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Conceptual Risk Assessment Framework
for
Global Change Risk Analysis SRP

Version 1

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Prologue

This report is submitted as a deliverable of the SRP project Global Change Risk Analysis which aims at applying risk analysis as a unifying notion for quantifying and communicating threats to ecosystem services originating from global change and for prioritising the appropriate adaptive responses.

This report aims at reporting current thinking around the risk quantification of the five sectors of study. It is likely, however, that some modification is likely as new insights and understanding develop as the project develops and these will be reported in future versions.

In addition it should be noted that emphasis has been on conceptualizing the approach and technical details which will become pertinent in later phases will also be added in the later versions.

Finally, the authors gratefully acknowledge the patience and co-operation of our collaborators for sharing their insights and providing feedback on our understanding.

Contents

1 Introduction

Under the mandate of CSIR to conduct research in the public good of South Africa, this SRP envisages to look into means of quantifying risk due to climate change. Drawing from the motivation of the proposal that "*climate change is occurring and will intensify during this century, by an amount that depends largely on the success of mitigation activities undertaken collectively by humankind*", we propose to develop a suitable risk assessment framework for the five selected sectors of Southern Africa, under various global scenarios, which are likely to be most affected by climate change.

The five focus sectors for this project are:

- Ground water dependent activities;
- Fire protection;
- Coastal infrastructure and ecosystems;
- West coast fisheries; and
- Climate regulation services provided by terrestrial ecosystems.

The basis of risk assessment is to provide key stakeholders concerned with the occurrence of extreme events a quantification of the risk in terms of occurrence probabilities, or in terms of return times. A quantification of risk can play a prominent role in the decisions a policy maker or planner makes, thereby aiding them to be better prepared in planning for future events. This can be of substantial benefit to the affected individuals/ areas. By devising a way of quantifying risk in each of the sectors, we would have a better understanding of how these systems will behave in different climate change regimes, guiding us towards how South Africa should push for international collaborative mitigation actions. Thus, the expected outcomes from the project are envisaged to guide in prioritizing adaptation actions, both within each of the 5 sectors, as well as between the sectors.

2 Concise Literature Review

"In preparation".

3 Risk Assessment Framework

Risk is associated with rare events. In statistics, the Extreme Value Theory (EVT) has evolved to develop mathematical models for describing unusual, or rare, events. In particular, analyzing extreme values (large or small) requires the estimation of the probability of events that are more extreme than those already observed. For instance, to set criteria for building a sea-wall, planners need an estimate of possible sea-levels for the intended life span of the sea-wall, based on available historical sea level data. The EVT provides a framework to extrapolate from historical data to extreme event possibilities. In the present investigation, it is envisaged that we will require the application of extreme value methods for sectors such a sea level rise. For other sectors, such as climate regulation services, methods to test shift in the centrality and spread parameters would be required.

3.1 Definition of concepts.

We introduce some concepts via an example. Suppose we intend to measure daily rainfall levels for n days, and denote the data as uppercase $X_1, X_2, ..., X_n$. Until a rainfall has been measured, the exact value of X_i on day i is unknown and is a random quantity. Once rainfall occurs, the observed value of X_i is denoted by lowercase x_i, the measured quantity.

3.1.1 Event

Let X represent a random variable whose outcome is uncertain. The set of possible outcomes of X is called the sample space. Random variables can be discreet or continuous variables. An *event* is *a single* or *a collection* of outcomes from the sample space.

3.1.2 Probability

A probability distribution assigns probabilities to events associated with X, and is denoted by $P\{X = x\}$, where x is the realized value of the random variable X.

