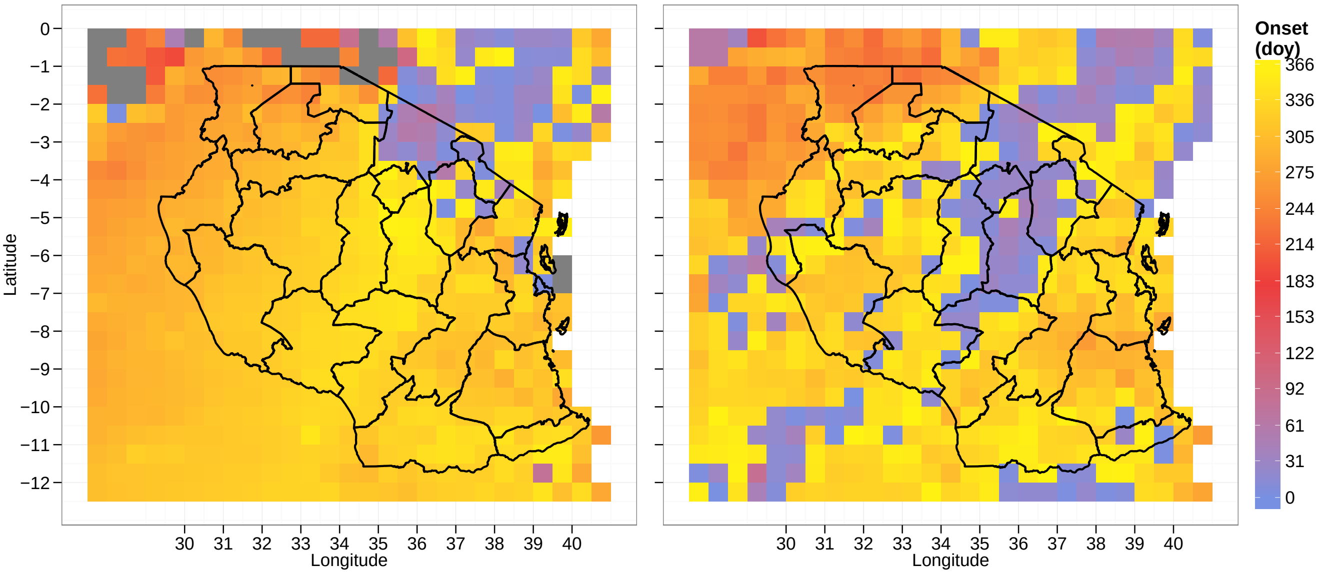

Figure 3: Average onset doy's (days of the year) for entire Tanzania based on WFDEI reanalysis weather data (0.5° grid data). Left: Average onset doy's of areas with one rainy season. Right: Average onset doy's of the second rainy season in areas with at least two rainy seasons.

2.1 Opportunities for improvement

Due to the heterogeneous yearly precipitation amounts within Tanzania, static onset restriction criteria are regional only limitedly able to differentiate between dry and rainy season. In wetter regions with rain events during the "dry season" the rainy season doesn't end (e.g. Fig. 1, Bukoba, Mwanza). In the semi-arid regions in Tanzania (e.g. Fig. 1, Dodoma, Songea) are the restrictions to strong so that in several years the conditions for the onset are not fulfilled. Laux et al. (2008) also argue that constant restrictions lead to unfulfilled restrictions in regions with low precipitation (no onset in one or over more years) and ongoing rainy seasons in wetter regions over more years. Thus, they use a fuzzy logic approach. This approach considers different "dry" and "wet" levels as semi-constant criteria. Boyard-Micheau et al. (2013) use a multivariate analyzes for determinate the onset and cessation for Kenya and Tanzania. They criticize that the approach with constant restriction criteria rarely is transportable to other crops and other climate environments. To solve this problem, they calculate the onset for all stations, for all years and various combinations of onset restrictions (k, l, m, and n). In a following step, they estimate the impact of the single criteria by a principal component analysis.

2.2 Rainy season, sowing date and farmer behavior

Frequently, farmers sow before the actual rainy season onset (dry seeding) or they start sowing only with the big rains (Graef and Haigis 2001). In both cases, rainy season onset and sowing date are not at the same day. In the case of dry seeding, the crop growing season starts at the rainy season onset (after the sowing date). The duration of the growing season depends on the crop selection; hence the cessation of the rainy season is not equal with the harvest date. This leads to the question, are the onset date calculated by Eq. 3 a good proxy for the sowing date?

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