Objective prioritization of intervention areas for the NAGA Foundation in the Kenya Tanzania border area

TECHNICAL REPORT · MARCH 2016

DOI: 10.13140/RG.2.1.4996.7769

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This research was (partly) funded by the NAGA Foundation.

Alterra Wageningen UR
Wageningen, March 2016

Alterra report 2711
ISSN 1566-7197

Hutjes, R.W.A., L. Fleskens, A.M.J. Jaspers, J.E.M. Klostermann, H.W. ter Maat, E.P. Querner, 2016. *Objective prioritization of intervention areas for the NAGA Foundation in the Kenya Tanzania border area.* Wageningen, Alterra Wageningen UR (University & Research centre), Alterra report 2711.
68 pp.; 35 fig.; 10 tab.; 28 ref.

The NAGA foundation aims to establish *Hydrologic Corridors,* wherein re-greening and restoration of the landscape interacts with regional rain-bringing wind patterns to intensify the local hydrologic cycle to a point that a permanently greener and more productive ecosystem can be sustained. The initial search area, as defined by NAGA, targets the Kenya-Tanzania border region and identified four possible Hydrological Corridors. This report supports an objective prioritisation of potential intervention locations in this larger domain. Therefore, readily available, geographically explicit information on soil, vegetation, hydrology and climate, as well as institutional settings that may affect the likelihood of success of such projects, were collected and analysed, and some climate-modelling experiments were performed.
Combining the findings of the four themes: hydrology, soil restoration, climate, and institutions, and ranking the four potential corridors objectively in order of priority, favours re-greening projects in the Tanzanian corridors could provide the best starting point: especially the most eastern one. In this area, many applicable land management options exist in combination with a high potential for restoring soil organic matter, the highest rainfall recycling potential in the more favourable long rainy season, and the apparent reliability of the Tanzanian governments at both national- and at local levels. The GIS data facilitate further focus on this particular corridor in search of specific project locations.

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Alterra report 2711 | ISSN 1566-7197

Photo cover: Carlo Wesseling (Naga); Amboseli savanne in Kenya

Contents

1 Introduction

The NAGA foundation *"...restores strategically located degraded lands on a large scale using rainwater harvesting techniques and conservation methods"* (nagafoundation.org). NAGA aims to create: *"Hydrologic corridors, large areas of land that are re-greened and interconnect as their vegetation and water cycles expand. They create local atmospheric changes that results in more and equally distributed rain in the whole area."* NAGA and WUR-ESG entered a Memorandum of Cooperation with the aim to strengthen the scientific basis of the *Hydrologic Corridor* concept. As a first practical action, a project was started to support an objective choice of potential intervention projects. NAGA requested that WUR collect and present (readily available) geographically explicit information on soil, vegetation, hydrology and climate, as well as institutional settings that could affect the potential of success in such projects.

The initial search area, as defined by NAGA, targeted the Kenya-Tanzania border region and identified four possible Hydrologic Corridors, wherein a series (~15) of smaller projects (each ~20km^2) could potentially 'seed' a permanent, self-sustained re-greening of the entire area. These four areas are delineated in the following graph.

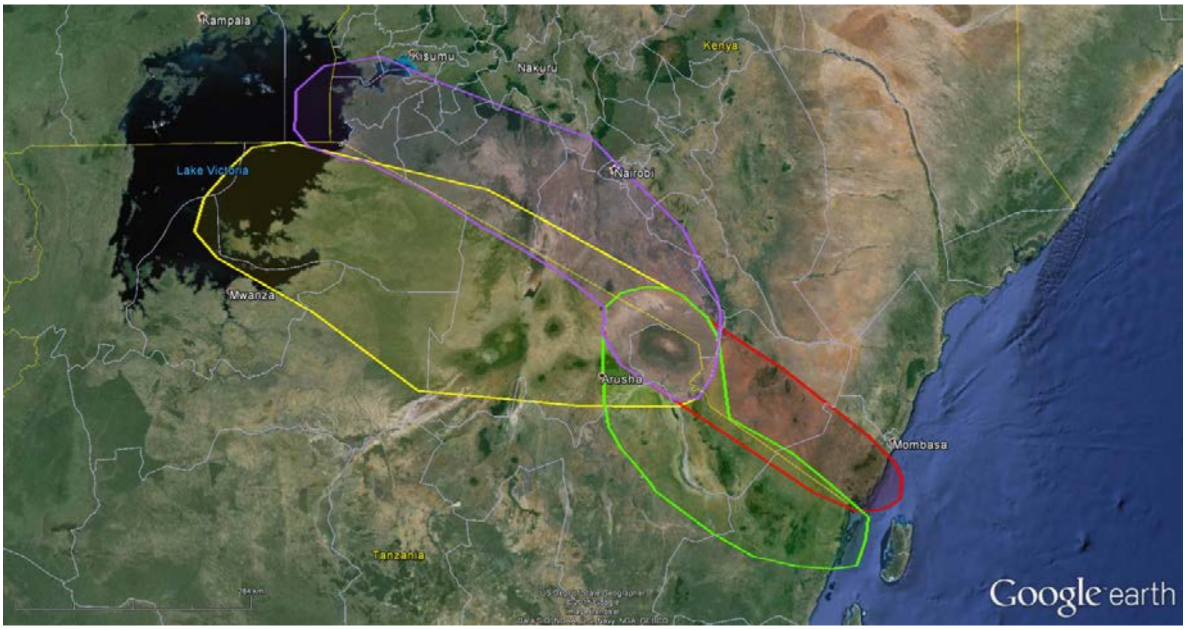


Figure 1.1 *Google Earth representation of the four potential Hydrologic Corridors in the Kenya-Tanzania border area: Kenya-East (Ke-E, red), Kenya-West (Ke-W, purple), Tanzania-East (Ta-E, green) and Tanzania-West (Ta-W, yellow).*

2 Approach to objective prioritization of intervention areas

Prioritisation of intervention areas for project locations in the *Hydrologic Corridor* concept can, and should, follow a number of objective criteria. Amongst these are degradation status (e.g. present vegetation loss, erosion and soil quality loss), soil characteristics affecting its Hydrologic functioning (slope, texture, soil depth), present drainage characteristics (streams, their drainage area, etc.), physical potential for restoration (which interventions options are available or optimal), possible climate effects (a dynamic characteristic, as opposed to the previous static characteristics) and institutional potential for restoration (capacity in the area, continuity of projects, etc.).

Once mapped, these characteristics were combined through weighting and aggregation rules, to reach a final (semi quantitative) assessment and ranking of map units in terms of suitability and priority for restoration projects. Giving weight to the various criteria should ideally involve all relevant stakeholders, which is beyond the scope of this report. The research was completed based on the expert judgement of the authors, without field knowledge or input from actors in the region. This situation could be improved with further investigation. Therefore, accompanying this report is a set of digital map layers (ArcGIS) of each of the physiographical characteristics listed above that can be further combined to give alternative weights to the various aspects if required to facilitate the search for optimally located projects.

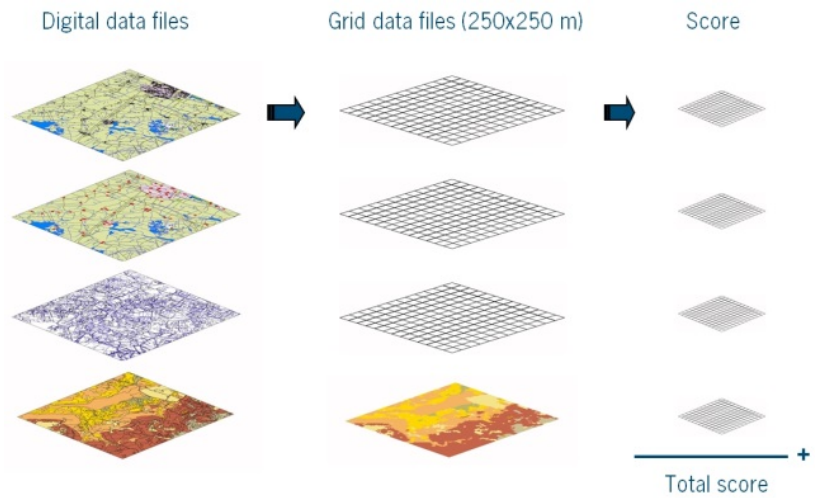


Figure 2.1 *Overall approach objective prioritisation using GIS overlays and scoring strategies. The layers do not necessarily need to be in GIS or quantitative, but can comprise of other formats and may be qualitatively ranked.*

This study serves as a 'desktop demonstration' of such an approach, based on readily available datasets, model structures and literature, rather than an extensive study that includes all details. The latter would require firstly more field work on: soil and groundwater characteristics (for Chapters 3 and 4); vegetation characteristics (i.e. sensitivity to drought stress) and meteorology (for Chapter 5); or local institutions, tribal structures and economic resilience (Chapter 6). Nevertheless, the approach is believed to be useful and the results are considered fairly robust at the scale studied here. For more detailed searches for optimal location of projects within the four corridors, such field work surely would be strongly recommended to generate the details for an otherwise similar approach.

In the following sections, analyses on comparative hydrological restoration potential will be described in Chapter 3 and soil and (implicitly) vegetation restoration potential in Chapter 4. In Chapter 5, the potential climatological effects of greening will be analysed, and in Chapter 6 will explore the effect of institutional conditions on adaptation potentials.

3 Hydrological status

3.1 Approach and data sources

Water retention is important to meet the three NAGA objectives of: Re-Greening; Flood Protection, or Erosion Protection. From a hydrological perspective, those areas with the either the greatest natural water retention capacity or water retention that can be augmented by interventions were sought. This chapter focuses on natural water retention as characterised by infiltration capacity and certain slope and drainage characteristics augmented by stream-based intervention measures. Chapter 4 focuses on soil water holding capacity, as determined by soil texture and organic matter, and is augmented by more field-based measures (from the WOCAT database). As such, the two should be considered complementary.

It is critical that rainwater can effectively infiltrate into soil. Often in the process of degradation, the ground surface becomes impermeable, which can stop or reduce the infiltration capacity of the soil. It is also essential that more water is stored in the upper soil (or root zone) or seeps to deeper layers. Water flow to deeper layers is beneficial for the recharge of groundwater reservoirs that eventually drain downstream in the basin and increase the base flow. Alternatively, this water can be utilised as drinking- or irrigation water once extracted by pump. In addition, the reduction of surface runoff towards streams is important to reduce soil erosion and prevent local flash flooding, and damage to (river) infrastructures. The local storage of surface water is also beneficial for groundwater recharge, as well as flood- and erosion control.

Different water storage abilities and infiltration measures were considered alongside landscape situations that were suitable for the infiltration of water. Important factors influencing water storage included ground slope, infiltration capacity, land use, variation in rainfall intensity, etc. as well the surface water infrastructure, of river basins and sub-basins. Favourable water retention and infiltration measures were identified and weighted against the important factors described above.

A spatial database was created and information collected on relevant properties was visualised, combined and weighted.

For the spatial hydrological analysis, the following data were used:

- Digital elevation model (DEM) and derived data of the surface slope and surface water network (basins and sub basins, depressions, etc.);
- Soil map and derived data on infiltration capacity; based on ISRIC AFSOILGRID250 (in Chapter 4 based on S-World);
- Rainfall data and derived data on maximum intensities, variation, etc. The same WFDEI data as used in Chapter 5.

3.2 Selected results and example maps

From the DEM, a drainage map was constructed that not only shows the (most probable) location of (intermittent) streams, but that can also be used to calculate the upstream area of the catchment above any point along that stream (Figure 3.1). This map was used to identify potential locations of small dams for the reduction of stream flow and erosion and the enhancement of storage and infiltration and aquifer recharge.

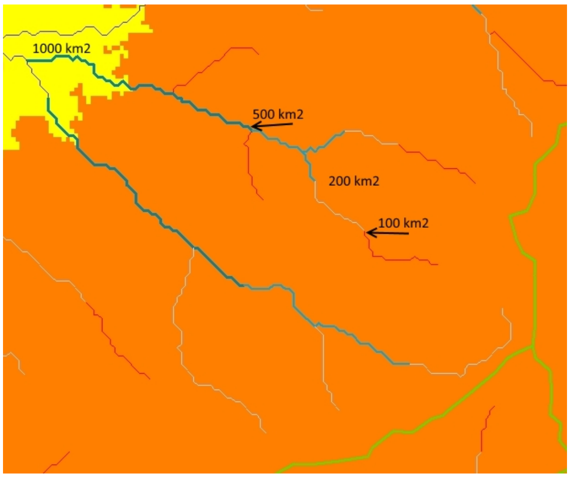


Figure 3.1 *Downstream in the river, the catchment area increases. A suitable structure in the river could harvest runoff from an area between 200 and 500 km^2.*

Next, multiple maps were combined by scoring each theme. Desirable characteristics for each theme were given a higher score than less favourable ones. With a degree of arbitrariness in this, and scores were subject to discussion. They required modification according to the objectives of the project and the discussions also helped to clarify the objectives. Table 3.1 shows an initial attempt to rank the desired characteristics.

On steeper slopes, the chance of rain infiltration of rain is generally reduced in favour of runoff. Therefore, steeper slopes were given a lower score. In the example, this may have been somewhat too conservative. Coarser soils (larger sand fraction) have a higher infiltration capacity. With ground water recharge as a project objective, sandy areas were identified and scored more highly. For recharge to occur, rain is required. Therefore, areas with sufficient rain were identified and scored more highly. However, too high rain intensities can exceed infiltration capacity and result in runoff and erosion. Thus, each theme was scored and combined with others as required.

Table 3.1

Table of possible scores per theme. The desired characteristics for each theme were given a higher score than less favourable ones. The scores below were subject to discussion and could be modified depending on the objectives of the project.

	DEM	Soil map	Meteorology		Upstream catchment	
Initial score	**slope**	**sand fraction**	**daily rain rate Febr-May**	**rain sum 5 consecutive day**	**small dams**	**large dams**
0	>1.0%	<0.35	<1mm	<30mm	<100 or >1500 km^2	<400 or > 5000 km^2
1	0.5-1.0%	0.35-0.45	1-2mm	30-40mm	1000-1500 km^2	
2		0.45-0.55	2-3mm		100-200 km^2	400-1000 km^2
3	0.25-0.5%	0.55-0.65	3-4mm	40-50mm	700-1000 km^2	2500-5000 km^2
4		>0.65	4-5mm	50-60mm	400-700 km^2	1000-1500 km^2
5	0-0.25%		>5mm	>60mm	200-400 km^2	

Below are two examples of combinations of map layers. Figure 3.2 shows the range in scores for this situation combining slope, soil and average daily rainfall (period February – May). The range in score is between 0 and 14. The darker (deeppurple) areas are the more sandy areas that do receive rainfall in this period. The Figure suggests that the highest potential is in Ta-E, whilst the lowest is in Ke-W. Figure 3.3 combines drainage channels with upstream areas suitable for small dams, plus average daily rainfall around Mt. Kilimanjaro.

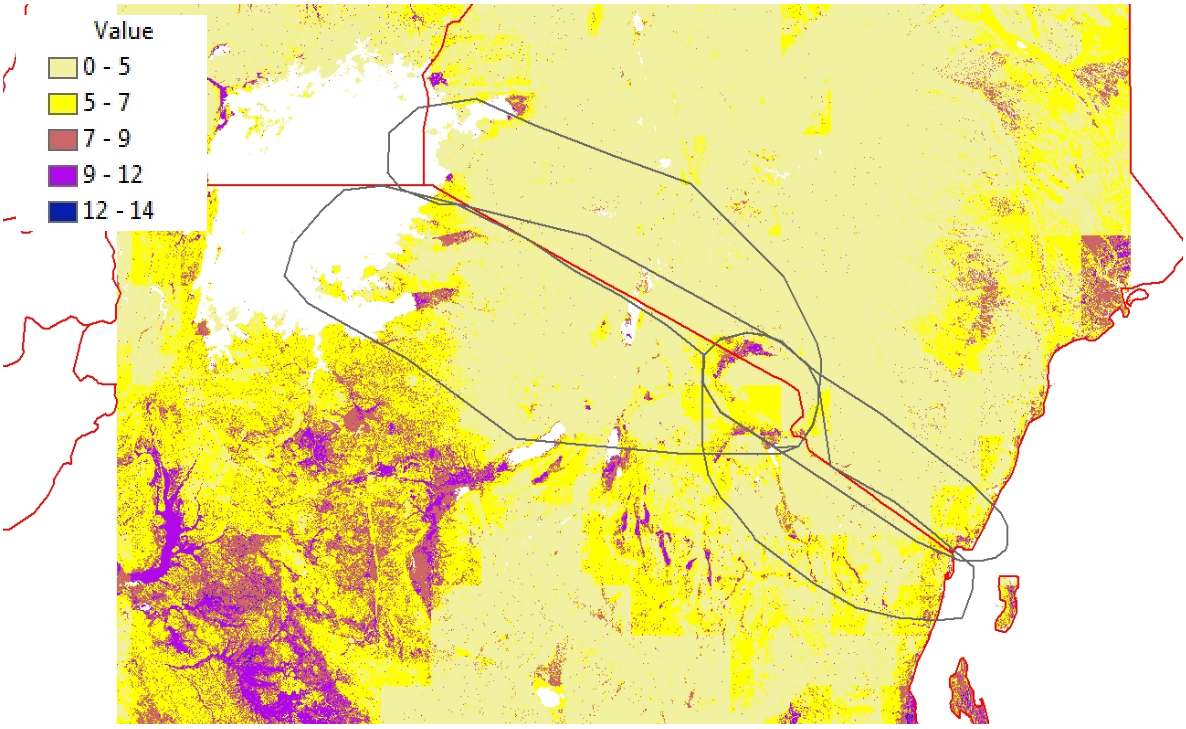


Figure 3.2 *The graph shows the range in scores combining slope, soil and average daily rainfall. The range in score is between 0 and 14.*

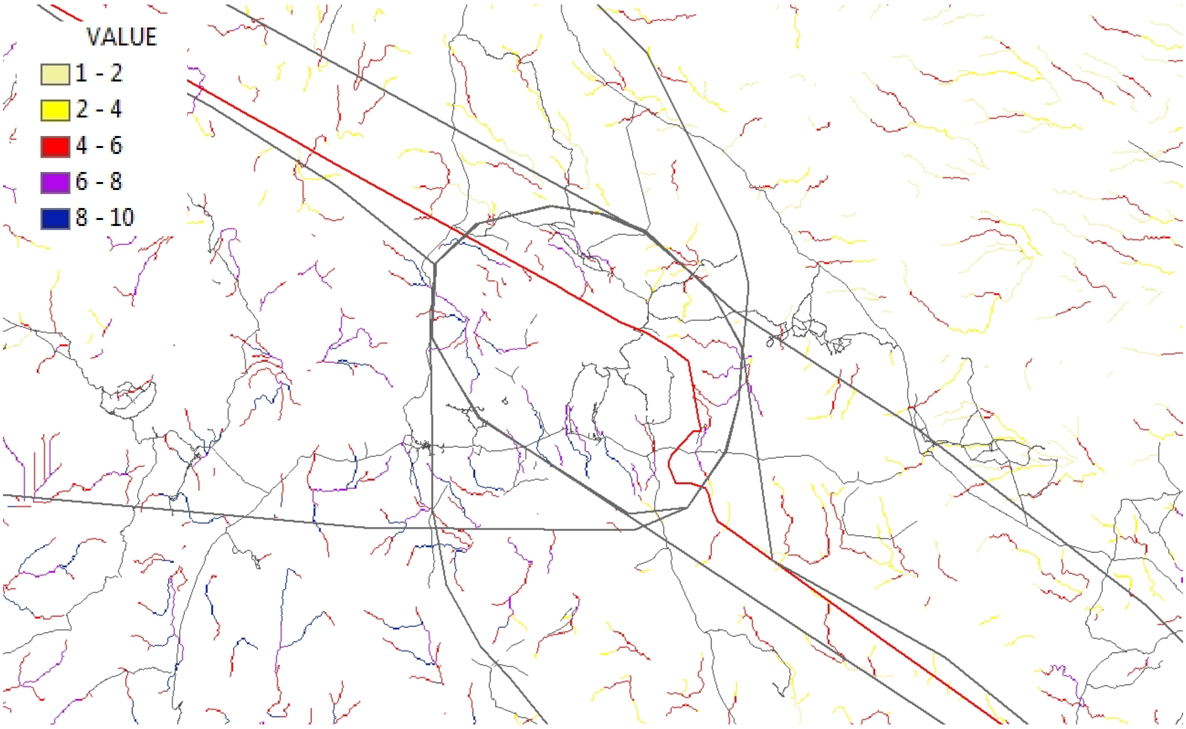


Figure 3.3 *The graph shows the range in scores combining drainage channels with upstream areas suitable for small dams, plus average daily rainfall. The thin black lines are (dirt) roads.*

4 Degradation state and restoration options

4.1 Approach and data sources

To identify areas with the largest potential for restoration and to choose the most optimal measures to effectuate this, a mapping approach was followed using the WOCAT database (www.wocat.net) to identify the effects of different categories of restoration options or sustainable land management (SLM) measures.

The mapping approach was built on the premise that SLM measures can affect soil degradation state in two ways:

- Restoring soil organic carbon (SOC); improving soil cover and enhancing soil health, either through amendment of chemical soil fertility (manuring, composting) or altering the physical or biological properties of soils (mostly indirectly), can restore the SOC content of degraded land.
- Preventing soil loss; controlling soil loss through erosion processes by reducing the susceptibility of soils to the impact of rain and wind, or limiting the transport capacity of these vectors can prevent loss of SOC.

Most SLM measures contribute to both effects simultaneously. To summarise the effects, both restoration and prevention were expressed regarding their effect on SOC, which can be considered a proxy indicator for soil productivity. The extent to which they do so depends on time. Figure 4.1 conceptualises that increasing levels of SOC effect can be obtained over time.

However, the shape of the restoration and prevention trend lines is governed by a number of factors (Fleskens *et al.*, in preparation):

- Time after investment; A literature survey on results from multi-year and long-term field experiments of restoration options showed that the most promising technologies tested achieve a logarithmic increase of SOC over time, i.e. rapid initial gain that flattens off over time. This logarithmic curve was generalised with the aid of WOCAT expert data.
- Maximum potential for SOC restoration; this provided ceiling values for SOC content based on given current land use or natural conditions, based on finding analogues for each situation. The maximum potential for SOC restoration was taken as the difference between current and maximum SOC in soils.
- Remaining soil depth for soil loss prevention; scenario analyses provided information on the diminution of topsoil depth over time due to soil erosion processes. Top soil loss was considered linearly in this study.

When implementing the above approach spatially, there were three possible situations:

1. If there is no restoration potential in a given grid cell, no SOC increase will be possible; note that for SLM technologies the potential is defined as keeping the same land use, whereas for reforestation options the natural potential is used as maximum value.
2. As long as restoration is possible and the potential is not reached, for SLM technologies SOC restoration is defined in proportion to the generic SOC restoration curve, with initial SOC stock, expert % SOC increase estimate, and assessment lag determining the level of SOC increase (see Figure 4.2)
3. When the potential level of restoration is reached, no further increase of the SOC is possible.

Figure 4.1 exemplifies how the restoration curve works for a variety of conditions. The standard SOC increase line (dotted line) is a basic function derived from literature. WOCAT expert opinion on SOC increase is presented as a percentage, by which SLM measures can increase SOC. As such, the initial SOC content has a large effect on how effective a measure is considered to be. For example, comparing the blue (lower) and orange (upper) curve in Figure 4.2, the difference between starting off with a current SOC level of 25 or 50 ton C ha-1 becomes apparent. Slow SOC restoration in very degraded conditions has been observed experimentally as well, which supports differentiation by initial SOC content.