3.1.3 Risk

The definition of "risk" relevant to our framework is interpreting it as: *Event with low probability and high consequence.* We define *probabilistic risk assessment* as the process of estimating the probabilities of the occurrence of undesirable events (which have severe impact) taking place within a specified time period, in a specific context (Brillinger *et al*, 2003). We will assume that such probabilistic risk can be objectively quantified. Thus, probabilistic risk assessment will involve the identification, quantification, and characterization of such events. An example of a risk event could be maximum rainfall $M_n = max\{X_1, X_2, ..., X_n\}$ exceeding a certain high threshold u.

3.1.4 Theory of extreme events

Extreme events are best described as those events that have low probability of occurrence, but have high consequence. Thus, the statistical model to investigate the behavior of extreme events, without loss of generality we consider *large* events, focuses on the statistical behavior of $M_n = max\{X_1, ..., X_n\}$. (For extremely *small* rare events, we would focus on $min\{X_1, ..., X_n\}$). Extreme value theory investigates the behavior of M_n, i.e.,

$$\begin{aligned} P\{M_n \leq z\} &= P\{X_1 \leq z, X_2 \leq z, ..., X_n \leq z\}, \\ &\rightarrow G(z) \text{ as } n \rightarrow \infty, \end{aligned} \tag{3.1}$$

for some high threshold of concern z. Here $G(.)$ is a limiting distribution, and it turns out that there are only three types of limiting extreme value distributions that satisfy (3.1), viz., Gumbel, Fréchet and Weibull type distributions. These three types of extreme value distributions can be combined into a single family known as the *Generalized Extreme Value (GEV)* distribution given by

$$G(z|\mu, \psi, \xi) = \exp\Big\{ - \Big(1 + \xi \frac{z - \mu}{\psi}\Big)^{-1/\xi} \Big\}, \tag{3.2}$$

where $1 + \xi \frac{z-\mu}{\psi} > 0$, μ is the *location* parameter, ψ is the *scale* parameter and ξ is the *shape* parameter.

The main alternative to the GEV distribution, is the idea of exceedances over a 'high' threshold, say u, and to investigate such exceedances of u. Two issues are involved here — *how many* such exceedances over a time period, and the *excess over the threshold* u for each such exceedance. Choice of threshold needs to be high enough so as to validate the asymptotic basis of the model, and thus avoid bias, but not so high that very few extremes are generated, and consequently the parameters estimated with high variance. A theoretical basis exists for the selection of threshold, and this will need to be adapted to the needs of the components of this project.

Considering only excess over a threshold, let $X_1, X_2, ...$ be sequence of independent and identically distributed (IID) random variables with a common distribution function $F(.)$. If $M_n = max\{X_1, X_2, ...\}$, then $P\{M_n < x\} \approx G(x)$, where $G(x)$ is the GEV distribution as given in (3.2). For an arbitrary X_i, say X, and for a large enough u, if we define $Y = X - u$ conditioned on $X > u$, then

$$\begin{aligned} P\{Y < y|X > u\} &= P\{X < u + y|X > u\} \\ &= \frac{F(u + y) - F(u)}{1 - F(u)} \\ &= F_u(y). \end{aligned}$$

For large u, $F_u(y)$ approximates to $H(y|\sigma_u, \xi)$ where

$$H(y|\sigma_u, \xi) = 1 - \Big(1 + \xi \frac{y}{\sigma_u}\Big)^{-1/\xi}, \tag{3.3}$$

where $\sigma_u = \sigma + \xi(u - \mu)$. Observe that σ_u depends on the choice of u. (3.3) is the Generalized Pareto Distribution (*GPD*). For the GPD, the role of the shape parameter ξ is most important in determining the quantitative behavior of the GPD.