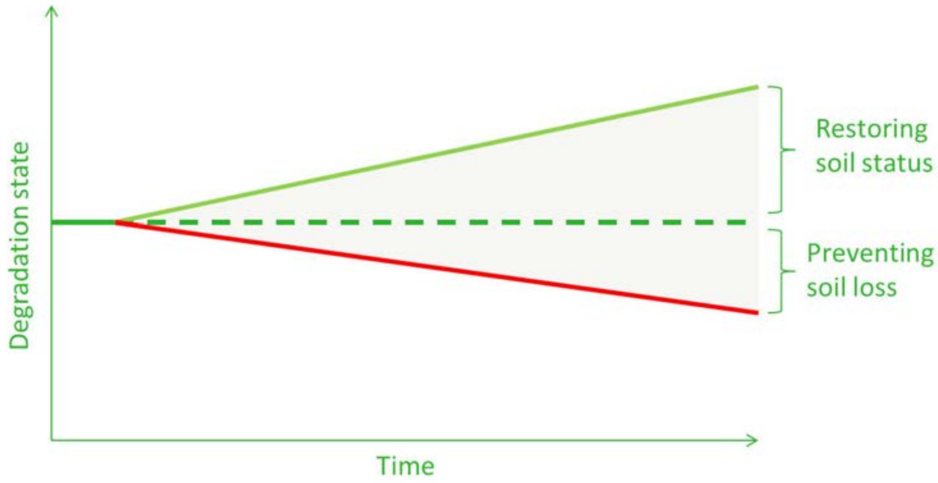


Figure 4.1 *Conceptual approach to consider degradation state and restoration potential. Degradation state can be assessed using different variables, e.g. soil depth or soil carbon content. Restoration enhances the soil degradation state, prevention decreases the soil degradation rate. In this study, the effects of restoration and prevention are summarised through their impact on soil carbon content as a proxy for soil productivity.*

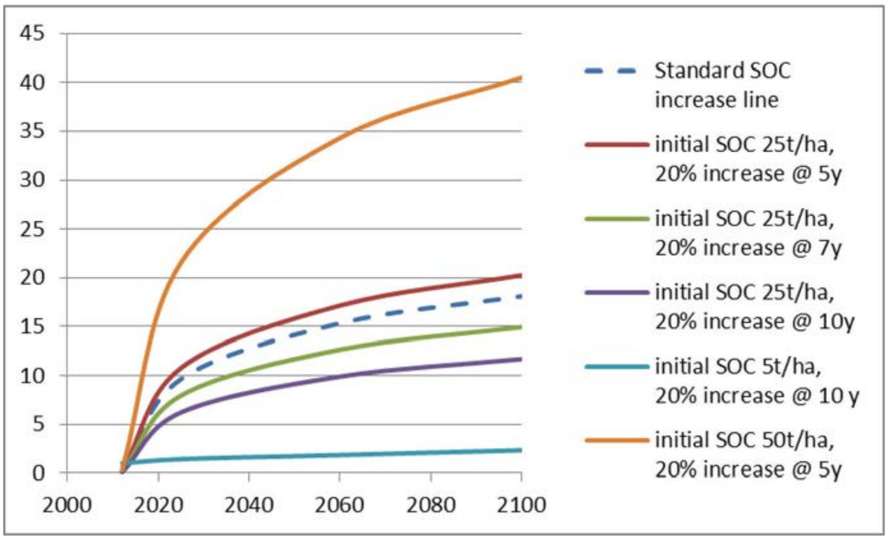


Figure 4.2 *Example SOC restoration curves modelled through hybrid consideration of expert opinion and experimentally determined standard SOC increase line.*

SLM measures were selected from the WOCAT Technologies database (www.wocat.net). The database in total features over 400 individual SLM measures originating from a variety of countries worldwide. Individual measures were selected for analysis based on the criterion that they included an estimate of the effect on SOC content of soils. This yielded a set of ~200 technologies, which was further delimited based on availability of realistic investment cost information. Based on this dataset, for the purpose of a global assessment of SOC restoration potential, a classification of SLM measures was needed that a) is sufficiently refined to meaningfully distinguish clusters of SLM measures that have similar applicability limitations, cost and effect; b) offers spatially differentiated potentials for restoration actions; and c) includes sufficient member technologies to characterise costs and effect of the category. The resultant classification of SLM categories was as follows:

SLM Category 1: Afforestation (AFFOR) - Plantation of trees or bushes for regeneration of natural areas or reclamation of degraded land. Afforestation is sometimes combined with other measures, such as terracing, and is often initiated especially to reduce off-site effects of land degradation (including wind erosion).

SLM Category 2: Agroforestry (AGROF) - Agroforestry entails the integration of trees or tree crops and agriculture for synergies in productivity and ecosystem service provisioning. Interventions are from a SLM perspective concerned with better soil cover and increased production.

SLM Category 3: Agronomic measures (AGRON) - Agronomic measures cover a broad range of options that need to be annually repeated and/or have a short-term effect.

SLM Category 4: Bunds (BUND) - Bunds are defined as structural, cross-slope measures that can be constructed without a massive amount of earth movement (which is characteristic for terracing). Over time, slopes treated with bunds can gradually form into terraces. Their main objective is to break slopes to reduce the velocity of run-off and increase infiltration.

SLM Category 5: Grazing land management (GRZMGT) - This category includes management strategies for grazing land and range lands in dry lands. Their main purpose is to facilitate the build-up of vegetation and soil organic matter. The environments covered by this category include grasslands and shrub lands.

SLM Category 6: Gully rehabilitation (GULREH) - The measures in this category serve to mitigate gully development or rehabilitate degraded bad lands. Frequently, the aim is to reduce flow velocity and/or protect gully banks and heads.

SLM Category 7: Home garden improvement (HOMGAR) - Home garden improvement measures are often combinations of multiple technologies requiring high or frequent resource inputs, especially of labour. They are, thus, often relatively expensive and usually confined to small-scale intervention areas.

SLM Category 8: Irrigation (IRRI) - Irrigation involves developing permanent access to water for increased productivity and/or increased water use efficiency of existing irrigation systems. Irrigation technology is often expensive, but leads to large productivity increases, out-of-season cropping opportunities and increased resilience to droughts.

SLM Category 9: Terracing (TERRA) - Terracing reduces slope length and slope gradient by substantial earth movement, sometimes accompanied by stabilisation measures (stone walls, vegetation). Construction of terraces is labour (or machine) intensive. Apart from controlling soil erosion, terraces may also achieve water conservation, and offer opportunities for intensification or increased productivity of agricultural systems. Terraces can enable agriculture in areas otherwise unsuitable, or allow introduction of irrigation.

SLM Category 10: Vegetative barriers (VEGB) - Vegetative barriers refer to cross-slope planting of vegetation as a permanent barrier. This intervention breaks the slope, thereby reducing velocity of run-off and increasing infiltration. Vegetative barriers are often combined with bunds, and the distinction is, to a certain extent, arbitrary.

SLM Category 11: Vegetative cover (VEGCOV) - Measures in this category aim at the (re-)establishment of vegetative ground cover to reduce the impact of rainfall and/or kick-start regeneration. The cover is sown and consists of annual crops, grasses and/or shrubs. Cover crops may be implemented to protect against soil erosion, but commonly also provide other services, such as fodder and nitrogen fixation.

SLM Category 12: Water harvesting (WATHAR) - Water harvesting increases availability of water through collecting, conveying and storing water, and is often applied when (in situ) precipitation is not sufficient to meet water requirements. A wide variety of water harvesting systems exist, some of which are applied within fields, whilst others capture water ex-situ. Water harvesting differs from irrigation in the sense that there is still a dependency on precipitation.

Reforestation measures: Afforestation of savannahs (AFSAV) – In a global assessment, apart from SLM measures, a range of different reforestation measures were also considered. For the location search for Hydrologic Corridors in Kenya and Tanzania, the option of the afforestation of savannahs is also relevant. This measure covers reforestation of areas in the savannah biome that are not under forest cover and agriculture.

Applicability limitations of restoration measures were considered for a number of factors based on globally available datasets of: Land cover; Rainfall; Slope; Soil texture; and depth. The criteria used are presented and discussed in appendix A: Applicability limitations of restoration measures.

4.2 Selected results and example maps

Degradation status
Figure 4.3 shows the annual soil depth loss in the research area, whereas Figure 4.4 shows the SOC restoration potential. This total 'scope' for restoration refers to the gross difference between the 2010 SOC status and the assumed undisturbed SOC contents for these soils under natural vegetation. Soil depth loss is predominantly confined to areas with steep slopes, e.g. the foot slopes of Mt. Kilimanjaro, Rift Valley in Ke-W and the Usambara Mountains in Tz-E. SOC restoration potential seemed particularly elevated in Tz-E. This area is to large extent in use as rain-fed farmland, which may explain a low current SOC content related to potential SOC content.

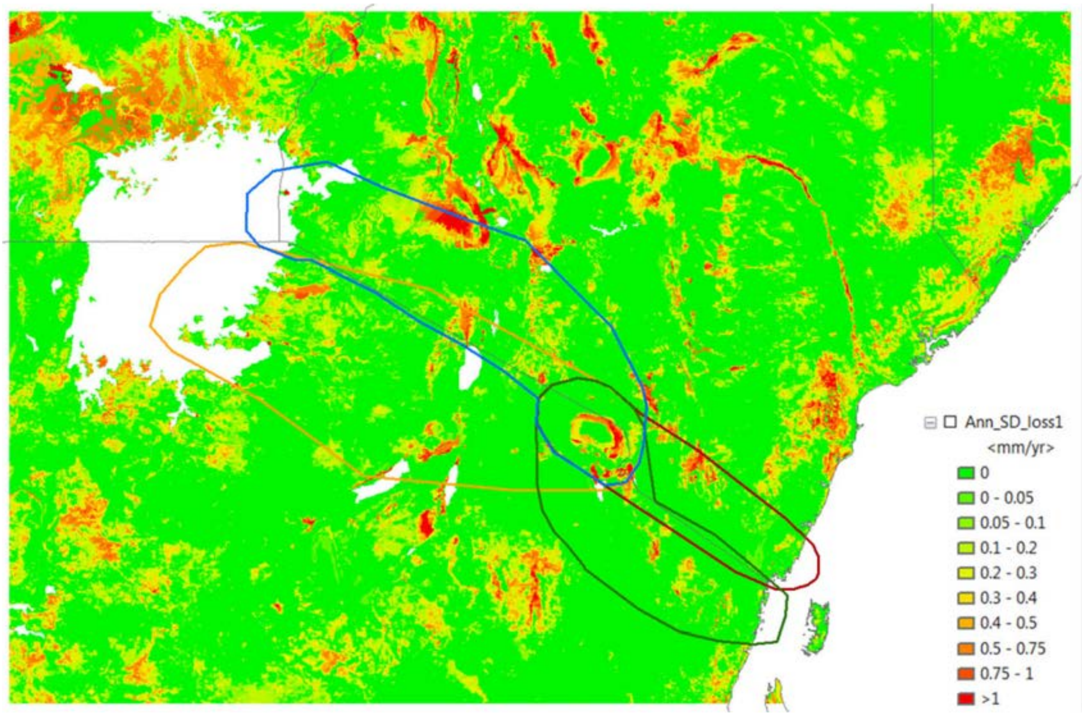


Figure 4.3 *Annual soil depth loss (mm/year).*

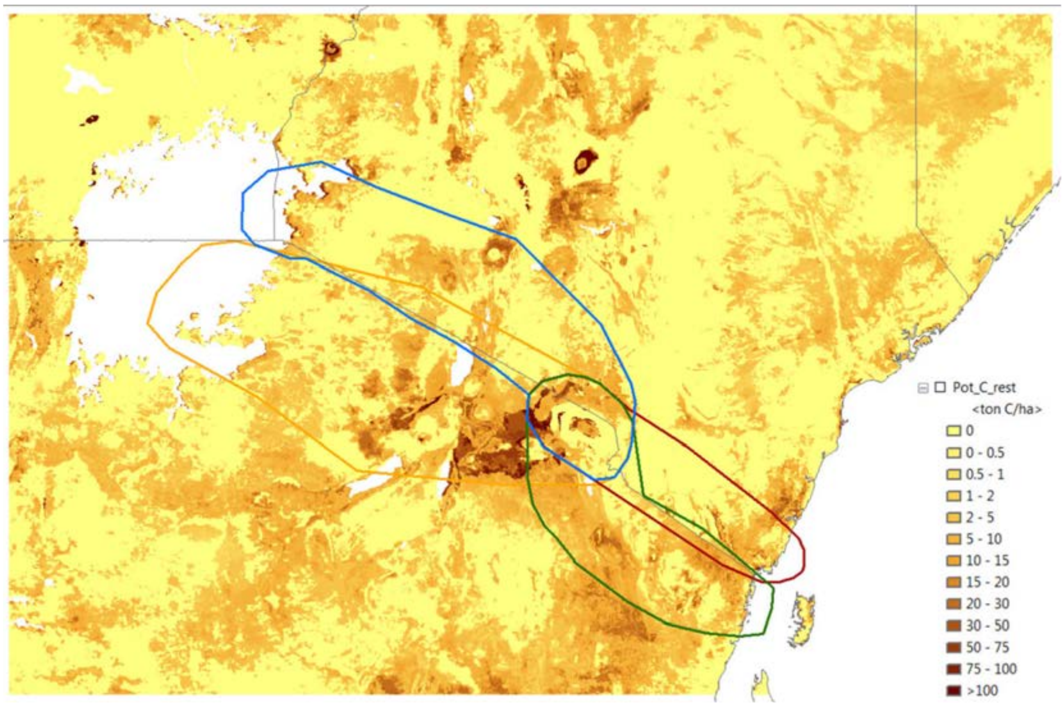


Figure 4.4 *SOC restoration potential (ton C/ha; reference year 2010).*

Figure 4.5 shows how many different types categories of measures can be implemented in each location. Most of the potential corridors show potential for several types of measures on most of the territory. An exception is Ke-E, where a significant proportion of the area is either not degraded and in need of restoration (as supported by Figure 4.4 and 4.5), or where no measures are applicable. Overall, Tz-E is the area where on average the highest variety of SLM measures are applicable. Figure 4.6 shows the potential for effective SOC restoration using the portfolio of SLM measures assessed. This *potential* refers to a realistically achievable increase in SOC over a period of 10 years. The pattern mostly reiterates where the highest SOC gains can be achieved (Figure 4.4), but also shows some areas where erosion control can make an effective contribution (e.g. Tz-E, cf. Figure 4.3).

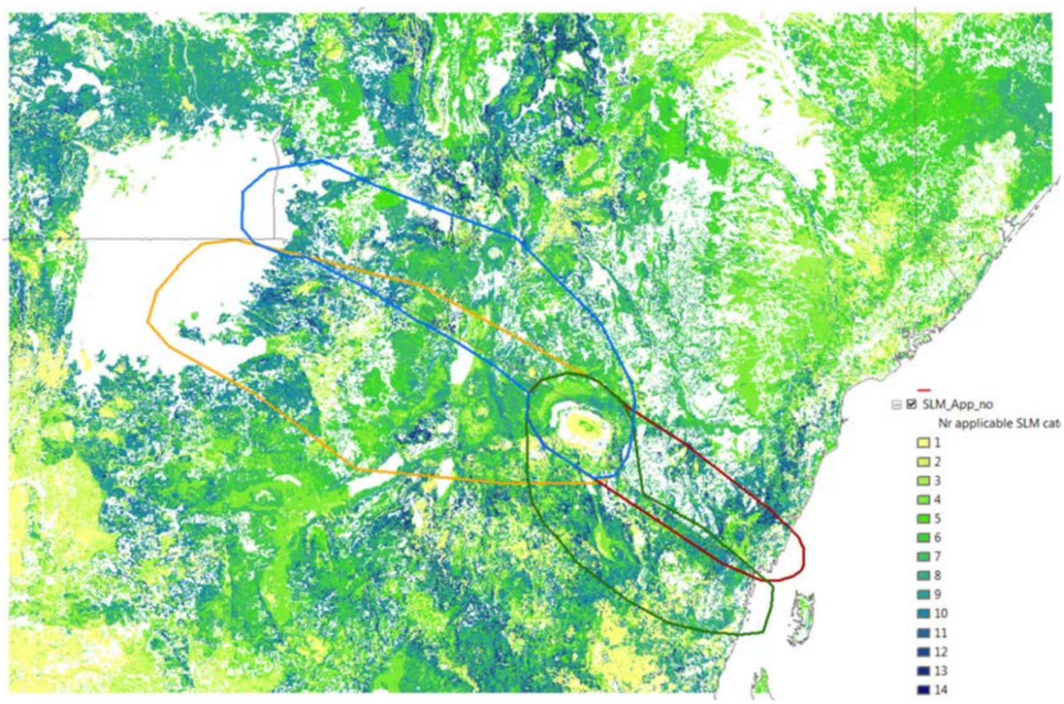


Figure 4.5 *Number of applicable SLM categories.*

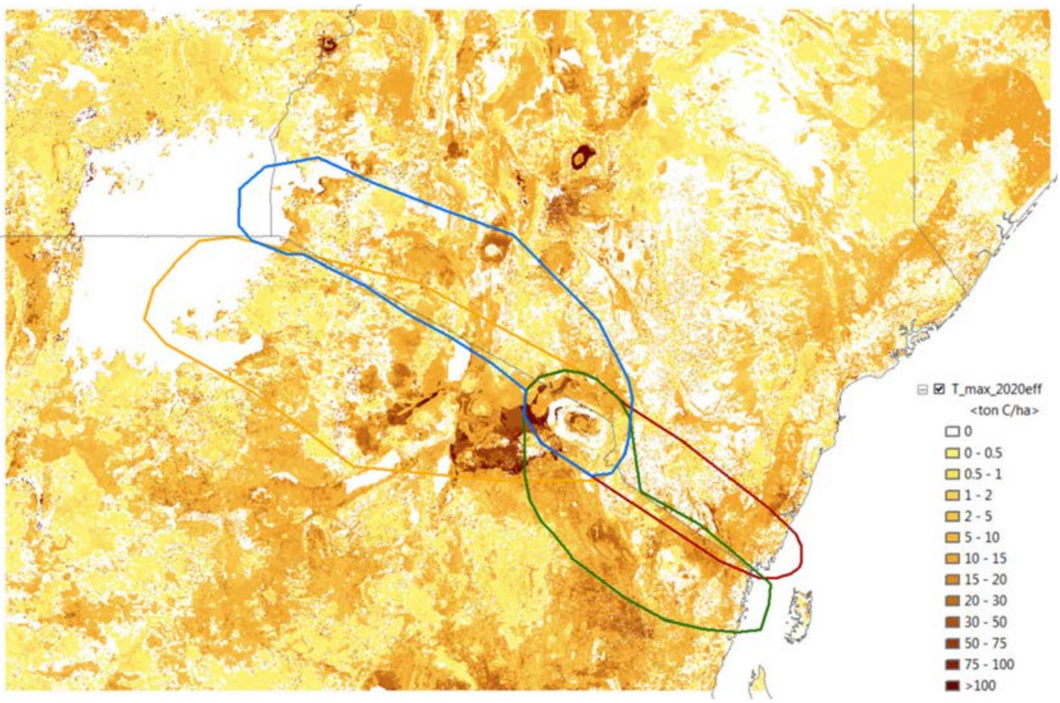


Figure 4.6 *Total effective SOC restoration potential by 2020.*

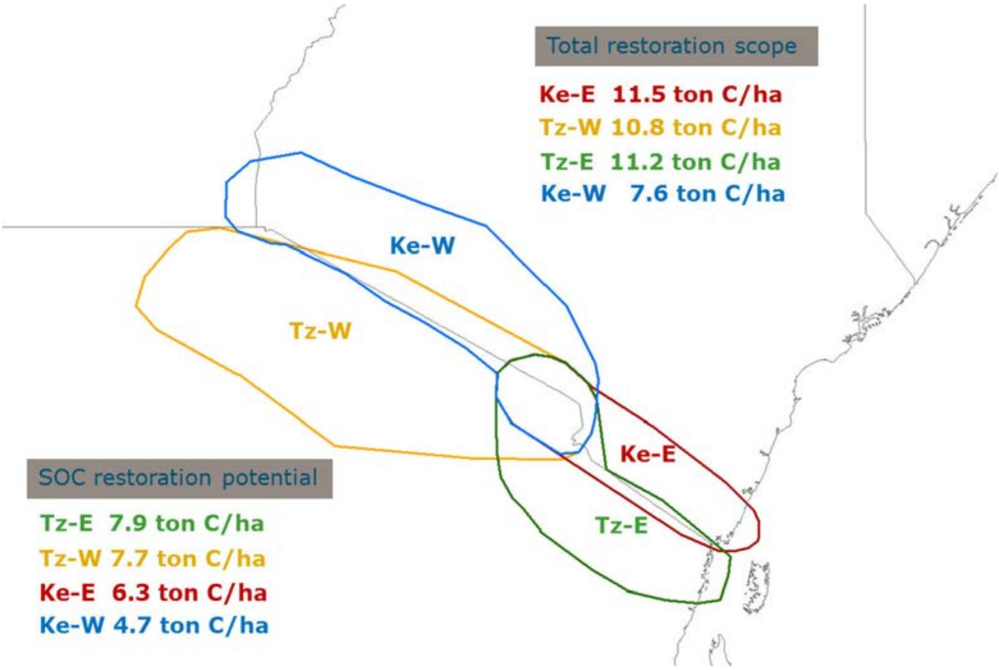


Figure 4.7 *Cumulative total SOC restoration scope and effective potential. Scope refers to the gross difference between the 2010 SOC status and the assumed undisturbed SOC contents for these soils under natural vegetation. The effective potential refers to a realistically achievable increase in SOC over a period of 10 years.*

Figure 4.7 schematically shows the total restoration scope and effective SOC restoration potential. Ke-E has a high overall scope, but relatively low potential for effective restoration using SLM measures. Tz-W and Tz-E have also quite high scope for SOC restoration, and in terms of achievable restoration potential using the SLM measures considered, they feature the highest potential. Ke-W scores lower on both accounts.

4.3 Concluding remarks on SOC restoration scope

The assessment was made using slope criteria derived from a relatively coarse-scale DEM. As other input layers (soil texture and depth, land cover, rainfall) were not available in a higher resolution, the slope criterion was also not precisely completed. However, for a more in-depth assessment of which SLM measures are possible where, slope can be a highly discriminatory criterion, and it could be useful to revisit the assessment with higher resolution data, when planning the interventions in more detail. Similarly, the assessment could be repeated for specific technologies rather than generic categories of SLM measures. It would then be useful to first refine and select specific measures for inclusion in the assessment. Finally, it should be noted that the assessment did not consider the boundaries of national parks. If these are well-protected, there should be limited land degradation within the parks, and, therefore, there should also not be much restoration potential within park boundaries. However, where areas within parks are degraded, not all SLM measures may be applicable. Afforestation and grazing management are example SLM categories that should still be possible, but most other SLM categories would not be suitable within protected areas.

5 Analysis of potential climate effects of a greener land surface

One of the novelties of the *Hydrologic Corridor* concept is that it not only aims to improve vegetation and hydrological conditions on the ground, but that it also leads to positive effects on local climate. Greening in particular circumstances may lead to more rainfall, i.e. more rain, longer rainy seasons and/or less inter-annual variability, that in turn lead to more lush vegetation, more groundwater recharge, less erratic river flow, etc. Feedback effects of increased evaporation from a greener land surface on rainfall can be expected in the transitional periods from dry to wet seasons and vice versa (Findell and Eltahir 2003, Tuinenburg, Hutjes *et al.* 2010). In the midst of the rainy season, the atmosphere is so moist (advected from the oceans) that rain will occur, irrespective of local evaporation. In the midst of the dry season, the atmosphere is so dry that local evaporation will not raise atmospheric humidity to condensation levels. It is in the transition periods, when atmospheric humidity is just below a threshold initiating rainfall generation and/or convection, that local evaporation may increase this to just above the threshold and cause positive feedback to further rain and evaporation.

However, prior to the rainy season, there is normally no soil moisture to sustain any evaporation, except in irrigated areas. Since NAGA aims to increase soil moisture and vegetation greening through rain harvesting and retention techniques, it was not expected that this would influence soil moisture towards the end of the dry season, and so this period was not considered. At the end of the rainy season and into the early dry season, there may be enough remaining soil moisture to sustain evaporation. For this reason, the first climate improvements from re-greening, if any, might be evident in this period. This analysis, thus, targeted these periods.

Positive effects on rainfall can only occur when the enhanced atmospheric humidity from local evaporation is lifted to condensation levels, where cloud formation and rain generation can occur. Unfortunately, the same evaporation that adds moisture to the atmosphere also cools it, thus, reducing buoyancy of the air and reducing boundary layer growth and preventing the (albeit humidified) air from reaching condensation levels. Therefore, in flat areas, the effect on precipitation is the result of two counteractive processes (humidifying and cooling) leading to rather uncertain overall effects. However, if the humidified air is blown against rises in the land (hills, mountains), the resultant orographic lifting may bring the humidified air to condensation levels, despite its cooling-induced, reduced buoyancy. Thus, higher chances of climate improvements were anticipated from re-greening when the land rises downwind of the greener areas.

Two tracks were followed to analyse these processes for the Kenya-Tanzania border area, where the topography around Mt. Kilimanjaro may increase the chance of positive climate feedback from greening:

- Firstly, the climatology of the area was analysed including the dominant wind patterns throughout the year and associated temperature, humidity and rain distribution
- Secondly, sensitivity experiments were performed with a regional weather model, in which greener vegetation within the four corridors was initially considered.

5.1 Analysis of the Mt. Kilimanjaro regional climatology

Using several global data sets (see appendix B: Climatology analysis Mt Kilimanjaro region) available daily at 0.5° resolution, an analysis was made of monthly patterns of wind, precipitation humidity and moisture transport in the Kenya-Tanzania border area. A full overview is given in the Appendix. The months around the end of the respective rainy seasons in the area were focused on when the largest effect of greening might be expected, as previously outlined.

For the 'long rains' (March-April-May, MAM), the May-June months in Figure 5.1 were analysed. For the 'short rains' (OND), December-January in Figure 5.2 were analysed.

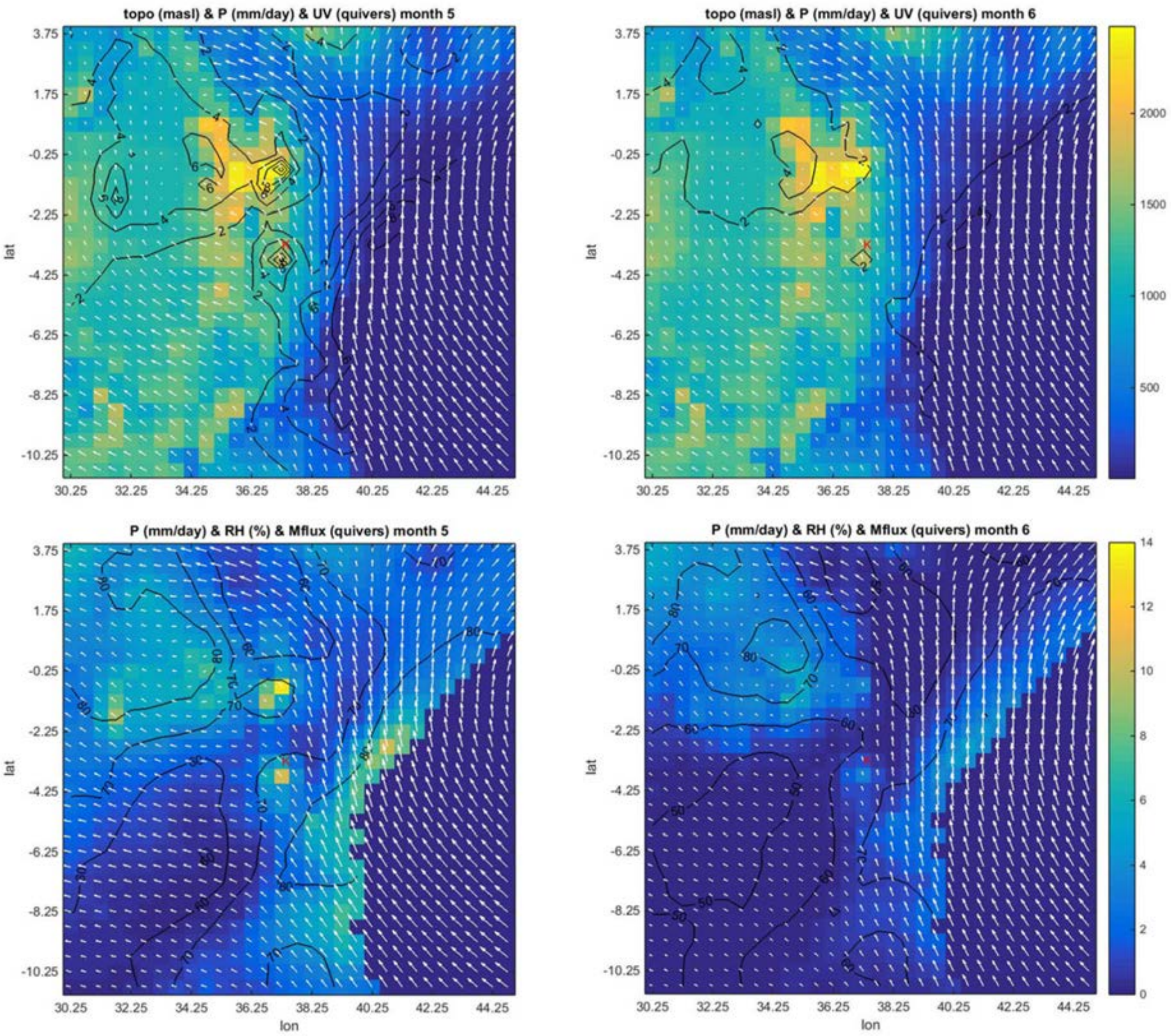


Figure 5.1 *'Long rains' transition period: maps on top row of monthly rain ('P', mm/day, contours) and wind ('UV', quivers) on a background of land elevation (topography, m amsl, colours) and on the bottom row of relative humidity ('RH', %, contours) and atmospheric moisture transport ('Mflux', quivers) on a background of precipitation ('P', mm/day, colours). Left for May. Right for June. The red 'K' indicates the location of Mt. Kilimanjaro.*

The figure above shows that in the May-June period, winds from the South East dominate the region, which are deflected and channelled by the topography to more southerly winds over Kenya, turning towards the West again over the Marsabit depression, and more winds from the East flows over Tanzania. In May, this leads to coastal rainfall concentrated north of Mombasa. In addition, orographic effects induce relatively high rainfall amounts around the Mt. Kilimanjaro and Mt. Kenya massifs, respectively, and again West of the Rift Valley. In June, the picture is similar, though moisture transport inland is already strongly diminished and relative humidity is already 10% lower.
In December-January (Figure 5.2), the wind comes from the North East. Though topography still concentrates rain on its windward sides, this effect seems reduced compared to the long rains transition. Instead, dry air masses penetrate the area from the North.

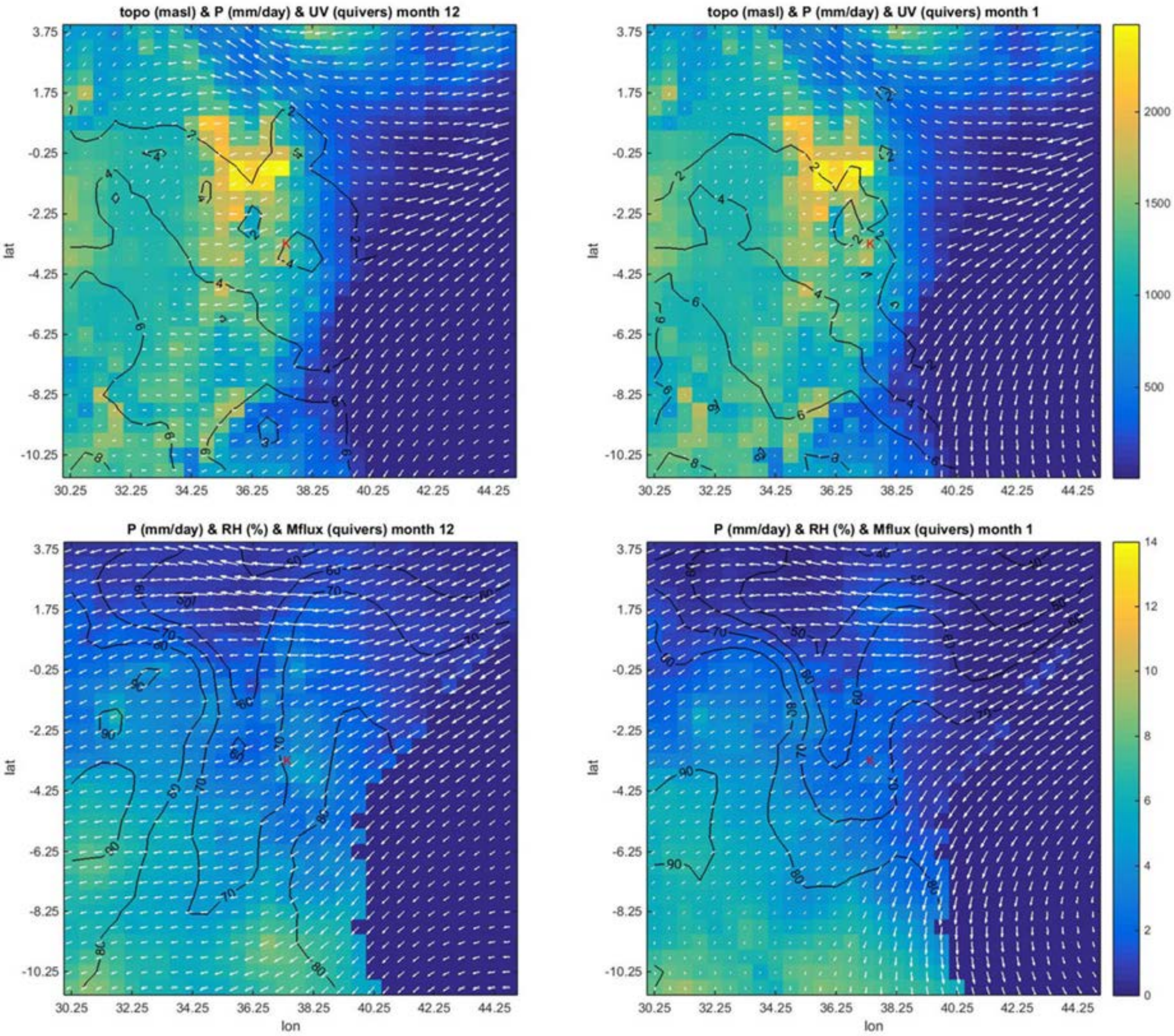


Figure 5.2 *'Short rains' transition period: maps on top row of monthly rain (mm/day, contours) and wind (quivers) on a background of land elevation (topography, m amsl, colours) and on the bottom row of relative humidity (%, contours) and atmospheric moisture transport (quivers) on a background of precipitation (mm/day, colours). Left for December. Right for January.*

From these simple analyses, it follows that during the transition after the long rains, the Tanzanian corridors probably have the largest effects on rainfall, as winds flow from the South East, bringing moisture directly from the ocean, especially in May. Following the short rains, the Kenyan corridors probably may have the largest effects on rainfall, as winds flow from the North East. However, as these pass over more land than in May-June, these winds are already drier and the potential for green enhanced rainfall may be reduced compared to the May-June period.

5.2 Model sensitivity of the May-June precipitation to greening

A regional weather model (RAMS v6) was used to assess the potential effects of greener vegetation on rainfall. For details on model grid and setup, see Appendix. As in the previous section, focus was on the end of the 'long rains', with simulations performed for the period 15 May-30 June. To provide lateral conditions for the model, ECMWF re-analysis data was used for June 1994 - a more or less average year in terms of annual precipitation.
A series of simulations was performed with
1. present-day vegetation (base line).
2. greener vegetation over the entire area of each of the four *Hydrologic Corridors.*

Greener vegetation was effectuated by upgrading most pixels in these areas to the next greener predefined land cover class (in the LEAF3 land surface model integrated in RAMS), which amounted to an increase of vegetation LAI_{max} as follows:
- Short grass (8, LAI_{mx} = 2) -> Tall grass (9, LAI_{mx} = 5)
- Tall grass (9, LAI_{mx} = 5) -> Wooded grasslands (18, LAI_{mx} = 6)
- Wooded grasslands (18, LAI_{mx} = 6) -> Mixed Woodlands (14, LAI_{mx} = 7)

The vegetation model used these maximum LAI values in a (fixed) phenological cycle to calculate to a time-varying LAI throughout the seasons. For the period simulated, this led to the following modest *increases* in LAI and *decreases* in albedo. Surface roughness also marginally increased. See the Appendix for the respective maps of these changes.

Table 5.1
Realised changes in surface characteristics of the four sensitivity experiments.

Greened corridor	Simulation number	Sample area	Effective LAI		Effective albedo	
			baseline	green	baseline	green
Ke-E	ng122	38.2-39.2E; 3.5-4.0S	1.02	1.54	0.18	0.15
Ke-W	ng112	35.2-36.2E; 1.2-1.7S	1.08	1.55	0.19	0.16
Ta-E	ng102	37.5-38.5E; 4.0-4.5S	1.01	1.45	0.18	0.16
Ta-W	ng92	35.0-36.0E; 2.5-3.0S	0.70	1.20	0.22	0.21

These vegetation increases were not associated with higher initial soil moisture values. These were kept identical to those of the baseline simulation (i.e. soil moisture was initialised from ECMWF analysis). Thus, any potentially positive effects from rainwater harvesting techniques on this were not accounted for in this sensitivity experiment.

In the following, maps are presented of the difference in precipitation between the baseline simulation and each of the greened corridors, and the associated primary effects that may affect precipitation, namely the changes surface heat flux and especially evaporation and their effect on temperature and humidity.

In Figure 5.3 and following, the baseline situation is presented (left column) along with the effects of greening in the W and E corridors (middle- and right columns, resp.), given as the difference from the baseline, on evaporation (top row) and heat flux (2^{nd} row), both are in W/m^2 (680 W/m^2 evaporation roughly equals 1 mm/hr); percentage relative humidity (3^{rd} row) and temperature in Celsius (bottom row). Blue colours indicate moister or cooler conditions, red colours, dryer or warmer conditions (note different colour scales for each variable). For the two Tanzanian corridors (Figure 5.3), it can be seen that in the first week of the simulation, greening leads to an increase of evaporation, especially in the western corridor (from 141 to 185 W/m2 or 31%) and an associated, but smaller decrease in heat flux (due to the albedo increase, more solar energy is absorbed by the vegetation). This leads a slight increase of relative humidity in each area, and also similar changes elsewhere in the domain (for which, there is no clear explanation as yet). Temperature changes are marginal.

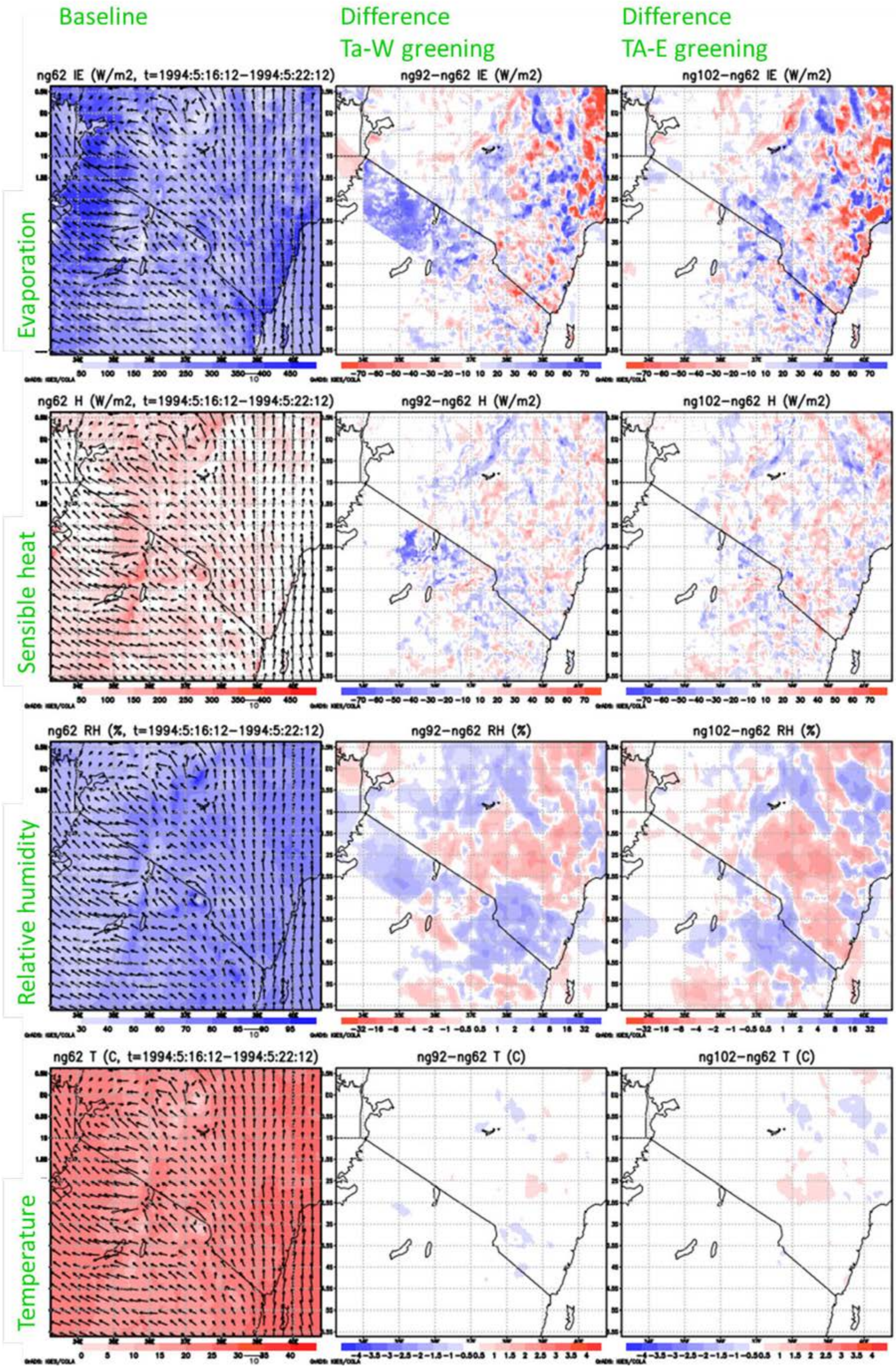


Figure 5.3 *Effects of greening the two Tanzanian corridors during the first week of the simulation (16-22 May 1994). See text for an explanation.*

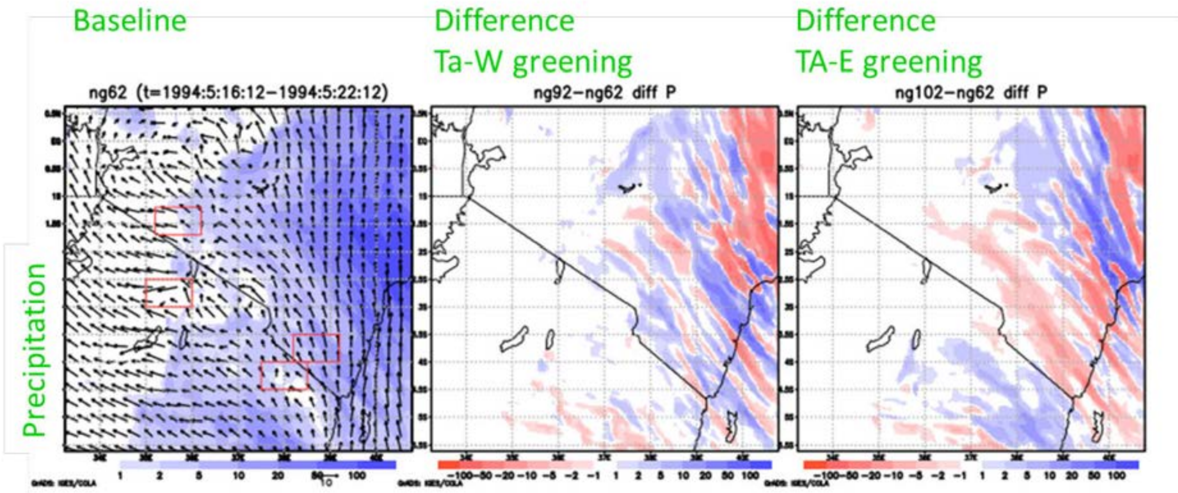


Figure 5.4 *Changes in precipitation for the same situations and period as the previous figure. Note the non-linear colour scale.*

Precipitation in the Eastern part of the domain responded rather sensitively to these surface changes (Figure 5.4): in the NE area there is a wave-like pattern of rainfall increases and decreases that confounds the effects of the greened corridors. Nevertheless, and considering also the average wind field for this week, the graphs suggest that greening the Western corridor in Tanzania has no effect on rainfall anywhere in the corridor (middle graph). Greening the Eastern corridor (at right) seems to enhance rain inside this corridor, but possibly at the same time reduce rain downwind across the Kenyan border: in the two right-hand side rectangular areas (Figure 5-4 left) the rain increased from 2 to 4 mm in the Tanzanian box, but decreased from 8 to 3mm in the Kenyan box. The greening may have triggered rain initiation in Ta-E but after having rained out less moisture seems to remain for rain in Ke-E.

In the following weeks, the pattern changes (see Appendix, Figures 8.5 to 8.9). The extra evaporation in the greened areas decreased and turns into reduced evaporation in the greened areas in weeks 4 – 6, especially in the Ta-W corridor. This is probably because the enhanced evaporation in the weeks before depletes soil moisture faster than in the baseline. As a result, relative humidity over the greened areas slowly reduced to below that of the baseline situation and temperature increases. Unfortunately, there was little inland rain in the subsequent weeks, though in Week 4, greening the eastern corridor enhanced rain a little downwind in Kenya, and in Week 6 it decreased it a bit over the corridor itself. Basically, as the wet season dwindles and the dry season strengthens, the inland atmosphere quickly dries out to the point that surface conditions will not affect rainfall. In this period, over the coastal areas only the atmosphere remained moist enough for rainfall to occur and for the land surface possibly affecting this.

For the two Kenyan corridors, the effects are very similar, although the effects on rainfall were even more inconclusive (Figure 5.5, Figure 5.6 and Appendix Figures 5.11 to 5.15).

Although a very distinct rainfall feedback due to greening was not shown in this particular simulation period, these sensitivity experiments do demonstrate the land-atmosphere complexities involved. Greening not only leads to more evaporation from leaves, but also to absorption of more solar energy that –if not used for evaporation- will heat up the air. More evaporation also depletes available soil moisture stores more rapidly, and, if not replenished, leads to reduced evaporation compared to the baseline, as time moves on. In the atmosphere (in the boundary layer more in particular, i.e. the first 1-2km or so), rain initiation depends on a subtle balance between enough moisture and enough buoyancy to bring that moisture to condensation levels. Surface conditions, evaporation and sensible heat flux, may affect both and the overall effect depends which is affected most in the direction of promoting rainfall.

Also some model limitations may have reduced a very clear feedback of greening on rainfall. The most prominent feature limiting this is the fact that the model has a static vegetation development that does not respond to more rain or more soil moisture by postponing senescence. In this model, the seasonal cycle is fixed, so even when soil moisture would permit otherwise, leaf area reduces as the season progresses. A so-called interactive vegetation model might have strengthened feedbacks.

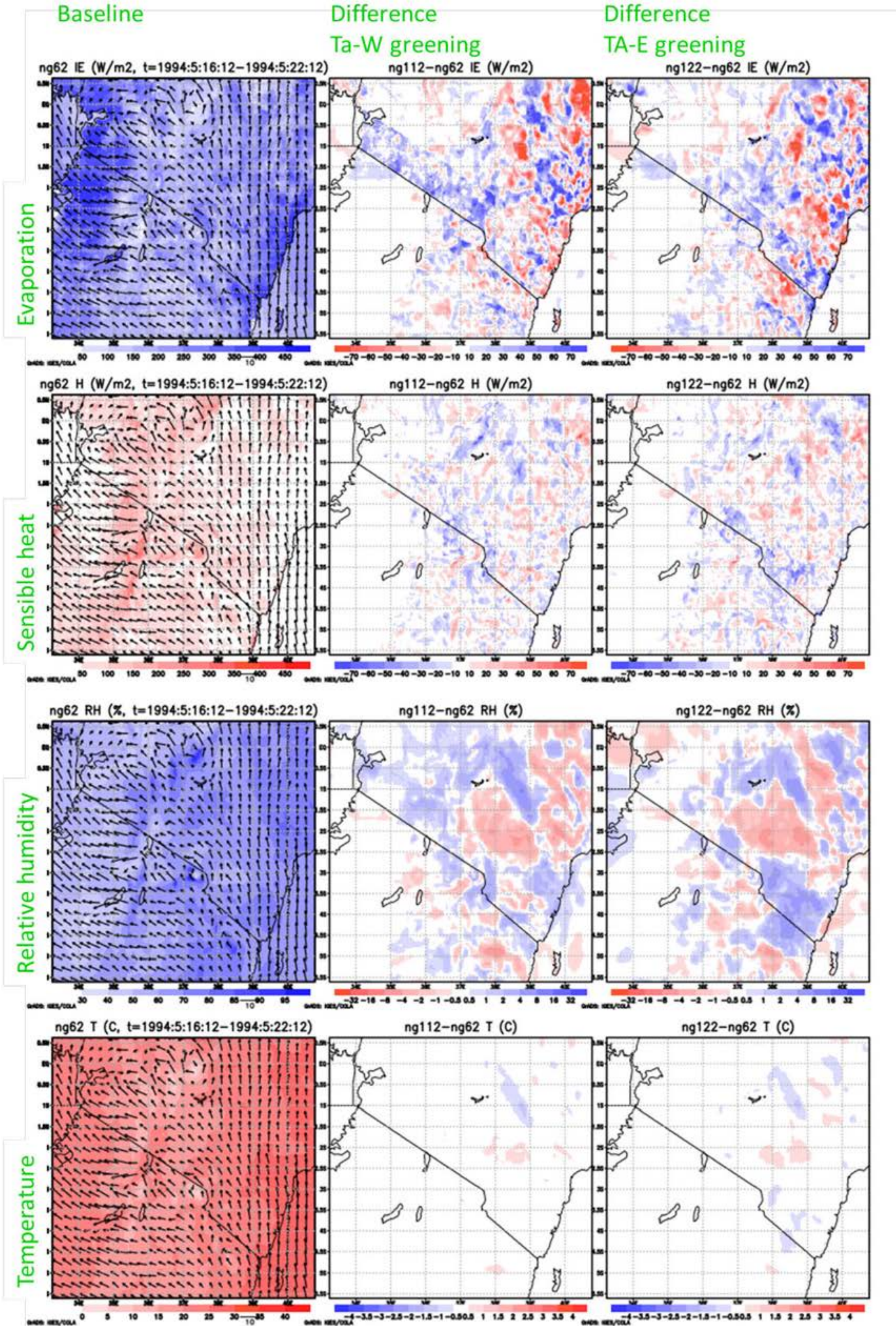


Figure 5.5 *Effects of greening the two Kenyan corridors during the first week of the simulation (16-22 May1994). See text for an explanation.*

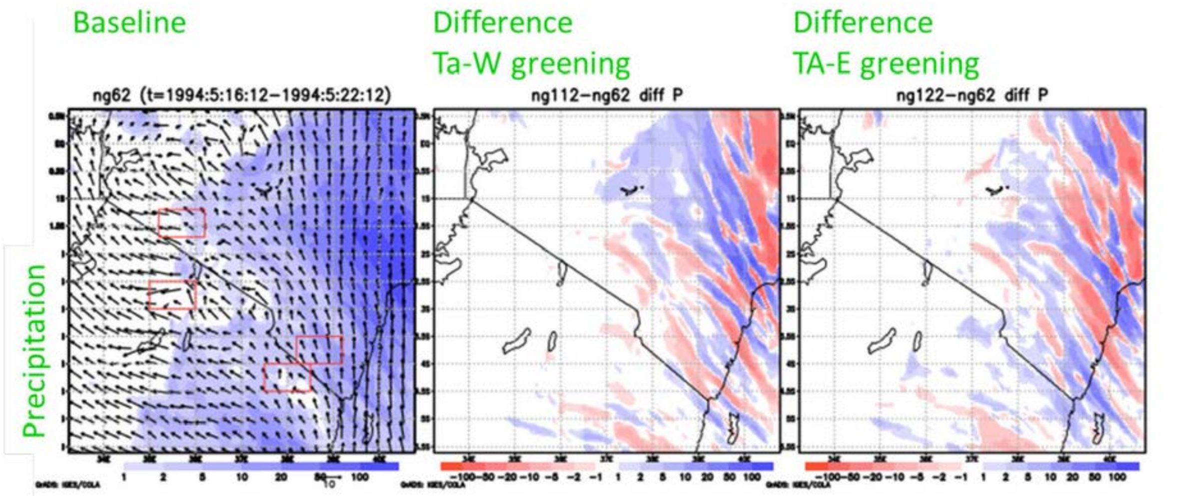


Figure 5.6 *Changes in precipitation for the same situations and period as in the previous figure. Note the non-linear colour scale.*

The second limitation stems from the fact that greening model experiments were not associated with higher initial soil moisture condition or even better soil moisture retention characteristics. If this would have been the case, the increased evaporation of the first weeks might have been stronger and more persistent, with possibly larger effects of rainfall. The imposed greening, though extensive in area, enhanced vegetation with limited magnitude only (LAI increased by 0.5 to still low values of 1.5 on average only, Table 5.1). With stronger greening, the effects may also have been stronger. However, whether that can be achieved for the full corridors remains to be seen. Instead, NAGA aims to start multiple smaller projects within these corridors, whereas in intense programmes, stronger greening could perhaps be achieved than modelled here. Resource constraints prevented exploring such alternative greening patterns, because higher model resolutions would have been required. Expert judgement may suggest that more intense greening of smaller areas may have similar effects as more limited greening in large areas, but this study cannot confirm or reject such an inference.