A natural extension of the GPD is to combine the information on *excess* values with *exceedance times* over a threshold u. We continue to assume that the underlying process is IID. Let N be the number of exceedances of the level u, and follows a Poisson distribution with parameter λ. Condition on $N \geq 1$, excess values $X_1, X_2, ..., X_N$ are IID from a GPD. Suppose $x > u$, then the probability that the annual maximum of the process is less than x is given by

$$\begin{aligned} P\Big\{\max_{1\leq i\leq N} X_i \leq x\Big\} &= P\{N=0\} + \sum_{n=1}^{\infty} P\{N=n, X_1 \leq x, ..., X_n \leq x\} \\ &= e^{-\lambda} + \sum_{n=1}^{\infty} \frac{\lambda^n e^{-\lambda}}{n!} \left\{1 - \left(1 + \xi\frac{x-u}{\sigma}\right)^{-1/\xi}\right\}^n \\ &= \exp\left\{-\lambda\left(1 + \xi\frac{x-\mu}{\sigma}\right)^{-1/\xi}\right\}. \end{aligned} \tag{3.4}$$

This is the *Poisson-GPD* distribution. This is same as the GEV distribution when $\sigma = \psi + \xi(u - \mu)$ and $\lambda = \left(1 + \xi\frac{u-\mu}{\psi}\right)^{-\frac{1}{\xi}}$. Thus, above the GPD threshold, the GEV and the Poisson-GPD are consistent with each other.

For dependent processes, a variant long in use by hydrologist and coastal engineers is the *Peaks-Over-Threshold (POT)* method. However, the POT method is amenable to the Poisson-GDP model, which is more versatile than the POT method (Davison and Smith, 1990; Smith and Weissman, 1994).

The choice of threshold u will be an important process during the implementation. From a physical point of view, the threshold should be so chosen that all values above the threshold can be considered as extreme values. From the model fitting point of view, it needs to be chosen so as to ensure the asymptotic validity of the model and the optimal use of information about the extremes (Cole, 2001).

3.1.5 Consequence

Consequence, in the current context, is the impact of the occurrence of a rare event. Other than loss of property and livelihood, adverse consequences of climate change can also have an impact on the economy. Stern (2006) describes climate change as the"*market failure of the greatest scale*". The reason for this description is that the consequences of climate change are borne by the global community, not only by those responsible for high greenhouse gas emissions. The economic analysis for this phenomenon faces a major challenge, and urgency, because of the influence it would have on policy recommendations. The greatest challenge to economic analysis is the assessment of the impact of the change in climate on society and the environment, as well the quantification of the cost component. The quantification of the cost of climate change is also important to the governing bodies of countries as they have to have strategies to mitigate and adapt to consequences that cannot be avoided.

4 Climate Change Indicators

The risk assessment models being proposed for the five sector areas are all focused on risk events with climatic drivers measured by climatic indicators. The quantification of the difference between the current risk of these events, and those under future climate change scenarios, will rely on the forecasts of future climate indicators. Properties of these climatic indicators could include:
- substantial temporal records
- spatial coverage of study areas.

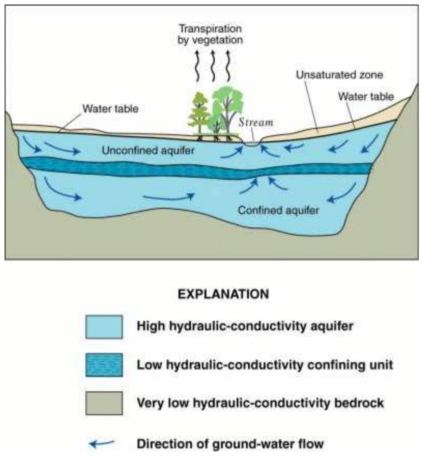
The risk assessment for the future events will all depend on outputs from GCMs, appropriately down-scaled to local climate models, to represent future climate scenarios. The framework to be developed is intended to be independent of specific GCM models so as to allow re-calibration if newer/ better models become available.

Refer: Global Climate Model (GCM), Climate Systems Analysis Group (CSAG) at UCT, African Center for Climate and Earth System Sciences (ACCESS).