5.3 Concluding remarks on rainfall feedbacks of greening the land

From the two previous sections it seems that from a positive rainfall feedback perspective the highest chances for realising an enhanced small/local hydrological cycle seem to exist in greening the Ta-E corridor. If the long rains, wind directions and advected moisture from the oceans are strong enough, additional evaporation from the land surface may positively influence rainfall at least windward of Kilimanjaro. In this same season, greening the Ke-E corridor would create extra evaporation, but as downwind of this area, elevation decreases, the chances of this extra evaporation leading to extra rain are even smaller.

Both Westerly corridors Ke-W and Ta-W seem already too far inland for greening to push atmospheric conditions just over the threshold to start rain. The analysis suggests the extra evaporation occurs in a too dry atmosphere already to be able to initiate rain in this season.

Inferring from the climatological analysis only, it seems the Ke-E corridor may be the more favourable for a positive rain effect from greening in the period following the short rains, since with winds from the North East, it is then upwind from the rise in topography. Nevertheless, atmospheric conditions in this season seem less favourable (somewhat drier air that passed over more land than in the other season) for rainfall enhancement, although it cannot be excluded.

The complexities and feedbacks in the various processes are many, and only very cautious and tentative conclusions on rainfall enhancement following greening certain areas can be drawn from this short study. Therefore we recommend not to give these considerations a substantial weighting in comparison to e.g. those listed in Chapters 3 and 4.

6 Institutional setting of NAGA intervention areas

6.1 Approach

The Hydrologic Corridor, as promoted by NAGA, is to be realised by re-greening and restoration of the landscape. For the selection of the best locations, it is of the upmost importance that that the changes are realised over a large area, are long lasting and are shared by the local population and future managers. This is not automatically the case as the NAGA initiative originates from outside the community and projects can hardly be realised without the agreement of higher administration: a basic conflict between top-down and bottom-up approaches would arise. Therefore, the project should be developed in a way that fits with available institutions, has the support of governments, as well as the local populations, builds on existing aspiration levels and makes use of available resources as far as possible.

For a prioritisation of project areas, a comparison study of these social and economic aspects is necessary. In addition, the outcome of such an institutional analysis can be supportive to the design of the programme, the project steps and processes for the bio-physical changes, as well as capacity-building and adapting the institutions in selected regions.

In this chapter, relevant formal and informal rules are roughly assessed to check if those rules would or would not support such an experiment. The assumption here is that the location with the most positive outcome (the most adaptive and most effectively governed location) would be the best option for the experiment. One could also reason that the location with the largest social- and institutional problems mostly needs such an experiment; however, the reasoning applied in this study is that an experiment can fail, and a very vulnerable location cannot carry the burden of such a failure.

6.2 Adaptation wheel assessment

The Adaptive Capacity Wheel (ACW, Gupta *et al.*, 2010) that was developed to assess if adaptive capacity is enabled by social institutions was used. The ACW was developed in the context of adaptation to climate change. The problem in the NAGA project is only partly related to climate change, but the set of criteria used in the ACW can, nevertheless, provide a relevant assessment. As an example, the drivers of agricultural success in sub-Saharan Africa can be fairly easily organised into the ACW (see Table 6.1).

Table 6.1
Drivers for successful agricultural development in sub-Saharan Africa compared to the dimensions of the Adaptive Capacity Wheel (Reij and Smaling, 2008).

Variety	• Involvement of users in all stages of the project cycle; joint experimentation by researchers and farmers
Learning	• efficient agricultural services, local capacity building • building up of national agricultural research infrastructure and staffing • farmer-to-farmer exchange visits • projects and programmes should be planned in a way that allows quantitative ex post evaluation and generation of useful 'lessons-learned'.
Room for autonomous change	• support to market information access • improved regional and foreign market opportunities • the capacity of African farmers to innovate at their own initiative and adapt their production systems to changing environmental, market and demographic conditions
Leadership	• sound macro-economic management facilitating agricultural markets
Resources	• access to rural finance systems • improved physical infrastructure
Fair governance	• better and enforced environmental legislation

The term 'institutions' is used in the broad definition of social rules governing (a part of) society. The method checked these institutions using 22 criteria, clustered in six dimensions. For each criterion, a score was given between -2 and +2 and an explanation of the score. Then, a simple calculation method was used to aggregate for the dimensions and for the overall score.

The first aim was to assess the four different regions identified before: Tanzania East / West and Kenia East / West (see Figure 1.1). However, this required detailed information on cultural differences between the peoples inhabiting those areas. This information is sketchy, sensitive, and the impression is that there is also some dynamic of people moving from one place to another. Therefore, it was decided to only look for differences between the two countries: the North-South gradient. There are many similarities between Kenya and Tanzania in languages, peoples, economy and landscape (Miguel, 2002). This means that the National Government can indeed be considered as the main factor to distinguish between the case study locations. Of course, cultural differences within the countries were also very relevant (for example, differences between cattle herders and crop farmers) and may have to be investigated further in a next phase of the project.

The data used were obtained from literature and one interview, in which feedback was requested on a first draft of this document. The tables are filled with mostly literal citations from the available literature. Validity of the results must be checked locally, as it was assessed from a distance with a limited amount of data.

The adaptive capacity wheel was applied at the national level for Kenya and Tanzania, to cover the North-South dimension of the case study options.

6.3 Results adaptation wheel assessment

For Kenya, data were more difficult to find, and literature on sub-Saharan Africa was used to fill a part of the gaps. In Kenya, variety appeared good, not only because of ethnic diversity, but also because many different solutions have been tried, and because many stakeholders are involved in the climate response strategy. However, learning is seriously hampered by a lack of trust due to relatively recent violence between ethnic groups. One would expect the room for autonomous change to be big in a country, in which people are left to their own resources, but in Kenya, people are severely limited in that respect, due to their dependence on either rain-fed agriculture or pastoralism. The freedom to fall back on illegal activities cannot be considered an advantage. The score for 'act according to plan' is quite positive based on a Government report; however the same report suggested that the forest cover just declined from 12 to 6% and so the 6% may simply be the forest that remained and not what has been re-planted. Structural governance dimensions the situation appeared quite problematic: leadership was lacking (or even negative by having a role in promoting inter-ethnic violence) and fair governance scored very poor. The resources appeared to be were also mostly lacking, although economy is growing and a new climate fund is being considered.

For Tanzania, the data were more comprehensive than those of Kenya, due to a recent, rather critical analysis of resilience to climate change (Hepworth 2010). The dimensions that describe the adaptive, flexible side of governance, showed that variety scored highly, due to cultural diversity, involvement of stakeholders in adaptation and experimentation with many different solutions. Learning showed some promise, due to investments in research. Room for autonomous change scores badly because of lack of data, lack of implementation and general poverty issues. Dimensions that reflect structural governance showed that leadership scored positively, due to the emphasis on the Tanzanian Nation at the expense of tribalism. Resources were problematic, especially due to a fast growing, uneducated population, but authority showed some positive aspects. Fair governance was weak, but on some criteria, positive developments were reported, such as strategic support for vulnerable groups.

Table 6.2

Results of the Adaptive Capacity Wheel assessment (for annotated results see Appendix E).

Dimension	Criteria	Score Kenya	Score Tanzania
Variety	Variety of problem frames & solutions	+1	+2
	Multi-actor, level and sector	+2	+2
	Room for diversity	+2	+1
	Redundancy	-2	-2
	Total	**+0.8**	**+0,8**
Learning Capacity	Trust	-2	0
	Double loop learning	-1	+1
	Discuss doubts	0	+2
	Single loop learning	0	-1
	Institutional memory	+1	-1
	Total	**-0,4**	**+0,2**
Room for autonomous change	Continuous access to information	-1	-1
	Act according to plan	+1	-2
	Capacity to improvise	-1	-2
	Total	**-0.3**	**-1,6**
Leadership	Visionary leadership	-2	-1
	Entrepreneurial leadership	0	+2
	Collaborative leadership	-2	+2
	Total	**-1**	**+1**
Resources	Authority	-2	+1
	Human resources	-2	-2
	Financial resources	0	-1
	Total	**-1.3**	**-0,6**
Fair Governance	Legitimacy	-2	0
	Equity	-2	+1
	Responsiveness	-2	-2
	Accountability	-2	-1
	Total	**-2**	**-0.5**
Overall		**-0.7**	**+0,1**

6.4 Concluding remarks on adaptive capacity of Kenya and Tanzania

The overall score of the two countries have indicated that Tanzania could be a better location than Kenya. Both countries achieved positive scores on the dimension of variety and neutral negative scores for learning, room for autonomous change, and resources. For room for autonomous change Tanzania scores were worse, whilst Kenya scored worse for leadership and fair governance.

The dimension of variety was positive in both tables, not only due to different tribes and languages, but also due to the involvement of many stakeholders in the analysis and planning of adaptation to climate change; and experimentation with many different solutions. The redundancy criterion scored low, because few people have a margin or a buffer for securing their survival. There were some signs of learning but these were mainly supported by foreign aid. Even in Tanzania, where there has been a major effort towards improving literacy, much remains to be done. In Kenya, learning is hampered by a lack of trust due to ethnic conflict. The room for autonomous change was limited in all criteria: a lack of information; not much acting according to plan due to weak governance; and a large part of the population lacking the margin to experiment (and fail). The biggest difference was found in the leadership dimension; here the use of ethnic conflict for political gain was considered as a negative form of leadership (Kenya), and the emphasis on national pride and equity as a positive form of leadership (Tanzania) for adaptive capacity. Resources are generally scarce everywhere in Africa. Although population growth can be seen as good for human resources, proper education of the youth is required for enhancement of adaptive capacity. Financial resources from foreign donors seem necessary for planning of adaptation. Even though the economies of both Kenya and Tanzania are growing, the revenues are not channelled towards the common good, due to a lack of fair governance. Fair governance appeared to be particularly bad in Kenya, because the country is still recovering from ethnic conflict, which occurred in 2007/2008. Tanzania is working hard towards fair governance, for example, by trying to change the role of women in society. A lot of corruption still occurs in this country, but there is an effort from the highest level to reduce it.

Although this analysis is based on limited data, Tanzania appears to be the better option for a large-scale, long-term experiment with re-greening. Governments at both national- and local levels seem more reliable. The realisation of such a project may take more time, because of the way that the governmental structures function and because local people should also contribute. One also needs to keep in mind how marginal the space is for local as well as non-local people to experiment with their resources.

7 Conclusions and recommendations

The aim of this report was to support an objective choice of potential intervention projects in which the NAGA Foundation could establish Hydrologic Corridors for re-greening and restoration of the landscape. Geographically explicit information was collected on soil, vegetation, hydrology and climate, as well as institutional settings that may affect the likelihood of success of such projects. Four corridors were pre-selected by the NAGA Foundation, all close to the Kilimanjaro region: Kenia- East, Kenya-West, Tanzania-East and Tanzania West.

Each of the analyses in previous chapters used different criteria to assess which of the four corridors would be most suitable for starting re-greening projects. The information gathered on hydrological and soil restoration potential (Chapters 3 and 4) was available at a very fine scale. The GIS data made available allow more detailed search for suitable project locations. The geographical level of detail of the climatological and institutional analysis (Chapters 5 and 6) are less detailed, but still provide useful information on how to deal with projects in these four corridors. At this level, the following conclusions can be drawn:

In Chapter 3, data on various hydrological characteristics were collected and combined. Though mostly useful for detailed site selection purposes, the potential for soil moisture and groundwater recharge seems highest in Ta-E, where more sandy soils promote infiltration of the available rain.

In Chapter 4, the aggregate scope and effective potential for soil organic matter or carbon (SOC) were assessed. Ke-E has a high overall scope, but relatively low potential for effective restoration using SLM measures. Tz-W and Tz-E have also quite high scope for SOC restoration, and in terms of achievable restoration potential using the SLM measures considered, they feature the highest potential, especially Ta-E. Ke-W scores lower on both accounts. For planning the interventions in more detail, a more in-depth assessment of which SLM measures are possible where, may be needed and it could be useful to revisit the assessment with higher resolution data. Similarly, the assessment could be repeated for specific technologies rather than generic categories of SLM measures.

In Chapter 5, it was established that from a positive rainfall feedback perspective, the highest chances for realising an enhanced small/local hydrological cycle seem to exist in greening the Ta-E corridor. Following the long rains, wind directions and advected moisture from the oceans are strong enough, such that additional evaporation from the land surface may positively influence rainfall at least windward of Kilimanjaro. In this same season, greening the Ke-E corridor will create extra evaporation, but since downwind of this area, elevation declines, the chances of this extra evaporation leading to extra rain are smaller. Both Westerly corridors Ke-W and Ta-W seem too far inland for greening to enhance rainfall. The analysis has suggested the atmosphere here is too dry for greening to have an effect.

With inference from the climatological analysis only, it appears that atmospheric conditions in the short rains season are less favourable for rainfall enhancement, although it cannot be excluded. If it happens, the Ke-E corridor may be the more favourable, since with winds from the North East, it is then upwind from the rise in topography.

In Chapter 6, it was concluded that both Tanzania and Kenya have positive scores on the dimension of variety, neutral scores for learning, and negative scores for resources. Variety was positive, not only due to different tribes, languages and livelihood strategies, but also due to the involvement of many stakeholders in adaptation to climate change. Much remains to be done in the area of learning, even in Tanzania where there has been a major effort towards literacy. Resources are scarce everywhere in Africa. For room for autonomous change, Tanzania scores worse than Kenya, but this may be due to better data on the situation in Tanzania. Kenya scores much worse on leadership and extremely badly on fair governance, although recent distribution of responsibilities to the county level may positively influence this. The use of ethnic conflict for political gain as a negative form of leadership (Kenya), and the emphasis on national pride and equity as a positive form of leadership (Tanzania). Overall, Tanzania seems the better option for a large scale, long term experiment with re-greening. Governments at both national- and at local levels seem more reliable. The realisation of such a project may take more time in Tanzania than in Kenya, exactly because the governmental structures are functioning and the local people can have some influence. One also needs to keep in mind how marginal the space is for local, as well as non-local people to experiment with their resources.

Table 7.1
Cross theme ranking (1 lowest to 4 highest) of the four potential corridors.

	Water infiltration potential	Realistic SOC restoration potential 2020	Absolute soil restoration potential	MAM rainfall feedbacks	OND rainfall feedbacks	Institutional potential	Total score
Kenya-East Corridor	2.5	2	1	3	4	1.5	**14**
Kenya-West Corridor	1	1	4	1.5	1.5	1.5	**10.5**
Tanzania-East Corridor	4	4	3	4	3	3.5	**21.5**
Tanzania-West Corridor	2.5	3	2	1.5	1.5	3.5	**14**
Total	10	10	10	10	10	10	60

In Table 7.1, we combine the findings of the various themes by ranking (1 lowest to 4 highest) the four potential corridors. These findings objectively favour the Tanzanian corridors and especially the Eastern one, to start with re-greening projects. There, many applicable land management options combine with high potential for restoring soil organic matter, the highest rainfall recycling potential exist in the more favourable long rains season, whilst finally, the Tanzanian governments both at national- and local levels seem more reliable. The GIS data facilitate further investigation of this particular corridor in search of specific project locations, especially with respect to hydrological and soil restoration characteristics, for which highly detailed information is available. It should be noted that the assessment did not consider the boundaries of national parks. If these are well-protected, there should be limited land degradation occurring within the parks. Moreover, if areas within parks are degraded, not all SLM measures may be applicable and perhaps only afforestation and grazing management are example SLM categories that should still be possible. For climate effects, the data are available at coarser resolution, but more importantly the feedback processes also work at larger scales. This study rather gives inside into the type of feedbacks that may be expected, but is too limited to give reliable magnitudes of these effects. Finally, the institutional setting could be further refined only with additional local communities expertise and local cultural views on land use.

This study serves as a desktop demonstration of an objective approach for prioritisation of intervention areas, based on readily available datasets, model structures and literature, rather than an extensive study, worked out in all details. The latter would require initially more field work on soil and groundwater characteristics (for Chapters 3 and 4), on vegetation characteristics (i.e. sensitivity to drought stress) and meteorology (to improve model parameterisations in Chapter 5) or on local institutions, tribal structures and economic resilience (Chapter 6). That would require collaboration with local research organisations in order to access their expertise. And interactions with local stakeholders to collectively determine the relative importance of various environmental improvement directions, i.e. to set the weights for the different data layers.

Nevertheless, it is considered that the approach is useful and the results fairly robust at the scale studied here. For more detailed searches for optimal location of projects within the four corridors, such field work would be strongly recommended to fill in details in an otherwise similarly structured approach.

8 Appendices

A: Applicability limitations of restoration measures

Applicability limitations of restoration measures were considered for a number of factors based on globally available datasets: Land cover, Rainfall, Slope, Soil texture and depth. The criteria used are presented and discussed below.

Land cover
The GLOBCOVER dataset (Bontemps *et al.*, 2011) for 2009 was used to assess land cover/land use applicability limitations. A major distinction was made between measures applicable on agricultural land, rangeland and forested areas. Some were in addition also considered applicable to artificial or bare areas. Table 8.1 shows in more detail which classes of the global dataset were considered applicable for each of the restoration measures. For reforestation measures, biomes were considered leading for applicability, but individual pixels within these were considered if not on agricultural and artificial land.

Table 8.1
Applicability related to land cover/land use of restoration measures.

SLM type	GLOBCOVER class[1]																			
	11	14	20	30	40	50	60	70	90	100	110	120	130	140	150	160	170	180	190	200
Afforestation			X	X			X				X	X	X		X					X
Agroforestry	X	X	X	X							X	X	X							
Agronomic measures	X	X	X	X																
Bunds	X	X	X	X							X	X		X						
Grazing management			X	X			X				X	X	X	X	X					X
Gully rehabilitation		X	X	X							X	X	X	X	X				X	X
Homegarden improvement	X	X	X	X															X	
Irrigation	X	X	X	X										X						
Terracing	X	X	X	X										X						
Vegetative barriers	X	X	X	X							X	X		X						
Vegetative cover	X	X	X	X									X	X	X					X
Water harvesting		X	X	X							X	X		X	X				X	X
Afforestation of savannahs					X	X		X	X	X				X		X	X	X		

[1] Legend for GLOBCOV classes: 11 irrigated cropland; 14 rainfed cropland; 20 mosaic crop/vegetation; 30 mosaic vegetation/ cropland; 40 closed/open evergreen forest; 50 closed deciduous forest; 60 open broadleaved forest; 70 closed needleleaved forest; 90 open needleleaved forest; 100 closed/open mixed broad/needleleaved forest; 110 mosaic forest - shrub/grassland; 120 mosaic grass - forest/shrubland; 130 closed/open shrubland; 140 closed/open grassland; 150 sparse vegetation; 160 closed/open broadleaved forest regularly flooded; 170 permanently flooded forest; 180 closed/open vegetation regularly flooded; 190 artificial surfaces; 200 bare areas; 210 water; 220 permanent snow and ice; 230 no data (none of the SLM measures were deemed applicable for the latter three classes 210-230).

Table 8.2
Applicability related to rainfall of the 12 SLM measures.

SLM type	Annual rainfall (mm)								
	<250	250-500	500-750	750-1000	1000-1500	1500-2000	2000-3000	3000-4000	>4000
Afforestation			X	X	X	X	X	X	X
Agroforestry		X	X	X	X	X	X	X	X
Agronomic measures	X	X	X	X	X	X			
Bunds		X	X	X	X				
Grazing management	X	X	X	X	X	X	X	X	X
Gully rehabilitation	X	X	X	X	X	X	X	X	X
Homegarden improvement		X	X	X	X	X	X	X	X
Irrigation	X	X	X	X	X				
Terracing		X	X	X	X	X	X	X	X
Vegetative barriers		X	X	X	X	X	X		
Vegetative cover		X	X	X	X	X	X	X	X
Water harvesting	X	X	X	X	X				

Rainfall
Rainfall was considered as an applicability limitation for SLM measures (reforestation measures being governed by biomes) (Table 8.2). The main reasons for limitations were:

- Minimum level of rainfall for vegetative measures; under deficient rainfall conditions, vegetation establishment is not possible.
- Maximum level of rainfall for land degradation mitigation effectiveness; at high annual levels of precipitation, several SLM measures (e.g. agronomic ones) are insufficient for erosion control.
- Maximum level of rainfall beyond which the measure is not required; irrigation and water harvesting are not necessary when levels of precipitation are high enough for reliable rain fed crop production.

Slope
Slope was considered as an applicability limitation for SLM measures. Several SLM measures are not applicable in steep and/or very steep environments. Conversely, some SLM measures are specific for steeper land and are not implementable on flat land and gentle slopes (e.g. bunds, terraces). Irrigation represents a special case as it can only be applied on steeper slopes in combination with other measures to store or apply water. Table 8.3 presents the slope applicability criteria as implemented. A slope map was generated from the SRTM90 elevation map.

Table 8.3
Applicability related to slope of the 12 SLM measures.

SLM type	Slope class						
	Flat 0-0.5%	Gentle 0.5-2%	Moderate 2-8%	Rolling 8-16%	Hilly 16-30%	Steep 30-45%	Very steep >45%
Afforestation	X	X	X	X	X	X	X
Agroforestry	X	X	X	X	X	X	
Agronomic measures	X	X	X	X	X		
Bunds		X	X	X	X	X	
Grazing management	X	X	X	X	X	X	
Gully rehabilitation			X	X	X	X	X
Homegarden improvement	X	X	X	X	X		
Irrigation	X	X	X				
Terracing			X	X	X	X	X
Vegetative barriers		X	X	X	X	X	
Vegetative cover	X	X	X	X	X		
Water harvesting		X	X	X	X	X	

Soil texture and soil depth
Soil texture was considered as an applicability limitation for SLM measures. Input for soil texture classification was based on current %-sand and %-clay content of soils (S-World simulations, Stoorvogel *et al.*). Three soil texture classes were defined: fine soil texture if clay fraction >40%, coarse texture if sand >50%, and moderate for remaining soils (Figure 8.1). Current soil depth was directly taken from S-World.

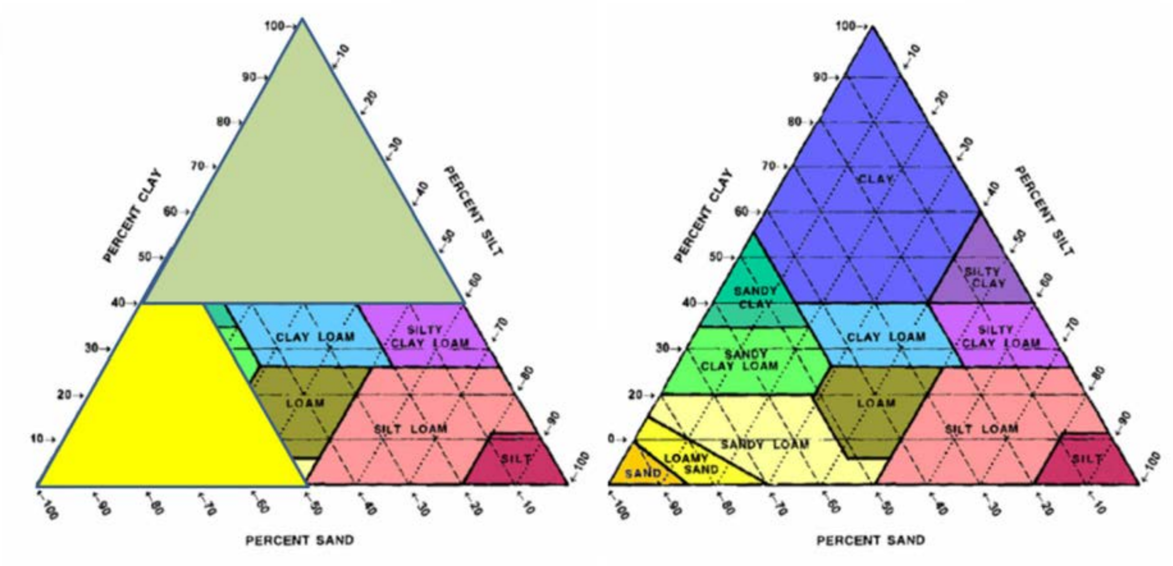


Figure 8.1 *Soil texture criteria for applicability limitations: coarse (sand > 50%, yellow triangle in left), fine (clay > 40%, grey triangle), moderate (other).*

Table 8.4 presents the applicability limitations considered with regards to soil depth and soil texture. A certain minimum soil depth is required for establishment of vegetative measures. This also applies to terracing. Irrigation requires deep soils. Soil texture limitations exist for stability of certain structural SLM measures (gully rehabilitation, terracing).

Table 8.4

Applicability related to slope texture and depth of the 12 SLM measures.

SLM type	Soil depth (cm)			Soil texture class		
	0-20	20-50	>50	Coarse	Moderate	Fine
Agroforestry		X	X	X	X	X
Afforestation		X	X	X	X	X
Agronomic measures	X	X	X	X	X	X
Bunds	X	X	X	X	X	X
Grazing management	X	X	X	X	X	X
Gully rehabilitation	X	X	X	X	X	
Homegarden improvement		X	X	X	X	X
Irrigation			X	X	X	X
Terracing		X	X	X	X	
Vegetative barriers		X	X	X	X	X
Vegetative cover		X	X	X	X	X
Water harvesting	X	X	X	X	X	X

B: Climatology analysis Mt Kilimanjaro region

The following data sets have been used for the climatology analysis. All daily data have been averaged to monthly means and cover the period 01-01-1979 till 31-12-2012. These data sets are widely accepted as one of the best representation of actual historic global weather; they are based on model analysed observations.

Variable	Afkorting	Data set
precipitation, daily totals	P	WFD-EI(-GPCP)
specific humidity at 2m, daily mean	Q	WFD-EI
temperature at 2m, daily mean	T	WFD-EI
easterly and northerly wind components at 10m	U, V	EI
easterly and northerly components of moisture transport over the total atmospheric column	Mflux	EI
topography in the weather model	topo	WFD-EI

WFD-EI: Watch Forcing Data based on ERA-Interim (Weedon, Gomes *et al.* 2011)

WFD-EI(_GPCP): as above, precipitation corrected to Global Precipitation Climatology Product (Adler, Huffman *et al.* 2003)

EI: ERA-Interim, model re-analysis of upper atmospheric (weather balloons), near-surface (weather stations, satellite) and seasurface temperature (buoys and satellite) observations by the ECMWF (Dee, Uppala *et al.* 2011)

The figures on the next pages (Figure 8.2, Figure 8.3) present monthly overviews of precipitation, relative humidity, wind, total column atmospheric moisture flux and model topography. It shows the generally, north easterly winds in the Kenya Tanzania border area in DJF turning to south south easterly flows in the remainder of the year. Topography deflects the main trade winds around it.

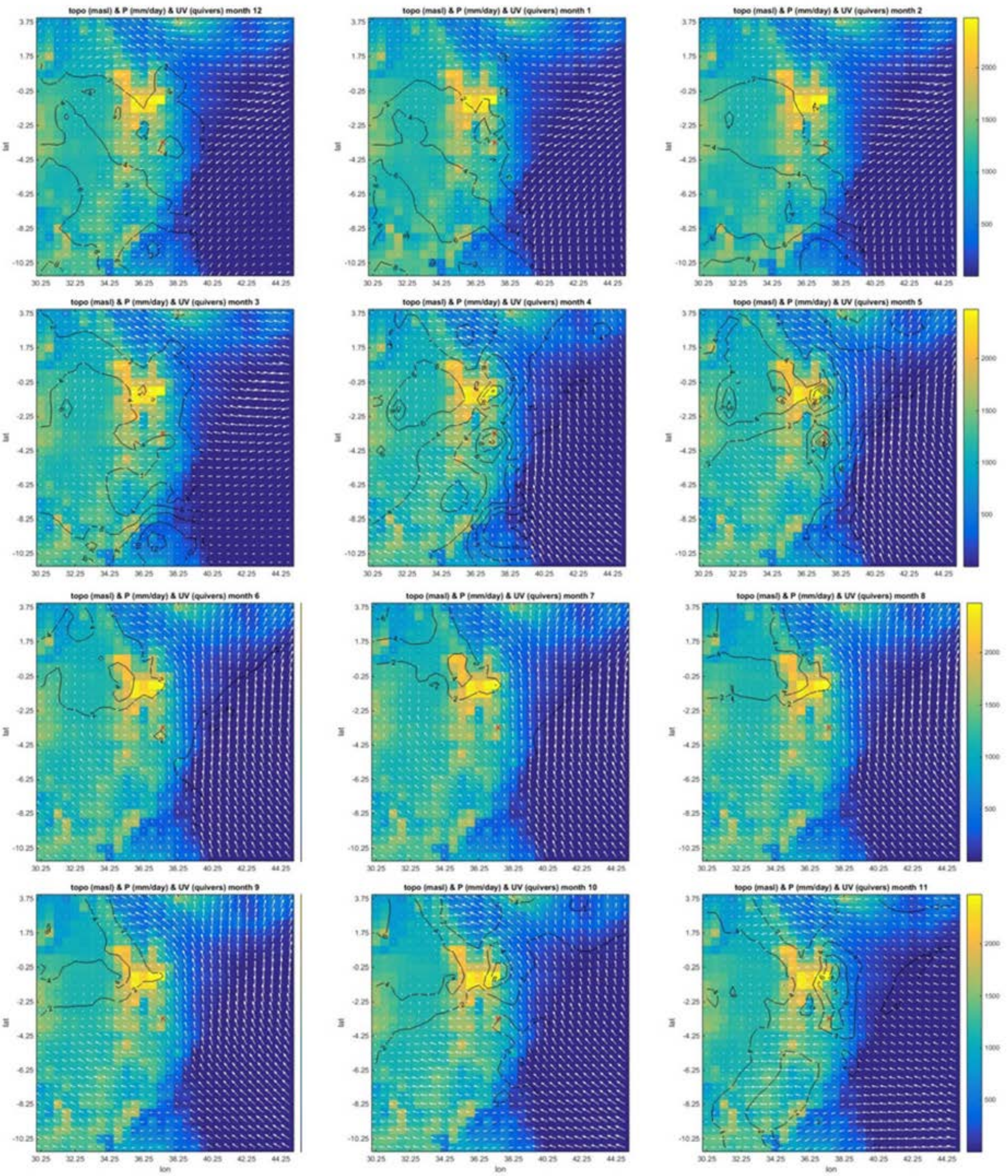


Figure 8.2 *Monthly mean precipitation (contours, interval 2 mm/day) and wind vectors (quivers) against a background of (ECMWF model) topography (colours, m amsl). Top to bottom: MAM, JJA, SON, DJF. The red 'K' indicates the location of Mt Kilimanjaro.*

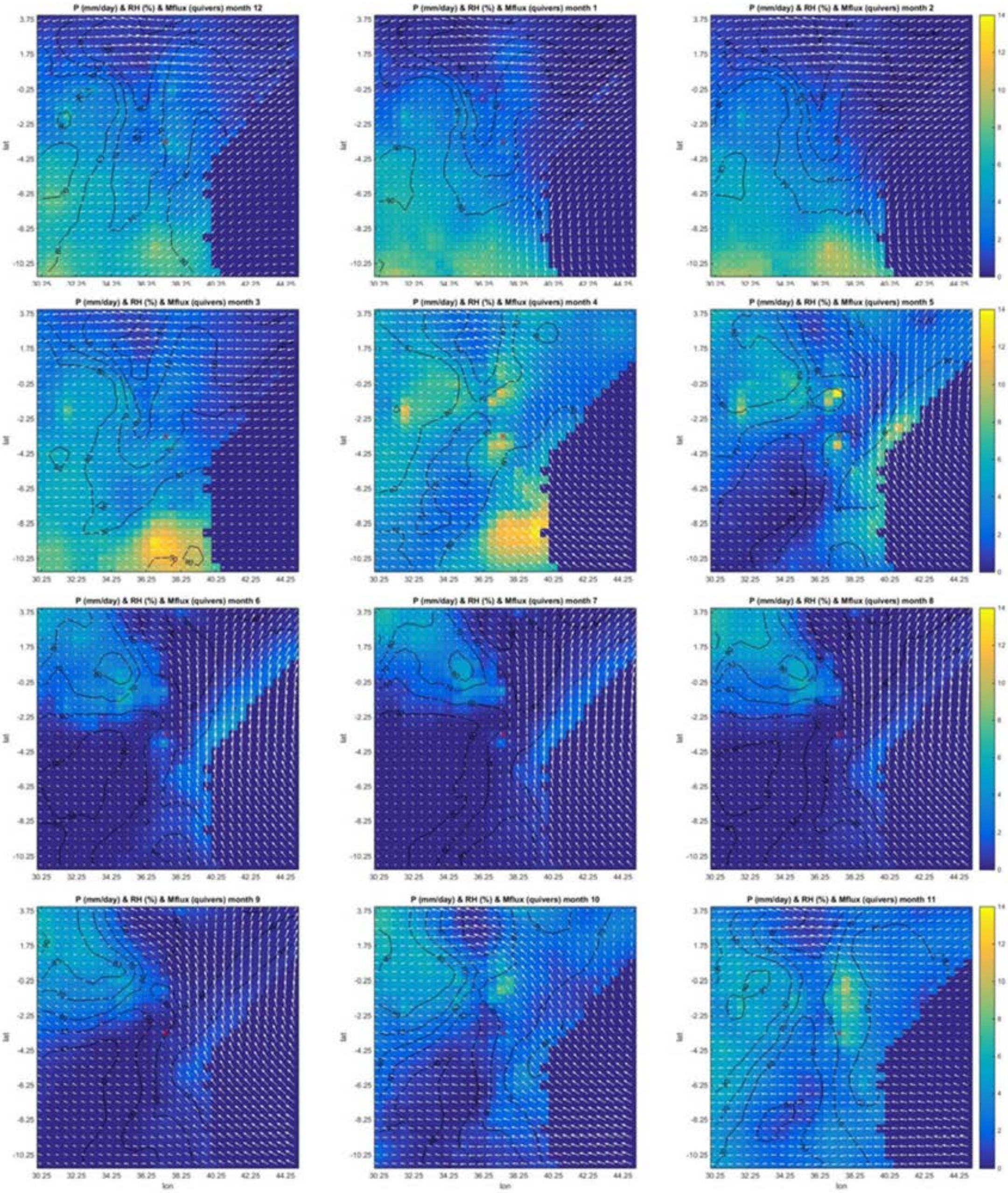


Figure 8.3 *Monthly mean relative humidity (contours, interval 10%) and wind vectors (quivers) against a background of precipitation (colours, mm/day). Top to bottom: MAM, JJA, SON, DJF. The red 'K' indicates the location of Mt Kilimanjaro.*

C: RAMS Model grid, setup and extended results

For the greening sensitivity experiments the RAMS models (v6) has been used (Pielke, Cotton *et al.* 1992), implementing three two-way nested grids of 27, 9 and 3km resolution respectively. After initial trials the configuration from the following figure best reproduced observed precipitation.

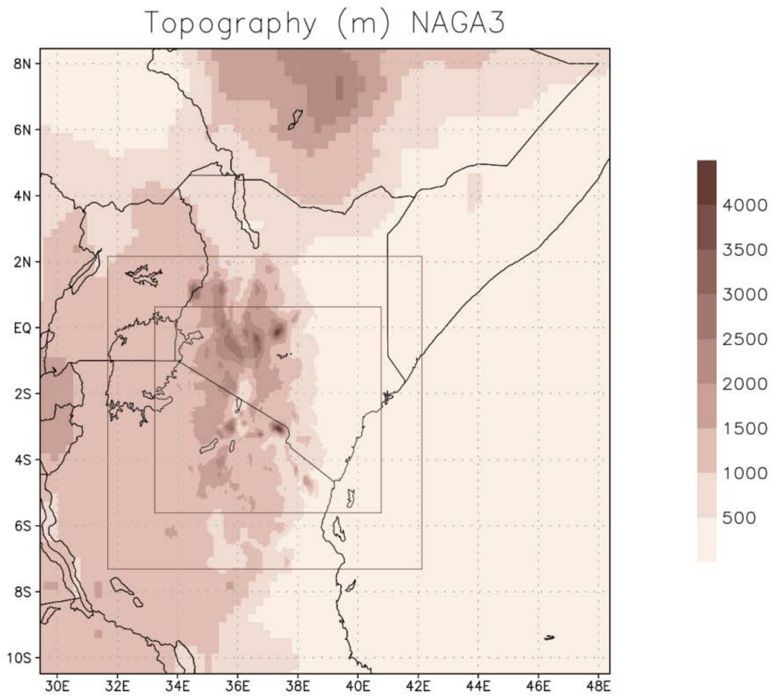


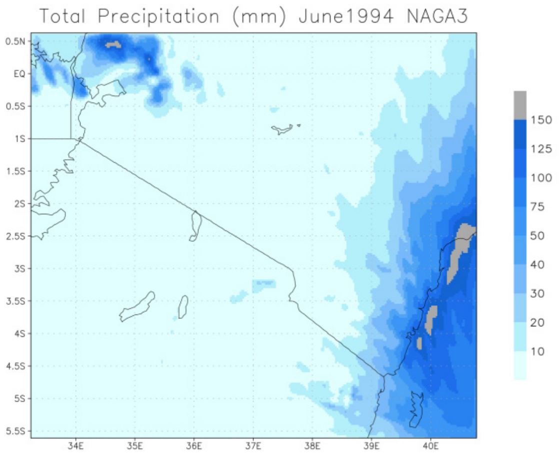
Figure 8.4 *Outline of the three nested grids used in the RAMS simulations.*

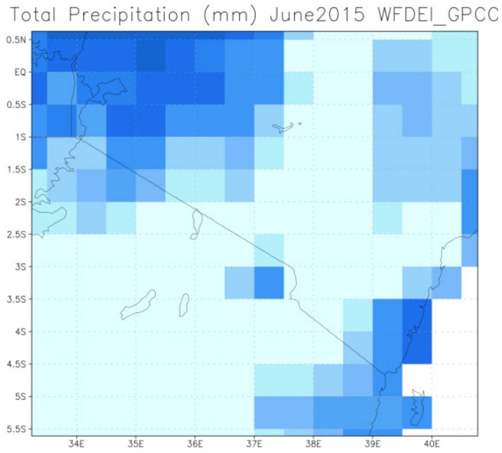
The parameter settings as given in the following table were used.

Table 8.5
Configuration of RAMS 6.1

Grids	1	2	3	4
dx, dy	27 km (80x80)	9 km (131x119)	3 km (281x232)	1 km (..)
dt	30 s	15 s	7.5 s	6.7 s
dz	50 – 1250 m (35 levels)			
Radiation	Chen & Cotton ((Chen and Cotton 1983))			
Topography	GTOPO30 (~1 km resolution)			
Land cover	GLCC USGS (~1 km resolution ((Loveland, Reed *et al.* 2000))			
Land surface	LEAF-3 ((Walko, Band *et al.* 2000))			
Diffusion	MRF ((Hong and Pan 1996))			
Microphysics	Full microphysics package ((Meyers, Walko *et al.* 1997))			
Forcing	ECMWF			
Nudging time scale	lateral: 1800 s (only on grid 1)			
Period	1 August 2006 – 31 August 2006 (+ preceeding spinup of 15 days)			

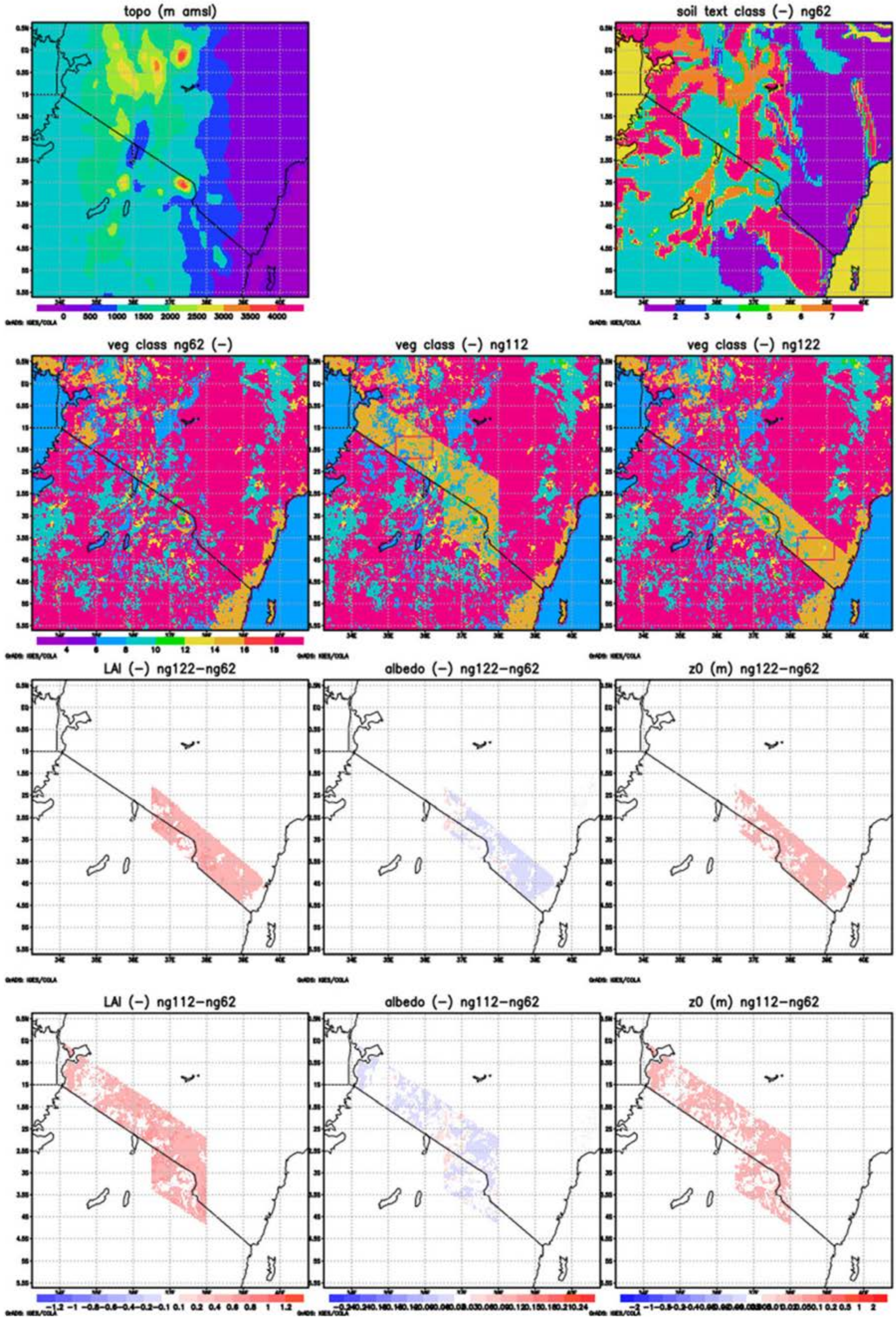
The baseline simulation produced the following rainfall patterns (left) compared to the WFD-EI values (right).





In Figure 8.5 the land use changes and their associated parameter changes are shown for the Ke-W and Ke-E corridors.

Figure 8.5 *(next page) Effectuated land cover changes for the two Kenyan corridors. Top row: topography at left, soil textural class at right (from class 2-8 the loam and clay content of the soil increases at the expense of sand content). The second row shows the land cover maps (class numbers refer to: 4 - Evergreen needle leaf tree; 5 - Deciduous needle leaf tree; 6 - Deciduous broadleaf tree; 7 - Evergreen broadleaf tree; 8 - Short grass; 9 - Tall grass; 10 - Semi-desert; 11 - Tundra; 12 - Evergreen shrub; 13 - Deciduous shrub; 14 - Mixed woodland; 15 – Crop / mixed farming, C3 grassland; 16 - Irrigated crop; 17 - Bog or marsh; 18 - Wooded grassland). The small rectangular areas depict the areas in which we sampled the change in parameters and effects (e.g. Table 5.1). The third row shows the resulting changes in LAI, albedo and roughness resp. for the Ke-E corridor, the fourth row the same for the Ke-W corridor.*


topo (m amsl)
0 500 1000 1500 2000 2500 3000 3500 4000
soil text class (-) ng62
2 3 4 5 6 7
veg class ng62 (-)
4 6 8 10 12 14 16 18
veg class (-) ng112
veg class (-) ng122
LAI (-) ng122-ng62
albedo (-) ng122-ng62
z0 (m) ng122-ng62
LAI (-) ng112-ng62
albedo (-) ng112-ng62
z0 (m) ng112-ng62
-1.2 -1 -0.8 -0.6 -0.4 -0.2 -0.1 0.1 0.2 0.4 0.6 0.8 1 1.2

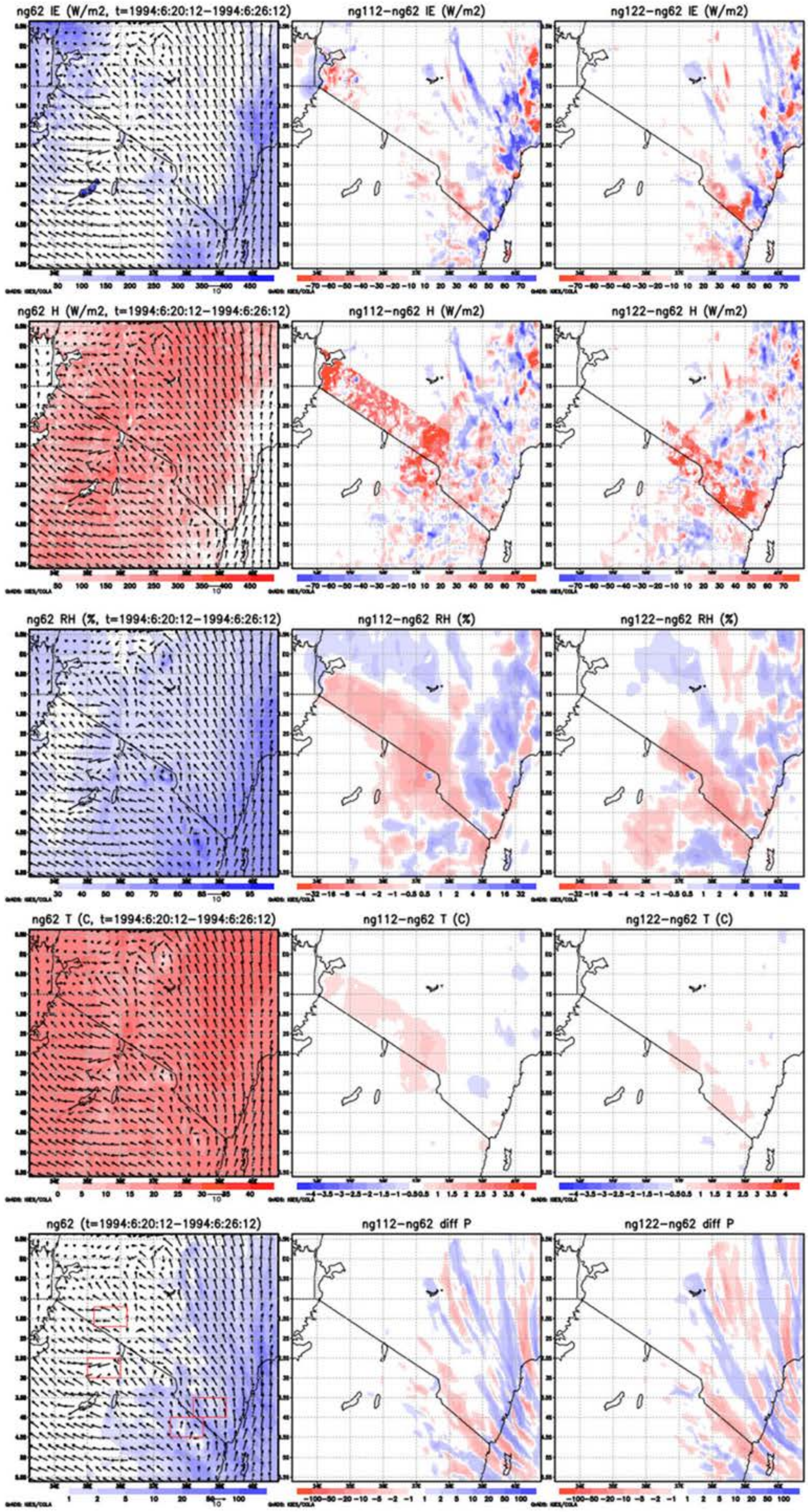

ng62 IE (W/m2, t=1994:6:20:12-1994:6:26:12)
ng112-ng62 IE (W/m2)
ng122-ng62 IE (W/m2)
ng62 H (W/m2, t=1994:6:20:12-1994:6:26:12)
ng112-ng62 H (W/m2)
ng122-ng62 H (W/m2)
ng62 RH (%, t=1994:6:20:12-1994:6:26:12)
ng112-ng62 RH (%)
ng122-ng62 RH (%)
ng62 T (C, t=1994:6:20:12-1994:6:26:12)
ng112-ng62 T (C)
ng122-ng62 T (C)
ng62 (t=1994:6:20:12-1994:6:26:12)
ng112-ng62 diff P
ng122-ng62 diff P

Figure 8.10 *on the following pages. Effects of greening the two Kenyan corridors during the second to sixth weeks of the simulation (counting from 15 May1994).*

We present the baseline situation (left column) and the effects of greening in the W and E corridors (middle and right column, resp.), given as the difference from the baseline, on evaporation (top row) and heat flux (2nd row), both are in W/m2 (680 W/m2 evaporation roughly equals 1 mm/hr); percentage relative humidity (3rd row) and temperature in Celsius (bottom row). Blue colours indicate moister or cooler conditions, red colours dryer or warmer conditions (but note different colour scales for each variable).