5 Sector Specific Risk Assessment Framework

5.1 Groundwater recharge.

Availability of potable water is a basic human necessity, both for direct consumption, as well as for sanitation and agricultural use. Groundwater provides a substantial portion of such use, and as such any adverse change in the recharge pattern of ground water will affect the population that depends on it. Groundwater reservoirs are sustained only when the rate of abstraction from the aquifers is equal to, or less than, the rate of recharge.



5.1.1 Risk assessment framework

5.1.2 Basic model formulation

We assume a basic setup for groundwater re-charge to initiate an initial pilot simulation model for the risk assessment framework. We recall, that

re-charge is the process by which ground water is replenished.

We introduce some notations as follows:

- Let p_{ijk} be the total precipitation in location i; in year j, at episode k;
- Let r be the re-charge proportion, assumed fixed initially;
- Let l_{ijk} be the level of the aquifer being replenished at location i, in year j, at the time of precipitation episode k;
- Let a be the abstraction/ extraction proportion, assumed fixed initially; and
- Let u be the threshold level of the aquifer below which a hydrological drought will occur,

where $i = 1, ...I$ and $j = 1, ..., J$ and $k = 1, ..., n_j$.

After a specific episode of precipitation, assuming no abstraction/ extraction takes place, the aquifer will now have a level of

$$l_{ijk} + (r \times p_{ijk}).$$

Introducing abstraction as a proportion of the aquifer height, we have the revised instantaneous height of water in the aquifer as

$$(1 - a) \times \{l_{ijk} + (r \times p_{ijk})\} = l^*_{ijk}, \text{ say.}$$

We denote the annual minimum net-instantaneous-height in location i of year j by m_{ij}, where

$$m_{ij} = \min_{k=1}^{n_j} \; l^*_{ijk}.$$

A hydrological drought occurs in location i in year j if m_{ij} falls below a certain level of threshold u. The task is to quantify the *risk* of such an event, and translate it into *return time* of the event.

Under the objectives of the SRP, we thus propose to evaluate the probability of the event of aquifer level m_{ij} being less than $u - \epsilon$, given that it is below u, $\epsilon > 0$. Notationally, we would evaluate the probability

$$P(m_{ij} < u - \epsilon \mid m_{ij} < u), \text{ where } \epsilon > 0. \tag{5.1}$$

We will refer to (5.1) as the risk model for a hydrological drought. It may be convenient to report the risk quantified in (5.1) as a return-time using the following formula $\frac{1}{P(m_{ij} < u - \epsilon \mid m_{ij} < u)}$.

We will considering m_{ik} as belonging to one of the following distributions characterized by the parameter set $\boldsymbol{\theta}$: the EVT family of distributions, the Peak-Over-Threshold method, or the Poisson-GPD distribution.

5.1.3 Estimation of the risk model parameters

It is assumed that a hydrological model will be available which will describe the re-charge process and which given, the necessary inputs including those related to climate, will generate estimates of the state of the aquifer.

Given a particular climate scenario ζ characterized by a set of parameters $\boldsymbol{\phi}_\zeta$ (examples of such parameters could be temperature, monthly rainfall, etc), the hydrological model will generate a sequence of heights which will extend over a number of years. Using probability estimation techniques, such as maximum likelihood estimation (MLE), the parameters of $\boldsymbol{\theta}_\zeta$ will be estimated.

We can add layers of complexity as follows by considering

- a distribution over the rate of the re-charge r
- a distribution over the rate of abstraction/extraction a
- different values of threshold u.

5.1.4 Extension to accommodate climate change

In order to extend the basic model to account for future climate change it will be necessary to have outputs from the defined hydrological model covering a number of climate scenarios (past, present, future), denoted by $\zeta = 1, 2, ...$, and characterized by $\boldsymbol{\phi}_1, \boldsymbol{\phi}_2, ...$. For each of these scenarios, a different set of risk model parameters $\boldsymbol{\theta}_1, \boldsymbol{\theta}_2, ...$ will be estimated.