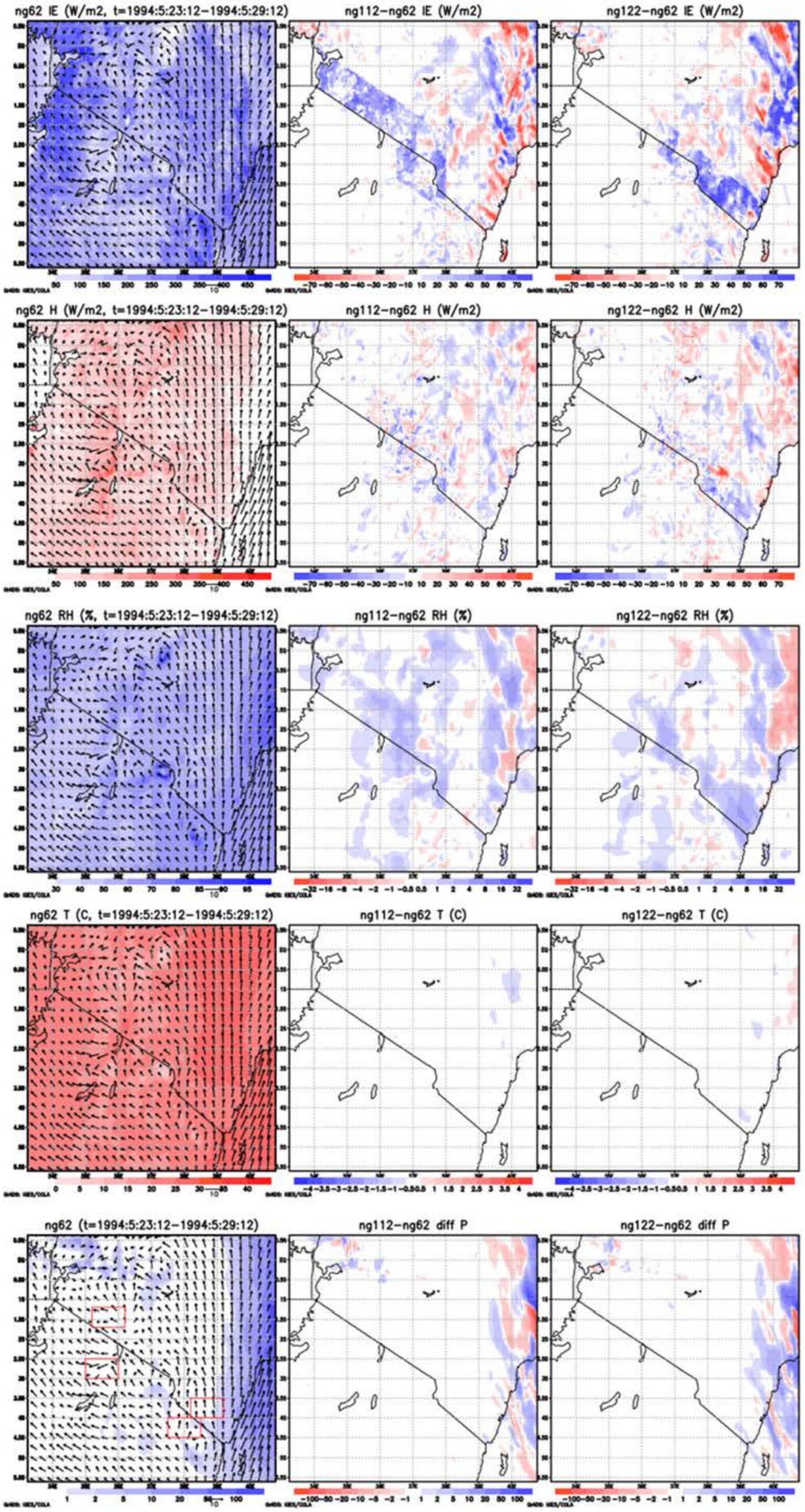

ng62 IE (W/m2, t=1994:5:23:12–1994:5:29:12)
ng112–ng62 IE (W/m2)
ng122–ng62 IE (W/m2)
ng62 H (W/m2, t=1994:5:23:12–1994:5:29:12)
ng112–ng62 H (W/m2)
ng122–ng62 H (W/m2)
ng62 RH (%, t=1994:5:23:12–1994:5:29:12)
ng112–ng62 RH (%)
ng122–ng62 RH (%)
ng62 T (C, t=1994:5:23:12–1994:5:29:12)
ng112–ng62 T (C)
ng122–ng62 T (C)
ng62 (t=1994:5:23:12–1994:5:29:12)
ng112–ng62 diff P
ng122–ng62 diff P

Figure 8.6

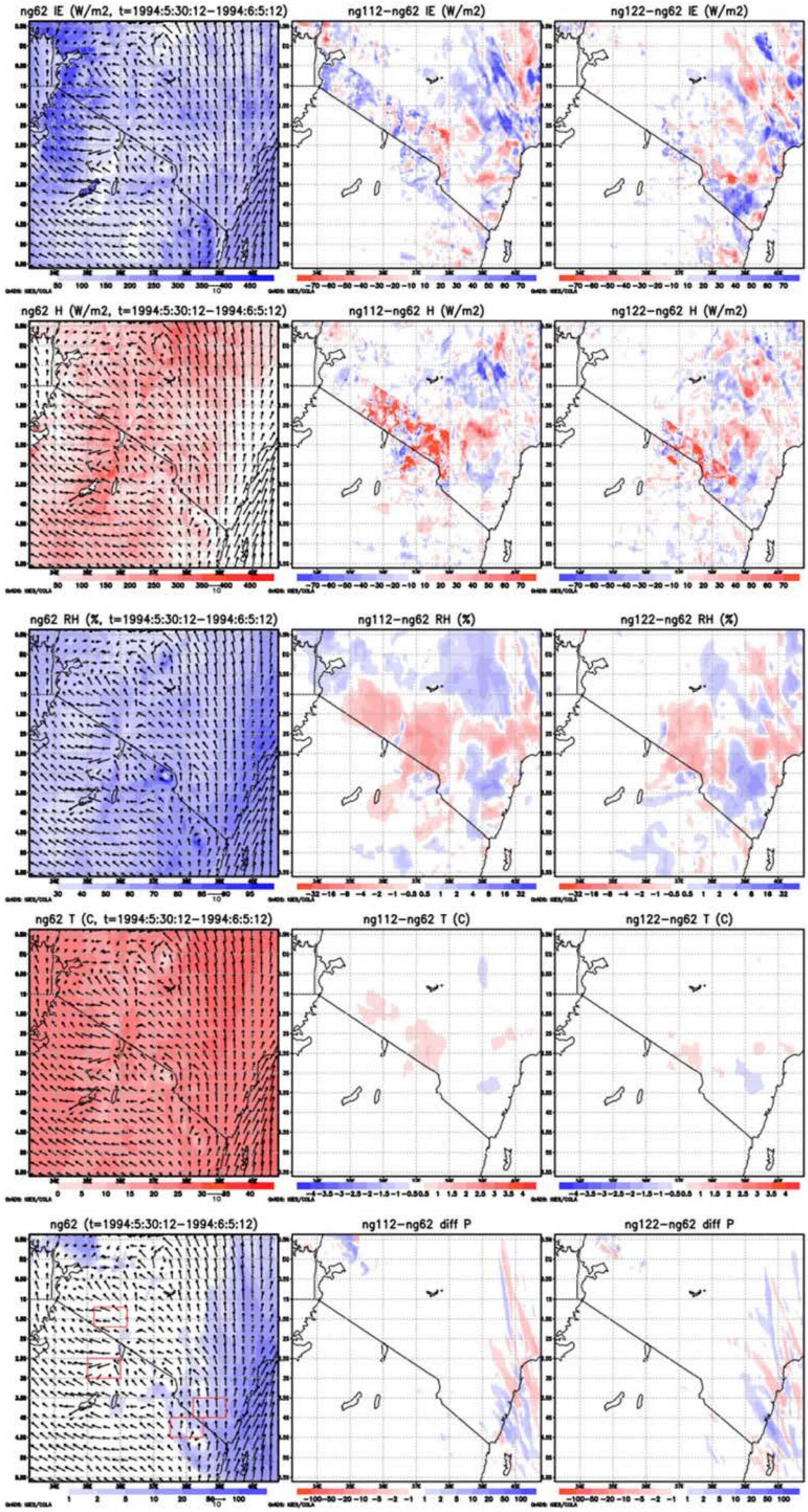

ng62 IE (W/m2, t=1994:5:30:12-1994:6:5:12)
ng112-ng62 IE (W/m2)
ng122-ng62 IE (W/m2)
ng62 H (W/m2, t=1994:5:30:12-1994:6:5:12)
ng112-ng62 H (W/m2)
ng122-ng62 H (W/m2)
ng62 RH (%, t=1994:5:30:12-1994:6:5:12)
ng112-ng62 RH (%)
ng122-ng62 RH (%)
ng62 T (C, t=1994:5:30:12-1994:6:5:12)
ng112-ng62 T (C)
ng122-ng62 T (C)
ng62 (t=1994:5:30:12-1994:6:5:12)
ng112-ng62 diff P
ng122-ng62 diff P

Figure 8.7

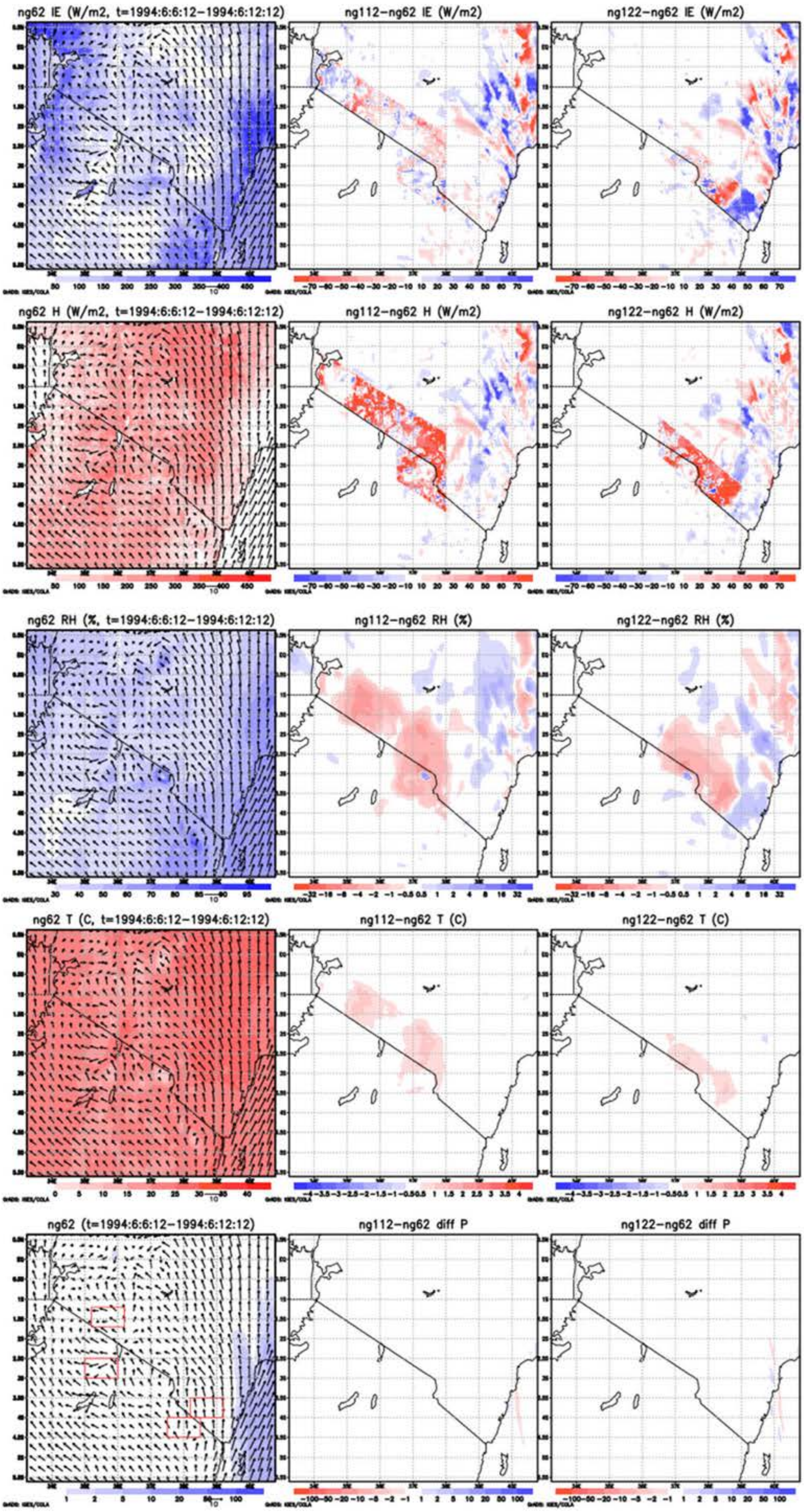
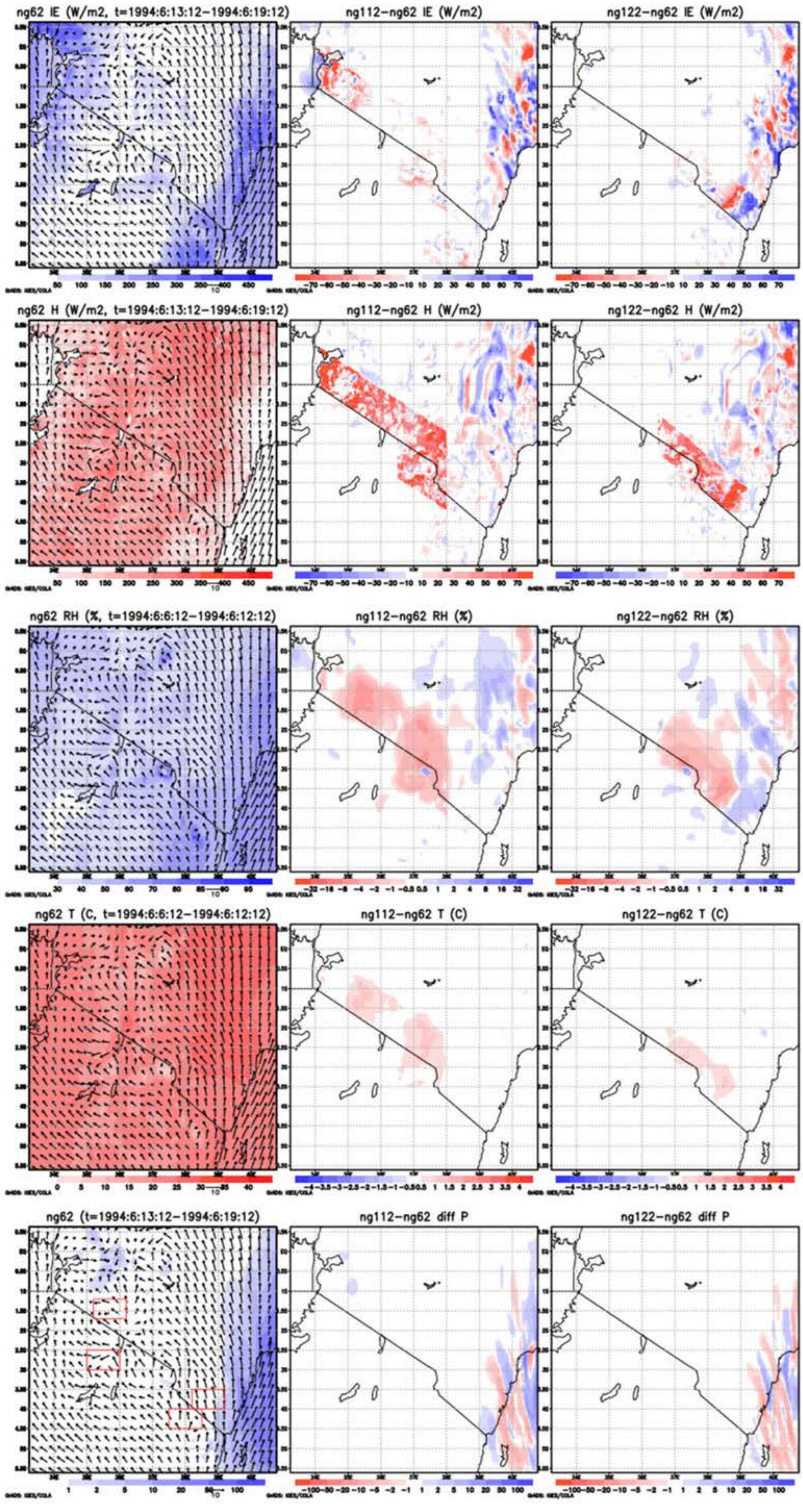

ng62 IE (W/m2, t=1994:6:6:12-1994:6:12:12)
ng112-ng62 IE (W/m2)
ng122-ng62 IE (W/m2)
ng62 H (W/m2, t=1994:6:6:12-1994:6:12:12)
ng112-ng62 H (W/m2)
ng122-ng62 H (W/m2)
ng62 RH (%, t=1994:6:6:12-1994:6:12:12)
ng112-ng62 RH (%)
ng122-ng62 RH (%)
ng62 T (C, t=1994:6:6:12-1994:6:12:12)
ng112-ng62 T (C)
ng122-ng62 T (C)
ng62 (t=1994:6:6:12-1994:6:12:12)
ng112-ng62 diff P
ng122-ng62 diff P

Figure 8.8



ng62 IE (W/m2, t=1994:6:13:12-1994:6:19:12)
ng112-ng62 IE (W/m2)
ng122-ng62 IE (W/m2)
ng62 H (W/m2, t=1994:6:13:12-1994:6:19:12)
ng112-ng62 H (W/m2)
ng122-ng62 H (W/m2)
ng62 RH (%, t=1994:6:6:12-1994:6:12:12)
ng112-ng62 RH (%)
ng122-ng62 RH (%)
ng62 T (C, t=1994:6:6:12-1994:6:12:12)
ng112-ng62 T (C)
ng122-ng62 T (C)
ng62 (t=1994:6:13:12-1994:6:19:12)
ng112-ng62 diff P
ng122-ng62 diff P

Figure 8.9

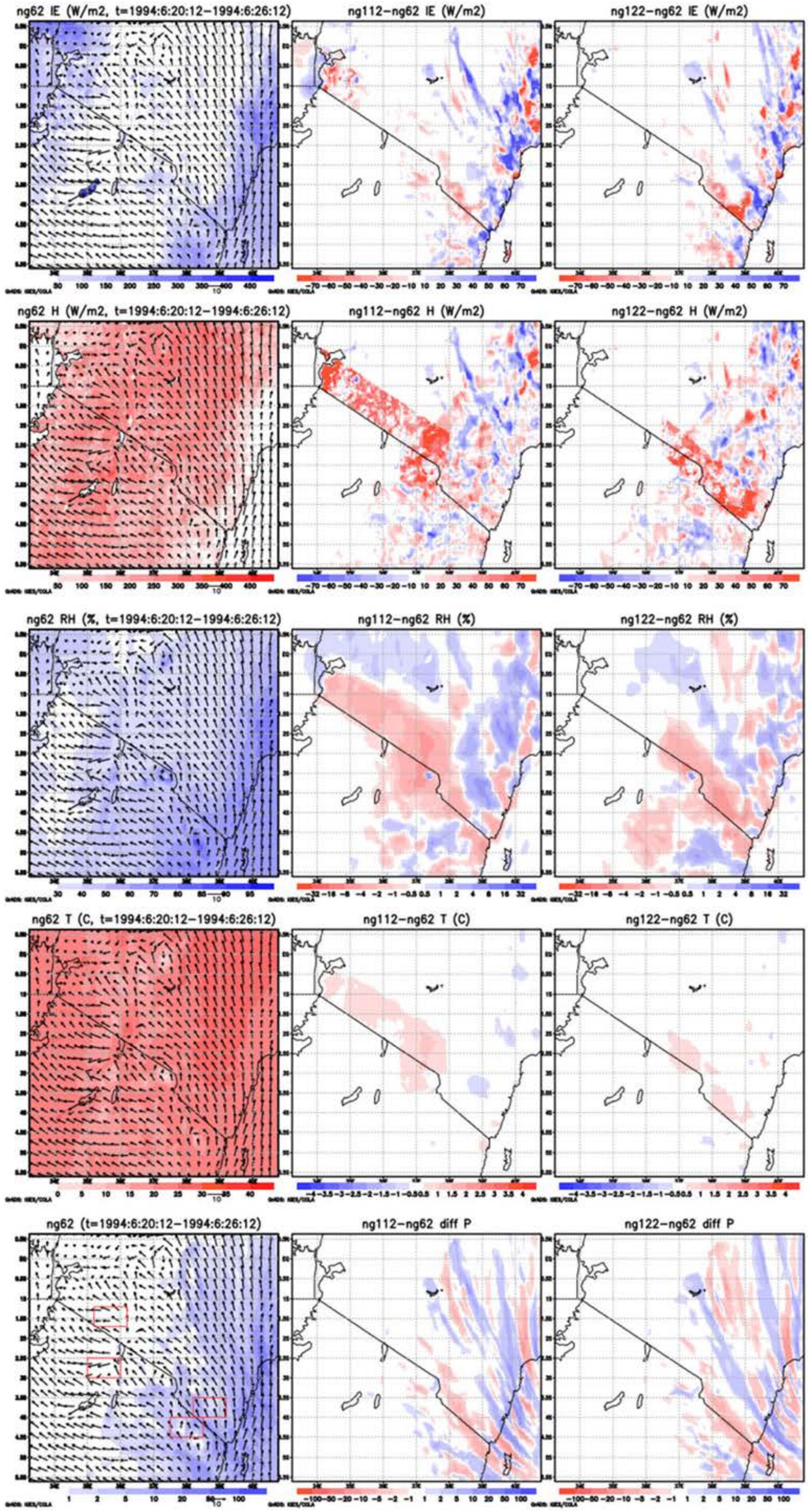

ng62 IE (W/m2, t=1994:6:20:12-1994:6:26:12)
ng112-ng62 IE (W/m2)
ng122-ng62 IE (W/m2)
ng62 H (W/m2, t=1994:6:20:12-1994:6:26:12)
ng112-ng62 H (W/m2)
ng122-ng62 H (W/m2)
ng62 RH (%, t=1994:6:20:12-1994:6:26:12)
ng112-ng62 RH (%)
ng122-ng62 RH (%)
ng62 T (C, t=1994:6:20:12-1994:6:26:12)
ng112-ng62 T (C)
ng122-ng62 T (C)
ng62 (t=1994:6:20:12-1994:6:26:12)
ng112-ng62 diff P
ng122-ng62 diff P