The task will be to determine the relationship between the ζ's and the $\boldsymbol{\theta}_\zeta$'s, so that ultimately $\boldsymbol{\theta}_\zeta$ will be a function of ζ. This will enable any future climate scenario to be evaluated in terms of the risk of hydrological drought.

It is possible that it may be found that reporting trends will be more informative than risks calculated for specific scenarios.

5.2 Wildfire.

In this sector, we focus on the behavior of wildfires in South Africa. Fires are the inevitable consequence of a combination of fuel, weather and a source of ignition, and are an important process that shapes and often rejuvenates vegetation. While fires are beneficial, and in many cases essential for healthy ecosystems, they also pose threats to crops, livestock, infrastructure and human life. Fires can occur at different frequencies and in different seasons, and they can burn at different intensities depending on the fuel and weather conditions at the time of a fire. The combination of repeated fires described in these terms is known as a *fire regime*. It can reasonably be expected that fire regimes that are currently typical of a given region may change as climate changes, both because climate determines fuel accumulation rates, and because it influences the weather, which in turn governs both the conditions that allow fires to occur, and the intensity with which they burn.

5.2.1 Risk assessment framework

When one considers the risks associated with wildfires, it is important to recognise that damaging wildfires are a subset of all fires. Wildfires that do damage are relatively rare, and they tend to occur during periods of exceptionally high, and prolonged, conditions of fire danger. While fires can be relatively common in certain areas at certain times of the year, there tend to be a few fires that burn a large area. For example, over the past 40 years over 2000 fires have been recorded in 10 conservation areas in the Western Cape, but 25% of the area burnt in only 20 of these fires. Similarly, 14 out of 212 fires in the Kruger National Park accounted for 81% of the area that burnt in the park in a single year. It is the conditions that lead to these large, rare fires that are of interest.

The first question that we wish to examine is whether there is any evidence that the conditions that lead to large fires are currently getting worse. This can be assessed through a statistical analysis of trends in daily fire danger indices, leading to the identification of threshold values for a fire danger index associated with large wildfires. Risk assessment could be for annual occurrence of daily values above a certain threshold, or the occurrence of two or more days in which the fire danger index is above a certain threshold.

The second question relates to the degree to which predicted changes in global climate will affect the occurrence of conditions that may lead to dangerous wildfires. The first step in this exercise would be to identify areas of South Africa which are (1) characterised by plentiful fuel, but rare incidences of hot, dry weather (*weather-limited systems*); (2) characterised by hot, dry areas where fuel accumulation depends on the infrequent occurrence of above-average rainfall (*fuel-limited systems*); and (3) arid areas which do not normally have enough fuel to burn (*low-risk areas*). The second step would be to obtain plausible scenarios for local climate and weather conditions for these areas (or samples within them) to see how these would change the likely occurrence of conditions that would lead to large, destructive wildfires. A final step in this process could involve the inclusion of estimates of future human population density, on the assumption that ignition densities (and therefore the probability of igniting a fire under dangerous conditions) would increase in proportion to human population density.

The climate change risk assessment will entail an analysis of the change in the probability of exceeding the thresholds, as discussed in the first question, under the scenario of climate change.

5.2.2 Inputs, outputs and available data

Typical contemporary fire regime data will be compiled from datasets of fire occurrence in protected areas in the fynbos and savanna biomes, and in forestry plantations. These will be related to fire danger indices on the day(s) of the fire. These fire danger indices will be estimated using weather data from nearby weather recording stations, and expressed as the McArthur Forest Fire Danger Index, and the Keech-Byram drought index.

Future climate scenarios will be obtained from appropriate sources.

5.3 Sea level rise and storm intensity.

Sea level rise is a classic situation for applying extreme event analysis. Although the recorded average rise in sea level is relatively modest (Church *et al*, 2004), the interaction with changing storm intensities and wind fields can produce changes in sea conditions that can overwhelm existing infrastructure. With South Africa's *Coast:Perimeter ratio* being 37%, rise in sea level is an important risk to the country's coastline and the shipping infrastructure, especially for the ports and coastal cities and towns.

Coastal infrastructure are designed to take the 'expected' sea states into account. If these sea states change, for example as a result of climate change, coastal infrastructure design may no longer be adequate, and undesirable events may become unacceptably frequent.

5.3.1 Risk assessment framework

In the setup of the approach to assessing risk to coastal development due to sea level rise, an important impact of the risk event will be the wave run-up at the shore. Such run-up occurs as a function of various physical attributes including wave-height. Other attributes could include topography, cover, depth, wave period, wave direction, wind speed, wind direction, etc. Run-up threshold values will be chosen to characterize extreme, possibly undesirable, values, and these will be transformed into offshore critical threshold values for wave-heights.

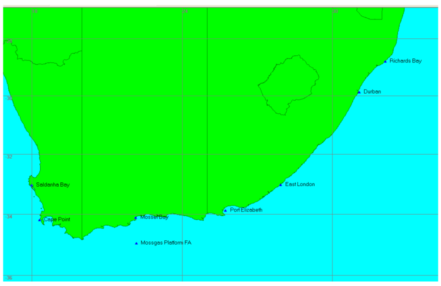
In view of the paucity of quantitative information, and to enable an assessment of the potential impacts of changes in regional weather systems and oceanic wind fields, a plausible scenario approach will be followed. In this scenario it will be assumed that the incident wave energies will remain in the same relative proportions and that the nett alongshore sediment transport will remain the same. It will further be assumed that the main beach changes and coastal impacts due to climate change effects, result from the increase in water depth and an increase in the cross-shore component of incident wave energy. A cross-shore wave run up model will be roughly calibrated based on a past measured extreme event, as described in the paragraph below. The water level will be increased (as per IPCC projections) and the wave height increased by 10% to determine the relative increase in run up. This relative increase will be applied to predictions of present short-term variations to derive new values for corresponding maxima.

The risk assessment framework will focus on a case-study for the reoccurrence of an actual observed event. In March 2007, a cut-off low-pressure system induced a sea storm, which wreaked havoc along the entire KwaZulu-Natal (KZN) coastline. This extreme wave event occurred at a time when the maximum gravitation forces exerted by the sun and moon were also at their 18.6 year peak (termed highest astronomical tide or HAT). Maximum run-up levels on the open KZN coast near Durban on the SA east coast during this storm, reached up to about 9 m above mean spring tide. The wave height recurrence period was found to be about 1-in-35 years, while the joint probability of recurrence of the wave height and tidal level (HAT) is estimated at more than 1-in-500 years. Direct infrastructure damages alone resulting from this storm is estimated to be over R400 million. This storm is particularly significant, not just in terms of its severity, but also in that the joint probability of the events is considered to be extremely low at present. However, due to Sea Level Rise (SLR), the tidal levels reached during this storm (19 yr HAT level) will effectively be reached during ordinary spring tides every 2 weeks by about 2100. This factor alone means that the potential return period of a similar event will be much reduced (i.e., will occur more frequently). In addition, due to potentially increased sea storminess (through climate change), similar storm wave heights could occur more often in the future. The joint probability of such a future, less extreme, wave height with ordinary spring tides would be much higher relative to the extreme rarity of the same conditions occurring at present. In other words, the same conditions could potentially occur much more frequently in future due to SLR and increased sea storminess. Thus, this event represents a particularly applicable case in terms of investigating coastal climate change effects, and is even more useful in that some of the causes (equivalent to future SLR and increased storms) and effects have been measured.

For risk characterisation associated with wave-height, a suitable extreme value probability distribution (GEV or other appropriate extreme value distribution) will be identified, and whose parameters will be estimated from available data. This distribution would enable comparison between different scenarios, and the forecasting of even more extreme events.