Figure 8.10

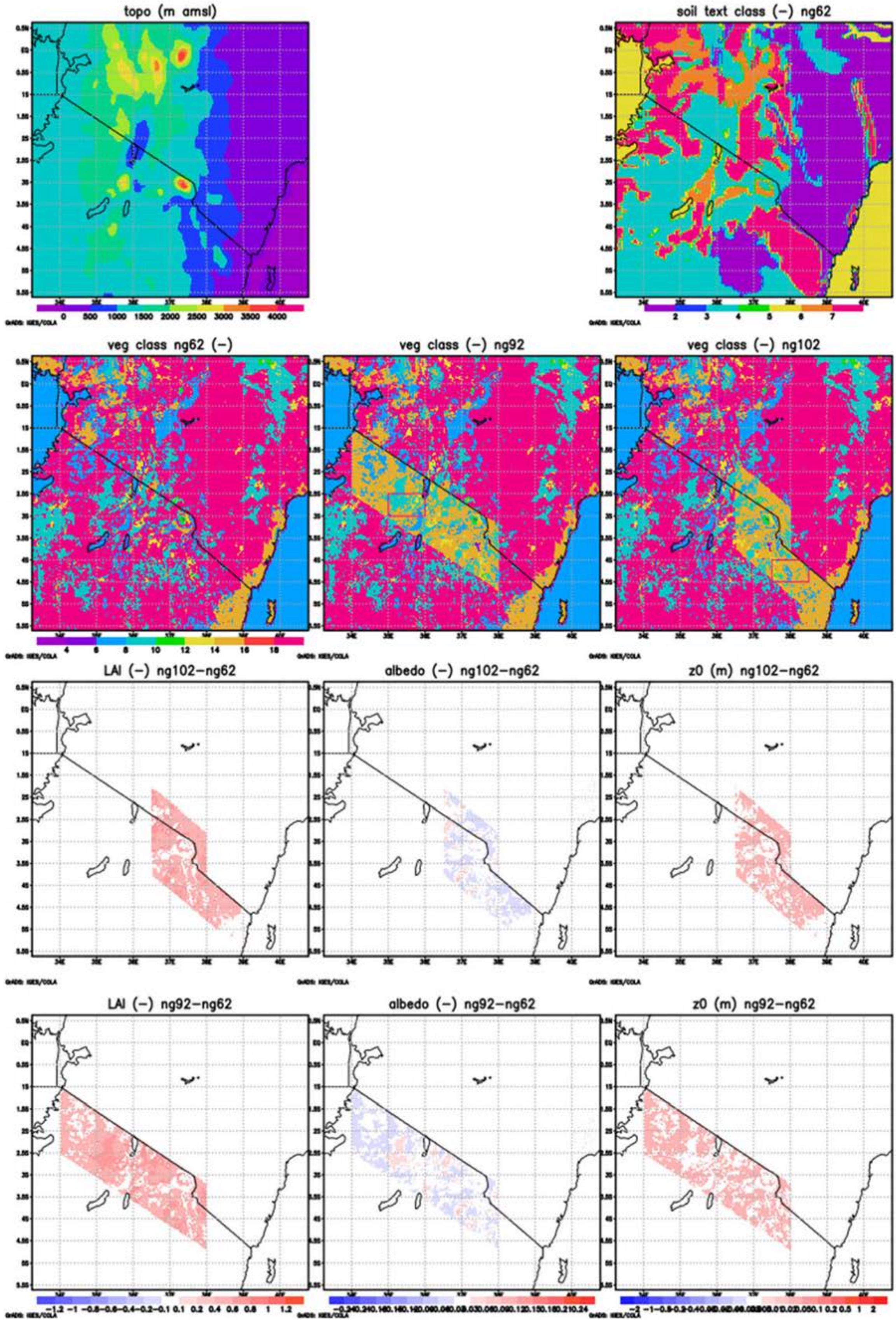
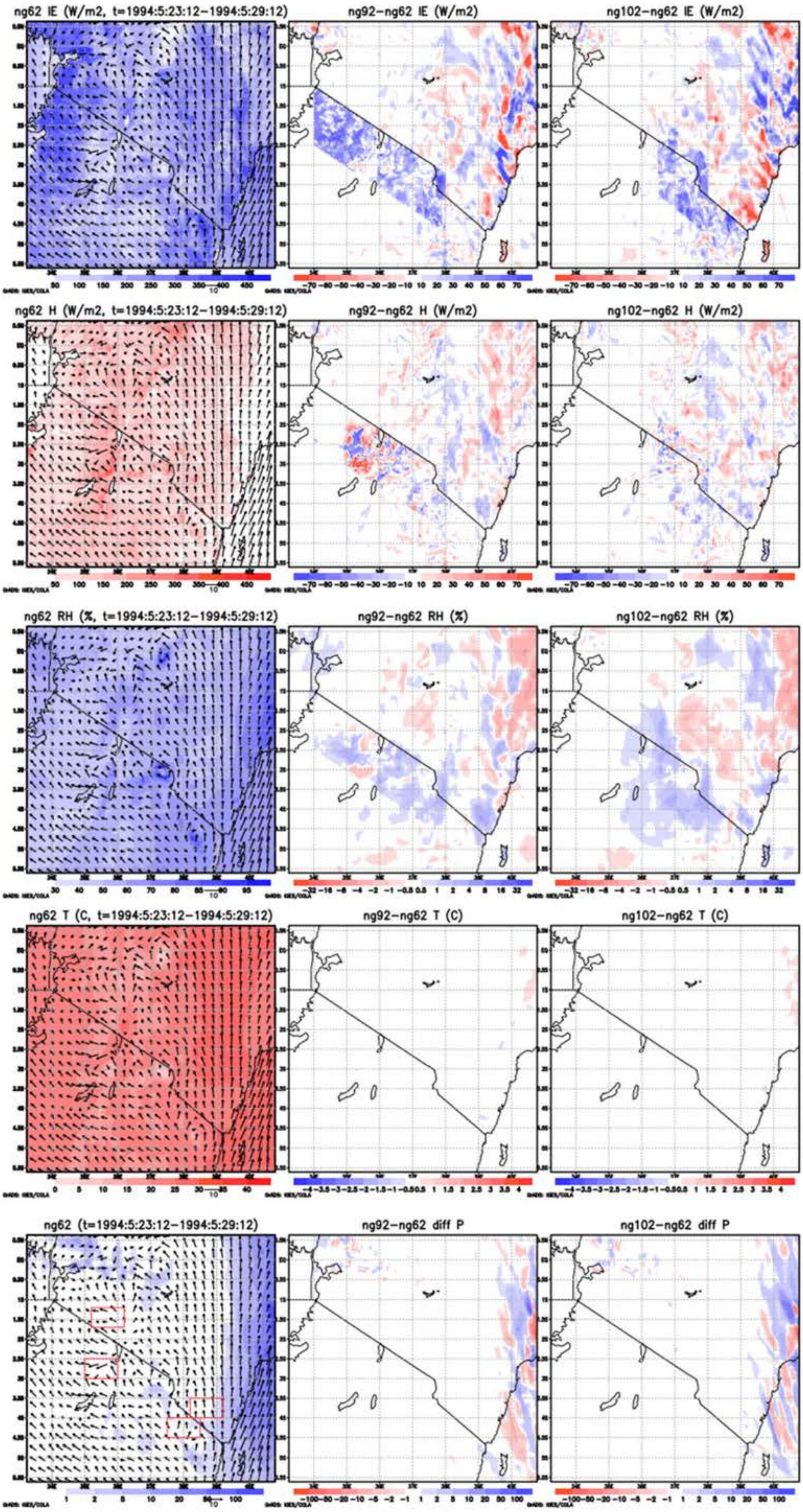


Figure 8.11 to Figure 8.16 *Same as Figure 8.5 but then for the Ta-W and Ta-E corridors. See there for a full explanation.*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ng102-ng62 IE (W/m2)
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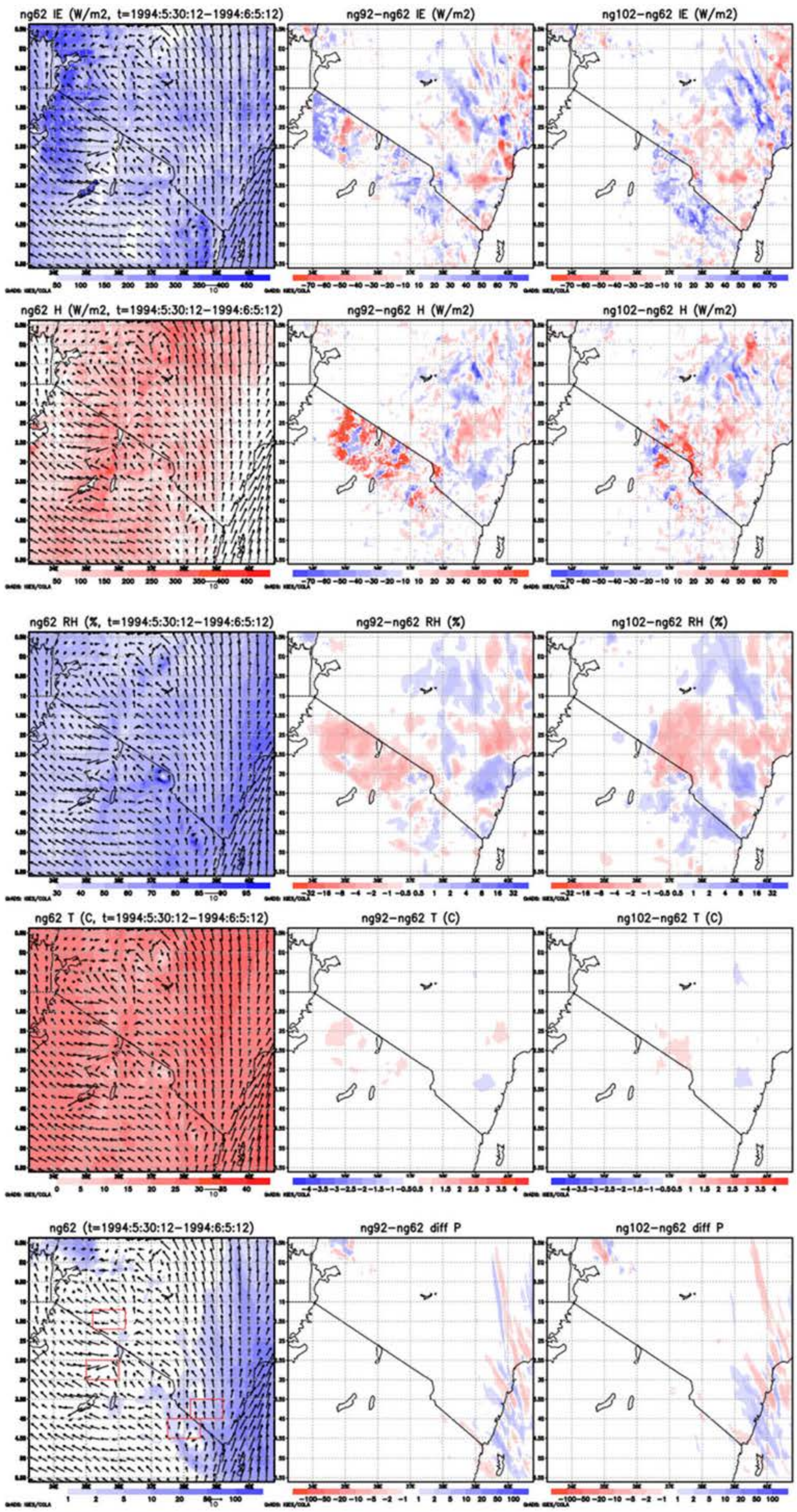
ng92-ng62 H (W/m2)
ng102-ng62 H (W/m2)
ng62 RH (%, t=1994:5:23:12-1994:5:29:12)
ng92-ng62 RH (%)
ng102-ng62 RH (%)
ng62 T (C, t=1994:5:23:12-1994:5:29:12)
ng92-ng62 T (C)
ng102-ng62 T (C)
ng62 (t=1994:5:23:12-1994:5:29:12)
ng92-ng62 diff P
ng102-ng62 diff P

Figure 8.12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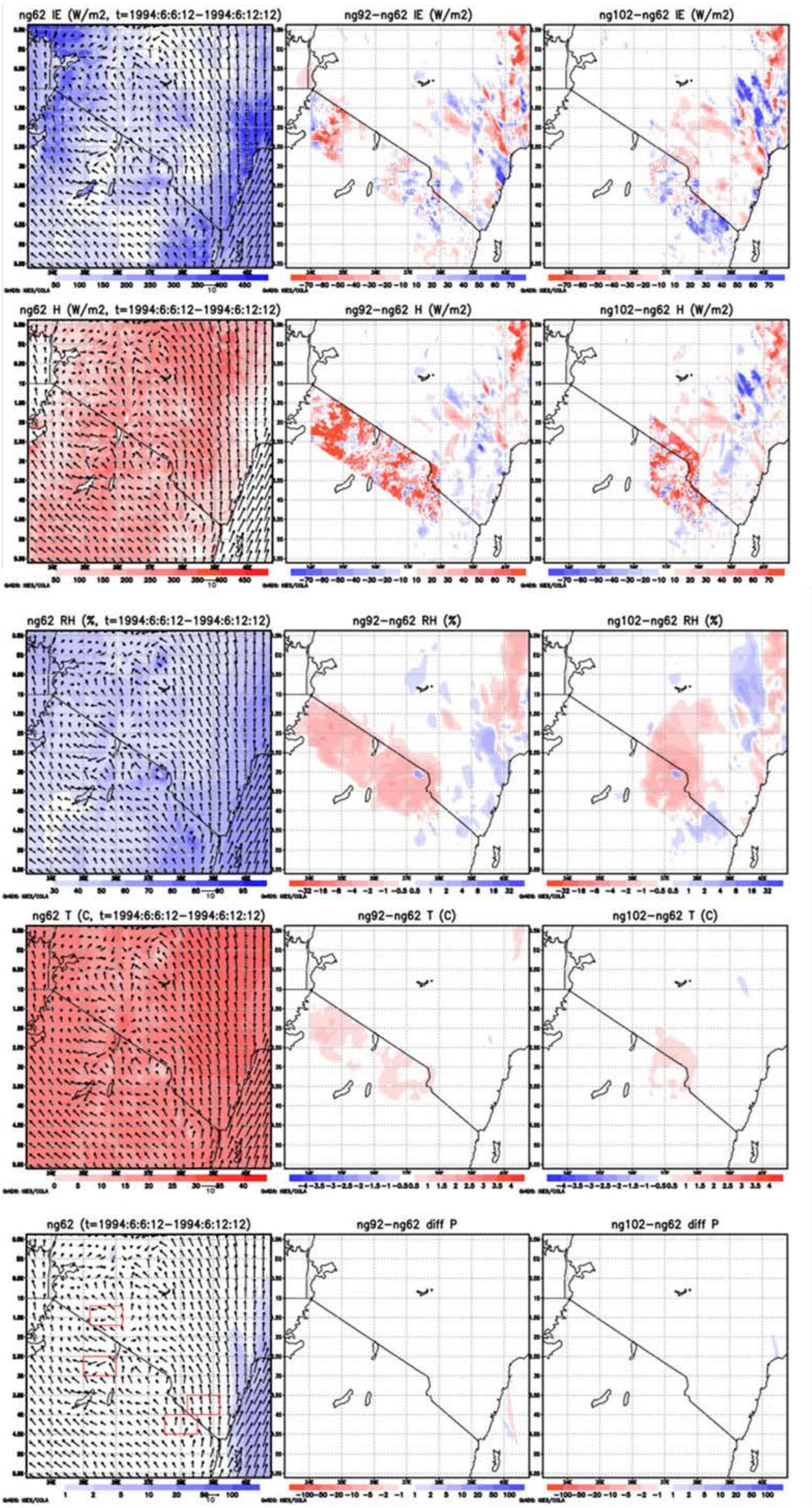
ng92-ng62 H (W/m2)
ng102-ng62 H (W/m2)
ng62 RH (%, t=1994:5:30:12-1994:6:5:12)
ng92-ng62 RH (%)
ng102-ng62 RH (%)
ng62 T (C, t=1994:5:30:12-1994:6:5:12)
ng92-ng62 T (C)
ng102-ng62 T (C)
ng62 (t=1994:5:30:12-1994:6:5:12)
ng92-ng62 diff P
ng102-ng62 diff P

Figure 8.13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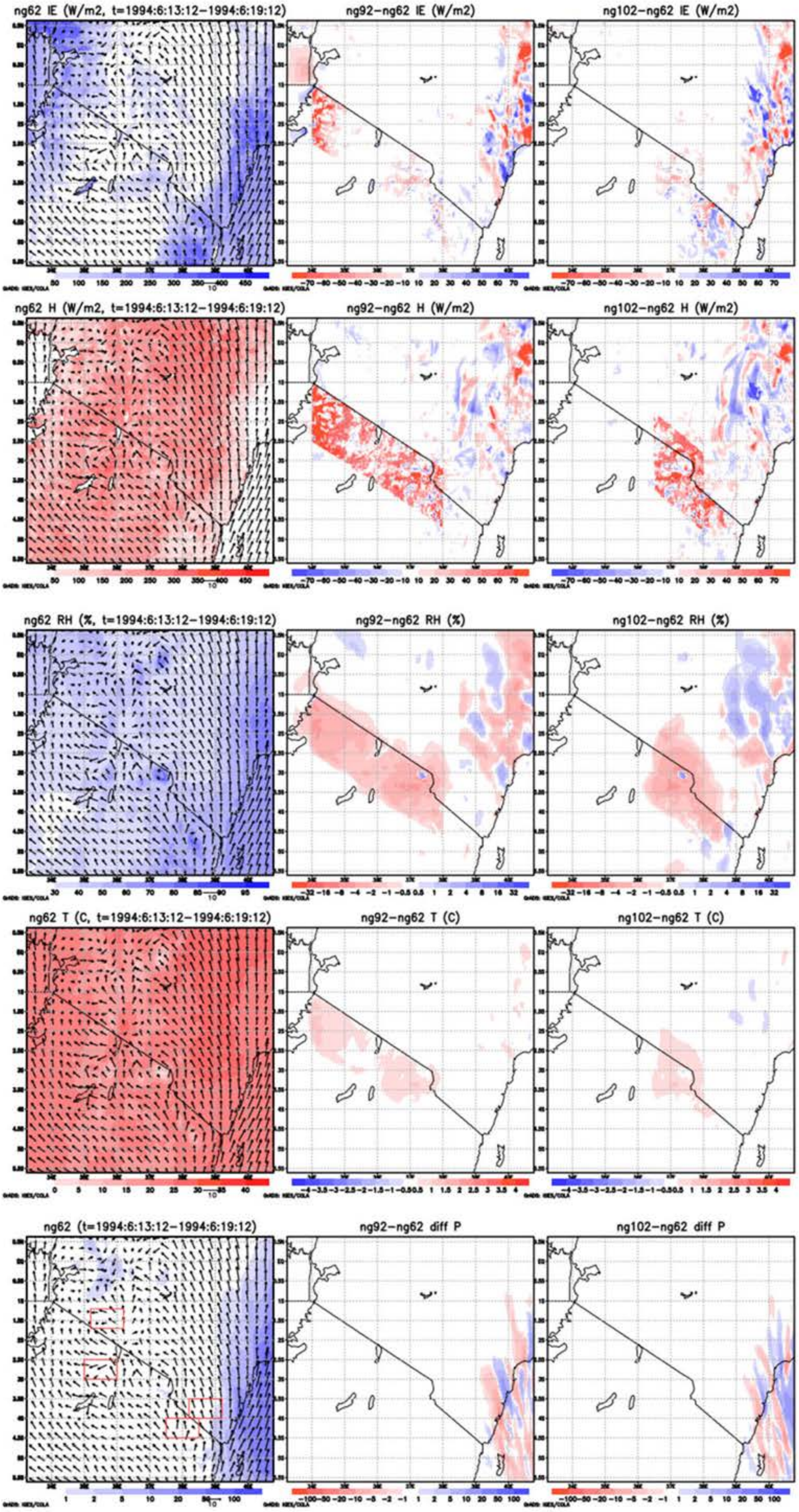
ng92-ng62 H (W/m2)
ng102-ng62 H (W/m2)
ng62 RH (%, t=1994:6:6:12-1994:6:12:12)
ng92-ng62 RH (%)
ng102-ng62 RH (%)
ng62 T (C, t=1994:6:6:12-1994:6:12:12)
ng92-ng62 T (C)
ng102-ng62 T (C)
ng62 (t=1994:6:6:12-1994:6:12:12)
ng92-ng62 diff P
ng102-ng62 diff P

Figure 8.14



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ng102-ng62 IE (W/m2)
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ng92-ng62 H (W/m2)
ng102-ng62 H (W/m2)
ng62 RH (%, t=1994:6:13:12-1994:6:19:12)
ng92-ng62 RH (%)
ng102-ng62 RH (%)
ng62 T (C, t=1994:6:13:12-1994:6:19:12)
ng92-ng62 T (C)
ng102-ng62 T (C)
ng62 (t=1994:6:13:12-1994:6:19:12)
ng92-ng62 diff P
ng102-ng62 diff P

Figure 8.15

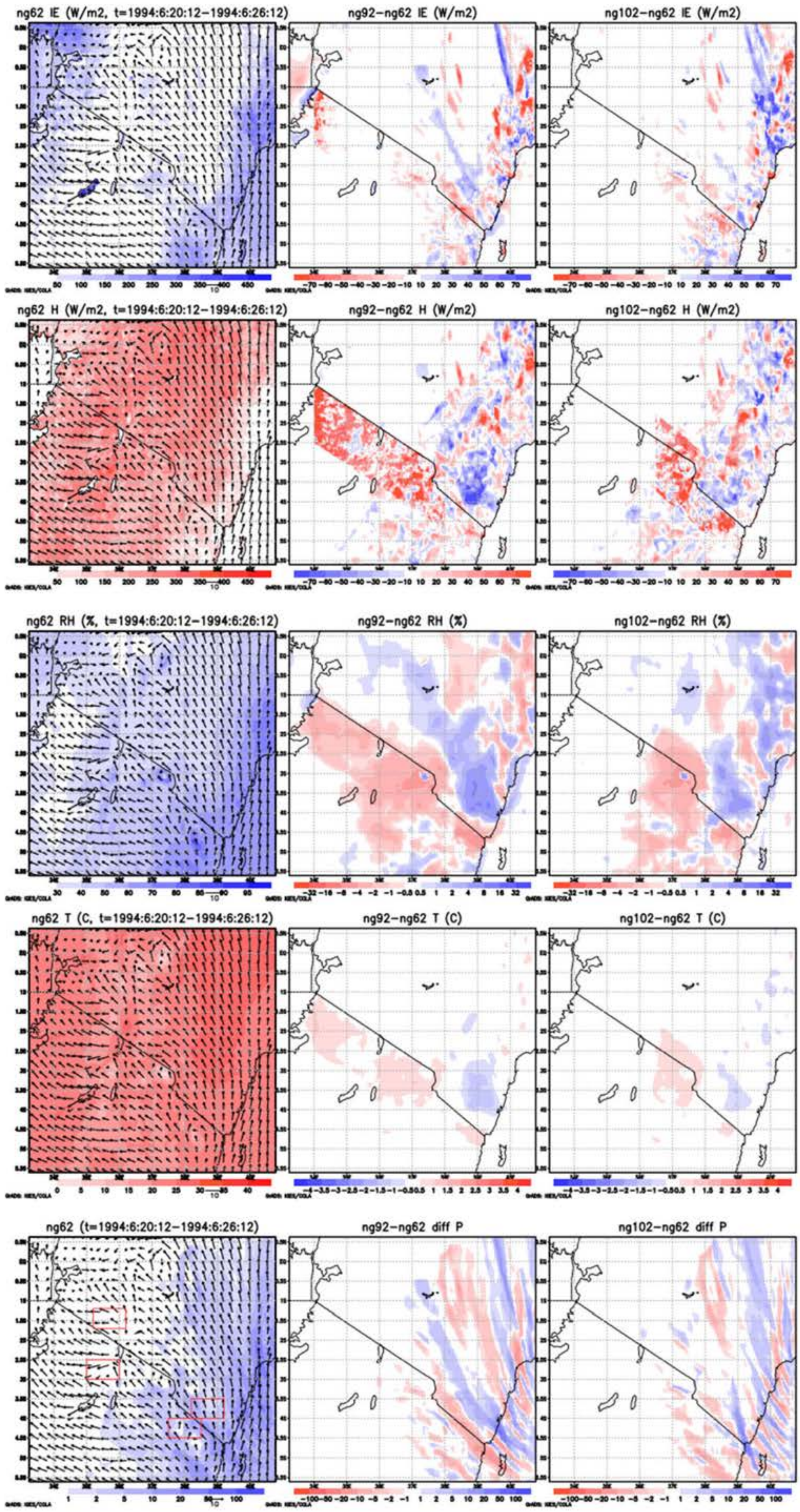
ng62 IE (W/m2, t=1994:6:20:12-1994:6:26:12)
ng92-ng62 IE (W/m2)
ng102-ng62 IE (W/m2)
ng62 H (W/m2, t=1994:6:20:12-1994:6:26:12)
ng92-ng62 H (W/m2)
ng102-ng62 H (W/m2)
ng62 RH (%, t=1994:6:20:12-1994:6:26:12)
ng92-ng62 RH (%)
ng102-ng62 RH (%)
ng62 T (C, t=1994:6:20:12-1994:6:26:12)
ng92-ng62 T (C)
ng102-ng62 T (C)
ng62 (t=1994:6:20:12-1994:6:26:12)
ng92-ng62 diff P
ng102-ng62 diff P