5.3.2 Inputs, outputs and available data

As part of the calibration required for the approach in Section(5.3.1), a trend analyses will be conducted on the appropriate available SA coastal wind data sets to determine the long-term trends. Wind data from locations such as the Cape Town International Airport and/or Durban will be analysed.



Once potential long-term wind climate trends are established through these wind data sets, the correlation between the wind and corresponding wave data can be described and put into perspective, with regard to potential long-term trends in the wind climate. As part of the case-study described in Section (5.3.1), it is proposed to use the wind and wave data at Richards Bay, since almost 20 years of wave data have been collected off the Port of Richards Bay.

5.4 Benguela upwelling fisheries.

Globally, upwelling systems appear as cold water anomalies from equatorial to subtropical ocean systems. It is likely that their continued existence may be sensitive to small changes in heat fluxes (thermocline depth) and wind stress (mixing). The Benguela system, because of its relatively good data coverage and process understanding, offers an opportunity to address a question of global interest using a local comparable advantage. Advancing our understanding in this question may provide important clues to the rates of changes in Southern African ecosystems as a whole. For fisheries the implications of this risk approach are related to the time scales for the discounting of the capital investments, as well as the adaptation strategies required if the sector is not likely to exist in a decadal time scale.

5.4.1 Risk assessment framework

For assessing the risk due to such upwelling, and the risks posed by climate change, we shall focus on two of the most important underlying factors supporting the ecosystem: *productivity* and *hypoxia* affecting harmful algae blooms (HABs) and the rock lobsters.

		Characteristics of relaxation periods in late summer	
		Short	Long
Early summer wind stress	Low	*low risk*	*low risk*
	High	*low risk*	*high risk*

The risk regimes are a function of two time scales — a 'high' wind stress in early summer (August-December), and the wind stress 'relaxation' event n the late summer (January-April). A *risk event* be defined as complex set of wind stress conditions involving both time and magnitude. For instance, four events could be defined in terms of at least two thresholds, as shown in the adjacent table, involving time and magnitude of the wind stress event. A particular impact may be linked to each event. For example the 'high risk' could be viewed as the event that results in hypoxia. Hypoxia is a condition which can lead to various negative impacts depending on the particular marine life, for instance rock lobsters stranding.

The exact definitions of the two seasonal occurrences resulting in the risk event, 'high' wind stress in 'early' summer and 'long' wind relaxation in 'late' summer, will be an input to the analysis. Such inputs will comprise specification of thresholds for both time, duration and magnitude of wind stress. The sensitivity of the risk assessment to the choice of threshold values will be assessed.

An important sub-problem will be to investigate statistical models for representing the probability of the occurrence of consecutive days of wind-stress-relaxation in late summer (viz., 1 week, 2 weeks or 3 weeks of relaxation).

An important component of the analysis in the above tasks will be the identification of appropriate family of distributions and the accompanying methods for parameter estimation. For example, the Generalized Extreme Value (GEV) family of (multivariate) distributions would be a strong candidate for describing the behavior of extreme value events.

In order to assess the change in risk brought about by climate change, future wind-stress scenarios will be used to re-calibrate the above models.

5.4.2 Inputs, outputs and available data

Input data for the analyses will be hourly wind-stress data for a specific location. Wind-stress data will be a function of the v-component (northward) of wind velocity. Specifically, hourly data from Saldanha Bay will be analyzed for the period 1957-2007.

Other inputs for the analysis will be the thresholds that define a risk event for the context as discussed in Section (5.4.3).

Since the risk event will be with respect to the period August-April, a meaningful pseudo-year will be defined as the July-June block.