Figure 8.16

D: Available ArcGIS map layers

E: Annotated Adaptation Capacity Wheel Assessments

Application of the Adaptive Capacity Wheel to Kenya

Dimension	Criteria	Score	Explanation
Variety	Variety of problem frames and solutions	+1	Water harvesting has been introduced to several parts of Africa, including Kenya, since the 1980s by nongovernmental and development organizations including the UN (Rockström and Falkenmark 2015). Agriculture: promoting irrigated agriculture, promoting conservation agriculture, value addition to agricultural products, developing weather indexed crop insurance schemes, support for community-based adaptation including provision of climate information to farmers, enhanced financial and technical support to drought resistant crops (Government of Kenya, 2013). Livestock and Pastoralism: Breeding animals tolerant to local climatic conditions, weather indexed livestock insurance, establishment of fodder banks, documenting indigenous knowledge, provision of water for livestock and humans, early warning systems for droughts and floods, and vaccination campaigns (Government of Kenya, 2013). Availability of on farm traditional ecological knowledge and deeper understanding of sustainable agricultural practices next to agronomic science (Karpouzoglou and Barron 2014) Irrigation with surface water from rivers and lakes receives too much attention compared to local water harvesting in the soil (Rockström and Falkenmark 2015)
	Multi-actor, level and sector	+2	The Ministry of Environment and Mineral Resources in partnership with stakeholders prepared and launched the National Climate Change Response Strategy in 2010. The Action plan is the result of a year-long, participatory process involving the public sector, the private sector, academia and civil society, under the leadership of the Ministry of Environment and Mineral Resources guided by a multi-stakeholder, multidisciplinary taskforce (Government of Kenya, 2013). Kenyan civil society groups are actively engaged in the political life of the country and media is considered vibrant and active (eldis.org). Rainwater harvesting has been noticed at high policy level, for instance in the Comprehensive Africa Agricultural Development Programme (CAADP) overseen by the New Partnership for Africa's Development (NEPAD: national and international organizations, development agencies and banks, stakeholders). BRICS countries and other investors, international and national private sectors. (Karpouzoglou and Barron 2014)
	Room for diversity	+2	The famous Fanya-juu terraces of Machakos, Kenya to conserve soil moisture (Rockström and Falkenmark 2015). Multitude of tribes and languages are cultivated (Miguel, 2002). Farmer households' strategies to diversify their income sources are rural–urban migration, emigration to other countries, and non-farm enterprises, including trading, motorcycle repair and transport services. (Karpouzoglou and Barron 2014)
	Redundancy	-2	High dependence on climate sensitive natural resources for our livelihoods and economic sustenance (Government of Kenya, 2013).
	Total	3/4=+0,75	

Dimension	Criteria	Score	Explanation
Learning Capacity	Trust	-2	65% cannot forgive perpetrators of post-election violence (2007/2008) yet (Society for International Development, 2012) Livelihood stress is increasingly reflected in tension and violence, while social disintegration and anomie are signalled in the upsurge of crime, violence and insecurity which have become a recent characteristic of rural Kenya (World Bank 2006). High levels of crime and violence have long been a feature of urban Kenya, but one of the main findings of this study is the extent to which crime and violence have come to permeate rural areas over the last five years. The new wave of rural crime is accompanied by unprecedented levels of brutality. One local response to the ineffectiveness of the police in maintaining public order has been the spread in rural vigilantism (World Bank 2006). Emerging farmer–farmer networks (Karpouzoglou and Barron 2014)
	Double loop learning	-1	When asked what was the main driver for moving out of poverty, in Kenya only 23% of households would refer to expansion of land under cultivation, compared to 49% who referred to crop diversification and commercialisation (Karpouzoglou and Barron 2014) Cultivating land and crop production are not the right kind of agriculture in this part of Africa (interview) At higher levels supportive institutions and policies are lacking which creates limitations for advancing knowledge. (Karpouzoglou and Barron 2014)
	Discuss doubts	0	
	Single loop learning	0	Educated or semi-educated youth find themselves without employment or assets, and forced to remain within the parental household well into adulthood (World Bank 2006). Experimenting with new technologies is an accepted practice (Reij and Smaling, 2008)
	Institutional memory	+1	Government agricultural extension services, for technology dissemination and adoption (Karpouzoglou and Barron 2014)
	Total	-2/5=-0,4	
Room for autonomous change	Continuous access to information	-1	A few organisations are starting to share their knowledge but on a small scale. A good example is the Arid Lands Information Network (ALIN) which publishes Joto Afrika, a quarterly magazine that carries climate change research briefings by African scientists. In 2011, ALIN partnered with the Climate and Development Knowledge Network (CDKN) and CARE to develop special issues of Joto Afrika. Based on these and the findings presented in the detailed report of the analysis, the establishment of an electronic system for managing climate change related knowledge has been recommended (Government of Kenya, 2013). Public awareness about climate change in Kenya is very low (Government of Kenya, 2013).
	Act according to plan	+1	The Machakos and Kitui regions of Kenya are areas with successful rainwater harvesting (Rockström and Falkenmark 2015) The Kenya Vision 2030 plans to plant seven billion trees to address food, water and energy security. During the last ten years, Kenya has been able to restore 6% of forest cover. It is expected that Kenya will attain the 10% tree cover in the next three years (Government of Kenya, 2013).

Dimension	Criteria	Score	Explanation
	Capacity to improvise	-1	Common strategies include diversification into new farm enterprises, off-farm and non-farm activities, and migration, though limited assets (and for women, inferior rights in property) severely limit room for manoeuvre. Many households are forced into marginal and even illegal activities such as squatting, charcoal production, illicit brewing, and commercial sex work (World Bank 2006). New forms of local collective action have also emerged, including a vibrant movement of women's groups providing rotational credit services and information/training on income-generating activities to their members, and community-wide initiatives which attempt to supplement the failing services of the state through the provision of, for example, teachers and school buildings. (World Bank 2006). African households have the possibility to experiment with rain harvesting technologies (Karpouzoglou and Barron 2014)
	Total	-1/3=-0,3	
Leadership	Visionary leadership	-2	Historical domestic tensions and contestation associated with centralisation and abuse of power, high levels of corruption, a more than two decades long process of constitutional review and post-election violence. The approval of the new constitution in 2010 and relatively peaceful elections in March 2013 are milestones constituting steps forward in Kenya's transition from political crisis (eldis.org[1]). At the global level, the 'old' policy focus on rising crop production and on crop productivity enhancement continues to persist without considering other dimensions of food security, or system based improvements including the availability of markets. Small scale, rain fed agriculture receives too little attention at high governance levels (Rockström and Falkenmark 2015)
	Entrepreneurial leadership	0	Its entrepreneurship and human capital give it huge potential for further growth, job creation and poverty reduction (eldis.org). The growing rates of rural crime are also driving out better off rural dwellers, as well as small businesses, thus changing the social and economic composition of some rural communities (World Bank 2006). Investment by aid banks an BRICS countries in agriculture, trade relations between BRICS and SSA economies, the entry of small-scale investors, business entrepreneurs and manufacturers (Karpouzoglou and Barron 2014) Lack of links between small-holder farmers with functioning value chains and markets for key produce that can raise farmer incomes (Karpouzoglou and Barron 2014) The New Partnership for Africa's Development (NEPAD: national and international organizations, development agencies and banks, stakeholders). (Karpouzoglou and Barron 2014)
	Collaborative leadership	-2	No nation building effort causing lack of cooperation between tribes. Tribal differences used to cause political violence before elections (Miguel, 2002)
	Total	-4/3=-1	
Resources	Authority	-2	Tribal chiefs stayed in command in villages reinforcing tribal differences (Miguel 2002) Main area of concern: Restoring public trust in the police through improved accountability and dialogue between police and the public; and a focus on community policing in rural areas (World Bank 2006).

[1] http://interactions.eldis.org/unpaid-care-work/country-profiles/kenya/social-economic-and-political-context-kenya

Dimension	Criteria	Score	Explanation
	Human resources	-2	High unemployment rates especially among the youth. More than 70 per cent of Kenya's population are below the age of 30 and the population under age 14 alone amounts to 43 percent (eldis.org) The Government has already established a National Climate Change Secretariat and other institutional arrangements that will provide for the implementation of the actions identified (Government of Kenya, 2013). Declining human capital due in considerable part to the impact of HIV/AIDS (World Bank 2006). African population is expected to grow from 1 billion today to 2,5 billion in 2050 (Rockström and Falkenmark 2015) Massive population growth is unsustainable (interview)
	Financial resources	0	Kenya has the largest and most diverse economy in East Africa, with an average annual growth rate of over 5% for nearly a decade. The recent discovery of oil and other mineral resources creates great potential for the Kenyan economy (eldis.org). New mobile money platforms give money directly to poorest families in Kenya (Karpouzoglou and Barron 2014) Tribalism causes lack of public investments in education and infrastructure (Miguel 2002) The creation of a Kenya Climate Fund (KCF) is intended as the key vehicle for mobilising and allocating resources from international development partners towards climate change activities in Kenya, and which could also be used for allocating domestic public resources towards climate change actions (Government of Kenya, 2013). Economic decline in rural areas (World Bank 2006). 300 million rural people in sub-Saharan Africa have an income of 1,25 dollar or less per day; NGO funding schemes but not always reliable (Karpouzoglou and Barron 2014)
	Total	-4/3=-1,3	
Fair Governance	Legitimacy	-2	Fear that the Executive, the Parliament, the Judiciary and the citizenry alike will fail to uphold the law (Society for International Development, 2012) Corruption or collapse of formal institutions has compromised the services provided to rural areas, particularly in the areas of agricultural marketing and services, physical security and education (World Bank 2006)
	Equity	-2	Tribalism causes inequity (Miguel 2002). Kenya remains a highly unequal society by income, by gender, and by geographical location (eldis.org). The Kenyan woman is still relegated to traditional roles and seen as unfit for high public offices. (Society for International Development, 2012). The highly inequitable land distribution system has conspired with population pressure, holding fragmentation, ecological degradation, and a corrupted system of land administration to make access to land problematic and insecure (World Bank 2006). No transparent land tenure rights; ethnic/social rights not acknowledged while international investors buy large amounts of land (Karpouzoglou and Barron 2014)
	Responsiveness	-2	Less than half (46.2%) of Kenyans agree that they can access law courts easily (Society for International Development, 2012)
	Accountability	-2	Widespread corruption obstructs and jeopardises political, economic and social development. Led by the Ministry of Justice, the Kenyan government is developing a reform mechanism that extends across different institutions and sectors to promote and maintain the rule of law within the Governance, Justice, Law and Order Sector (eldis.org).
	Total	-8/4=-2	
Overall		-16/22=-0,7	

Application of the Adaptive Capacity Wheel to Tanzania

Dimension	Criteria	Score	Explanation
Variety	Variety of problem frames and solutions	+2	Swahili coexists with other local languages (Miguel 2002). Six high-priority project proposals for adaptation encompassing food security and water availability in drought-prone and inundated areas; reforestation; mini hydro schemes and a health project on malaria control (Hepworth 2010). The Water Sector Development Strategy focuses on the development of alternative resources (rainwater harvesting, wastewater reuse, desalination and inter-basin transfer) to supplement during times of scarcity (Hepworth, 2010).
	Multi-actor, level and sector	+2	Water harvesting has been introduced to several parts of Africa, including Tanzania, since the 1980s by nongovernmental and development organizations including the UN (Rockstrom and Falkenmark 2015). The private sector is yet to be meaningfully engaged on climate change issues in Tanzania (Hepworth 2010). A formidable set of institutions and actors are, and should be engaged in Tanzania's response to climate change (Hepworth 2010).
	Room for diversity	+1	There are 138 separate ethnic groups in Tanzania, not counting refugees. (interview) Ethnic diversity is downplayed in government and education to support a peaceful society for all the ethnic groups; Swahilization of the country (Miguel, 2002).
	Redundancy	-2	Agriculture, 95% of which is rain-fed supports the livelihoods of two thirds of Tanzanians, employs 80% of the rural workforce and accounts for 46% of GDP5. 90% of Tanzania's energy is derived from wood and biomass fuel and only 5% of the population have access to the electricity grid. At a national level there is a very heavy reliance on hydro-electric power (Hepworth 2010). Agriculture is the mainstay of the economy, contributing close to 26 percent of GDP and employing 75 percent of the labour force. Tanzania is largely self-sufficient in its main staple crop, maize, but it still faces shortfalls in some years due to weather variability and low yields (USAID 2015).
	Total	3/4=0,8	
Learning Capacity	Trust	0	Strong presidents, who have endorsed the fight against corruption, as one of their main presidential goals have been the main drivers of change in Tanzania's fight against corruption. However, there are many shortcomings that are eminent in Tanzania's endeavour to fight corruption. Enforcement continues to remain limited and capacity, staff, and resources are lagging. Nonetheless, change in the control of corruption is perceived and real (von Wogau, 2010). The importance of witchcraft in planning and governance is often ignored. In a hospital, the lowest level of personnel can control the management by threatening with a curse. (interview)
	Double loop learning	+1	A major new research platform and coalition of NGOs working on the issues (Forum CC) have been established. In a recent stocktaking exercise by the donors, there were over 100 different ongoing initiatives concerned with some aspect of climate change in Tanzania (Hepworth 2010). Activities related to climate knowledge and forecasting, research, mainstreaming and capacity development are outside the scope of the NAPA (Hepworth 2010). Whilst expansion of irrigation is undoubtedly a major strategy for enhancing Tanzania's resilience to climate change, there is sparse consideration of future climate change within these planning documents (Hepworth 2010). Tanzania's research capacity on climate change is boosted by the presence of Professor Pius Yanda, an IPCC author who is Director of the Institute of Resource Assessment. Under his leadership the new

Dimension	Criteria	Score	Explanation
			research window supported by NORA D is likely to provide a major boost to the already reasonable research capacity and breadth on climate change in Tanzania (Hepworth, 2010).
	Discuss doubts	+2	In an official document the following quotation is published: 'The NAPA is just a wish list with no basis on reality. It's not good - as an author I know. We need a new NAPA - not based on chatting but on scientific analysis' (Hepworth 2010). This shows that people talk about their doubts and that it is also possible to publish it.
	Single loop learning	-1	Education is a key component of the Government of Tanzania's development agenda. The country has made significant gains in access and equity in primary education, and today Tanzania has one of the highest net enrolment ratios in Africa, with girls' enrolment very close to parity with boys' at all primary education levels. Despite these successes, many challenges persist related to retention, completion and transition to secondary education, as well as quality of education, actual learning outcomes and the relevance of skills that graduates bring to the economy. When Tanzanian children finish primary level their performance is extremely poor with seven out of every ten children unable to read basic Swahili and nine out of every ten children unable to read basic English (USAID 2015). Performance in education is very poor, for example, a school near here has 1500 pupils and only 4 teachers. Tanzania has increased visa costs for expatriates, including desperately needed teachers and doctors, making it even more difficult for expatriates, including Kenyans and Ugandans, to come to and live and work. (interview) The statistics on education results are totally unreliable. Numbers in general tend to be polished up and changed for a variety of unclear reasons (interview)
	Institutional memory	-1	A National Climate Change Technical Committee, providing a forum for national dialogue across government was established to produce the Initial national communication. In 2009 it was reported that this body's last meeting was held in 2003, although there have been recent attempts to re-establish its role (Hepworth 2010). Constraints to systematic monitoring of climate include: inadequate financial resources with a 3.1 Billion TSh shortfall in requested budget for 2009; low network coverage; equipment shortage; poor telecommunication facilities; lack of O& M and calibration (Hepworth 2010).
	Total	1/5=0,2	
Room for autonomous change	Continuous access to information	-1	Ongoing research and available data: It was acknowledged that the capacity for monitoring climate trends was lacking and that analysis of climate change came from Europe and North America (Hepworth 2010). For the Tanzania Meteorological Agency, constraints to systematic monitoring of climate include: inadequate financial resources; low network coverage; equipment shortage; poor telecommunication facilities; lack of O& M and calibration (Hepworth 2010). The TMA again has reasonable technical capacity but due to resourcing issues struggles to maintain its observational network and to communicate in ways which could benefit those vulnerable or able to act on weather events and climate change (Hepworth 2010).
	Act according to plan	-2	Almost no funding has materialized for the proposed adaptation projects, although some GEF funding has recently been committed (Hepworth 2010). The NAPA does not consider how climate change adaptation can be integrated into national and sector policies, plans and activities; and the projects proposed in the NAPA have not been included in the sector plan and budgets by the institutions responsible for each sector (Hepworth 2010). As in other sectors the translation of disaster management policy into action is a problem (Hepworth 2010).

Dimension	Criteria	Score	Explanation
			Despite the significant financial support progress is very slow in most basins and the lack of implementation of water resource management threatens to prejudice poor water users, particularly as demand increases and as the climate becomes more uncertain. Research in 2009 found that large commercial water users were obtaining water-use permissions but that poor farmers and villages were either unaware of the system or less able to access it. When conflict or scarcity arises in a basin it will be these larger water users whose use rights are protected over those of the poor (Hepworth 2010).
	Capacity to improvise	-2	While nationally, 34 percent of Tanzanians are below the income poverty line, in some regions as much as 57 percent of the population are unable to meet their basic needs (USAID 2015). Historically the primary focus of Disaster Management in Tanzania has been on response rather than prevention and like many Tanzanian institutional arrangements reaching from national to local level, resources tend to be limited and not concentrated towards the local level where action has greatest potential (Hepworth, 2010). Many look to the government for help but feel that it has done little to address local problems. government representatives say their eff orts are limited by inadequate resources (Hepworth, 2010).
	Total	-5/3=-1,6	
Leadership	Visionary leadership	-1	Coordination and leadership on climate change issues needs to be strengthened. To balance, on the one hand, the need for a sustained high level of political attention on climate change-related issues, with the need for sound technical input and more efficient coordination (Hepworth, 2010). Bureaucrats often tend to obstruct rather than facilitate because it gives them more of a sense of control. (interview)
	Entrepreneurial leadership	+2	Mtandao wa Vikundi vya Wakulima Tanzania (MVIWATA), founded in 1993, is an influential national level organisation operating as a key facilitator for the promotion of farmer interests (Karpouzoglou and Barron, 2014). The Trade and Investment Hub programs include trade capacity building, improvements to the private sector enabling environment, better market access and opportunities, trade facilitation, food security programs, and export promotion support for African products (USAID 2015).
	Collaborative leadership	+2	Conscious nation building and downplay of tribalism through public schools and Swahilization. This enhances good cooperation in a culturally diverse country (Miguel, 2002) The Tanzania Disaster Relief Committee (TANDREC) is made up of Permanent Secretaries from Government Ministries or any other agencies determined by the Prime Minister as having a key role in disaster preparedness and response. Its functions are to: oversee and coordinate the activities of the Government designed to secure the effective prevention of disasters; oversee the preparedness and operation of affairs in the event of a disaster; and to guide, direct, approve and control the activities of the Disaster Management Department as well as activities of the Sub-Committees (Hepworth, 2010).
	Total	3/3=1	
Resources	Authority	+1	Systematic nation building and top-down government. Strong, renewed, elected Village Councils and District Councils (Miguel, 2002). The Division of the Environment in the Vice President's Office, where responsibility for CC currently lies, suffers from a lack of authority, capacity and ability to influence across government. Some new entity or existing body should be involved with the required levels of authority and sufficient political influence to reach and drive change across government (such as the Prime Minister's Office or the Ministry of Finance and Planning) (Hepworth 2010).

Dimension	Criteria	Score	Explanation
	Human resources	-2	44 million people, fast population growth (USAID 2015). The population growth is not sustainable, especially when coupled with the decreasing levels of functional literacy. (interview). The technical capacity and resources which exist tend to be tied up in serving the needs of the international agenda (servicing the needs of the UNFCCC and international meetings) rather than actively planning and working to build Tanzania's domestic resilience (Hepworth 2010).
	Financial resources	-1	Tanzania has an average annual gross domestic product growth rate of 6-7 percent over the past decade. Limited financial resources, weak infrastructure, and poor policies have not provided incentives to develop the agricultural sector (USAID 2015). Support of development partners, in particular the Norwegian, British and Danish donors. Donor dependence remains high with Official Development Assistance (ODA) grants accounting for around 40% of total government expenditure (Hepworth, 2010). Tanzania remains one of the world's poorest and least developed countries with the Human Development Index (HDI) placing it 151st out of 182 countries (Hepworth 2010). Finance can come from foreign donors but donors need to listen to local people on what will and will not work. European countries chose to fund the basket funds with hundreds of millions in donor money. The Dutch money which formerly went directly to hospitals now goes to the basket funds. In one district, this year, senior health officers planned a meeting in a fancy hotel far away from the district. They discussed how to spend the basket funds for the year. That one planning meeting alone used up 25% of the entire health care budget of the district. (interview)
	Total	-2/3=-0,6	
Fair Governance	Legitimacy	0	Externally driven initiatives which threaten to fill the space of a more legitimate, Tanzanian owned response should be discouraged (Hepworth 2010). Much initiative is externally driven. Tanzanians can take more control than they traditionally think they can. Internal initiative should of course be encouraged. But external initiatives need not be threatening or illegitimate. (interview)
	Equity	+1	Downplay of tribalism, emphasis on being Tanzanians (and Africans) (Miguel 2002) In 1984 the Bill of Rights was added to the constitution stipulating the equity of all citizens in the pursuance of justice (UNDP 2013). Legal aid services improve justice for women who remain unprotected from violent partners, widows of partners with HIV/AIDS who are left without an inheritance or denied custody of children, offenders who are incarcerated without access to legal defence, and HIV-positive individuals suffering from discrimination (USAID 2015). The country has received international recognition for the priority it has placed on gender empowerment in its response (Hepworth 2010). The absence of robust prioritisation of drought and flood management in the water sector, the use of fixed level abstraction permits rather than conditions proportional to flow, and difficult barriers in the implementation of water resource management reforms means that vulnerability to climate variability and change through water based impacts will persist, particular within poor communities, and that inequitable resource access will continue (Hepworth 2010).

Dimension	Criteria	Score	Explanation
	Responsiveness	-2	Democracy and good governance in Tanzania are challenged by corruption and poor delivery of government services (USAID 2015). The reach and efficacy of government in supporting the most vulnerable communities is weak irrespective of climate change and there are systemic problems with governance, public sector functionality and the efficacy of aid (Hepworth 2010). The Danish government couldn't get any government ministry to even write a grant request. There sometimes appears to be an almost total lack of interest in governance. (interview)
	Accountability	-1	Since 1990 Tanzania has undertaken public sector reforms aimed at improving transparency and accountability: financial management, local government and the legal sector (UNDP 2013). Good governance is facing increasing challenges with a recent sharp decline to a rank of 126th of 180 countries in Transparency International's (TI) Corruption Perception Index (Hepworth 2010).
	Total	-3/4=-0,75	
Overall		-3/22 =0,1	

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Alterra report 2711
ISSN 1566-7197

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The mission of Wageningen UR (University & Research centre) is 'To explore the potential of nature to improve the quality of life'. Within Wageningen UR, nine specialised research institutes of the DLO Foundation have joined forces with Wageningen University to help answer the most important questions in the domain of healthy food and living environment. With approximately 30 locations, 6,000 members of staff and 9,000 students, Wageningen UR is one of the leading organisations in its domain worldwide. The integral approach to problems and the cooperation between the various disciplines are at the heart of the unique Wageningen Approach.

To explore the potential of nature to improve the quality of life

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Alterra Report 2711
ISSN 1566-7197

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