5.5 Climate regulation services.

Both natural and managed ecosystems exert a very strong influence on climate either directly through their biophysical impacts on albedo (the reflection of solar radiation) or indirectly through their biogeochemical role as either sources or sinks of greenhouse gases. Human activities have not only contributed to the increases in emissions responsible for global warming, but have also changed the ability of ecosystems to regulate the climate directly or indirectly. The main drivers of change in climate and air quality as identified by the Millennium Ecosystem Assessment (MA 2005) are deforestation, agricultural practices and biomass burning. Of concern is the finding that the interactions between ecosystems and the atmosphere are highly non linear with many feedbacks and thresholds that, once exceeded, could lead to sudden climate and ecosystem changes. In this project the aim is to understand and spatially depict the processes responsible for climate regulation in South African ecosystems in order to:

- inform management of these ecosystems as climate regulators;
- predict the potential impacts of climate change on these processes responsible for climate regulation;
- incorporate protection of these regulating services into landscape planning processes.

The approach will include a detailed case study in the Little Karoo region, which will then be extended to the rest of South Africa's biomes. The Little Karoo is the site of much research into biodiversity and ecosystem services in planning frameworks and is the meeting point of 3 of South Africa's biomes. The methods include a sensitivity analysis with SiB3 (a surface coupling model) which will explore the importance of other factors, such as roughness and bulk stomatal conductance. A radiative transfer model will be used to express both carbon storage (and other GHG's) and albedo changes in a common metric ($Watts/m^2$). A regional climate model will be perturbed for an area of the little Karoo to test whether the indirect climate feedback processes may be operative. The objective is to map the climate regulation service for all or large parts of the country, so that it can be used as an input to systematic conservation planning.

5.5.1 Risk assessment framework

In terms of climate regulation services, two related approaches can be envisaged: in the first, a model for the radiative forcing resulting from climate change is combined with a dynamic ecosystem model (Century model); while in the second, risks at loss or reduction in the climate amelioration service associated with specific impactful events will be estimated.

In the first approach, the model will require a set of input parameters, some of which will reflect parameters of climate that are expected to be sensitive to climate change, and others to describe the ecosystem to be studied such as land use etc. The output of the system will be measured in terms of the net balance of carbon dioxide uptake and loss. This, in combination with the albedo characteristics, and estimates in net changes in other greenhouse gases, notably CH_4 (methane) and N_2O (nitrous oxide), will result in a measure of radiative forcing. Running this model over time would enable the generation of net change in radiative forcing relative to a baseline value, denoted as $\Delta\ Watts/m^2$, to be estimated. This output, tracked over a simulated extended period, say of 20 years, would then be the input for a statistical analysis to quantify, in probabilistic terms, the statistical significance of a meaningful shift, say $\delta(> 0)$, of the change in the radiative forcing from zero. This can be addressed by standard tests for centrality. A key issue will be in the specification of a range of values of δ by domain specialists.

In the second approach, the model will be required to define an event whose risk is to be quantified. An example may be a fire which converts a a high-stored carbon forest into a low-carbon grassland. This may well turn out to be an extension of the first approach, where the change in Δ over time, will drive some process operating within fixed thresholds, and the risk events will be defined as the process crossing either threshold. For this approach, a model will be required to relate the carbon output of the first approach into the processes of the physical system of interest. For example, in the carbon sequestration system, the changes in Δ will contribute to the identification of whether a specific ecosystem is operating as a carbon sink or source. The statistical techniques employed will be essentially distribution fitting and time-series. A potentially novel approach would be to apply techniques from the area of quality control where the objective will be to identify when the process starts to operate outside the acceptable thresholds.

5.5.2 Inputs, outputs and available data

Inputs to the models above would be climate drivers of ecosystem carbon assimilation and loss such as:

- rainfall and its seasonal patterns and trend;
- temperature;

- CO_2;
- land use;
- disturbance regimes such as extreme droughts, fire, weather changes.

These are available for a number of test sites per major biomes in South Africa, and interpolating variables are available for the whole of South Africa.

5.5.3 Implementation methodology

MCMC methods will be implemented for the proposed models.

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7 References

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