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ASSESSMENTS OF REGIONAL PRECIPITATION CHANGES IN NAMIBIA DUE TO MAN-MADE ENHANCED GREENHOUSE WARMING

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Zusammenfassung: Regionale Niederschlagsänderungen in Namibia aufgrund des anthropogen verstärkten Treibhauseffektes
Regionale Niederschlagsänderungen in Namibia, die im Falle einer fortgesetzten globalen Erwärmung aufgrund der anthropogenen Freisetzung von Treibhausgasen eintreten könnten, werden mittels der Methode des statistischen Downscalings abgeschätzt. Geopotentialdaten des 1000 hPa, 500 hPa und 300 hPa Niveaus, die die großskalige atmosphärische Zirkulation repräsentieren, werden über multiple Regressionsanalysen für einen 30-jährigen Kalibrierungszeitraum (1968-1997) mit monatlichen namibischen Stations-Niederschlagsdaten verknüpft. Nach einer qualitätsorientierten Auswahl von Regressionsmodellen in einer unabhängigen Verifikationsperiode (1951-1967) werden diese zur künftigen Niederschlagsabschätzung eingesetzt, indem die aktuellen Zirkulationsprädiktoren durch entsprechende Daten aus einem GCM-Lauf ersetzt werden, der die Zirkulationsverhältnisse bei verstärktem Treibhauseffekt simuliert (transiente Simulation mit dem ozean-angekoppelten Hamburger Klimamodell ECHAM4). Die Ergebnisse zeigen, dass bei verstärktem Treibhauseffekt die räumliche Niederschlagsverteilung und die Gesamtsummen des Sommerniederschlags zwar im wesentlichen erhalten bleiben, sich jedoch intrasaisonale Umverteilungen in Richtung akzentuierterer Verhältnisse abzeichnen mit erhöhten Niederschlägen vor allem im Januar und Februar sowie etwas geringeren Werten zu Beginn und am Ende der Regenzeit, insbesondere in den zentralen Landesteilen im Monat März.

Summary: Assessments of Regional Precipitation Changes in Namibia Due to Man-Made Enhanced Greenhouse Warming
Regional precipitation changes in Namibia which might be expected in case of a continued global warming due to man-made emissions of greenhouse gases are assessed by means of statistical downscaling techniques. Geopotential height data at the 1000 hPa, 500 hPa and 300 hPa levels representing the large-scale atmospheric circulation are linked to Namibian monthly station rainfall data by multiple regression analyses for a 30-year calibration period (1968-1997). After selective confirmation of these models during an independent verification period (1951-1967) they are used to assess future rainfall amounts by replacing the actual circulation predictors by corresponding data from a GCM run simulating dynamic conditions for an enhanced greenhouse warming (transient simulation by the Hamburg model ECHAM4 coupled with an ocean model). Results indicate that spatial distribution patterns and summer rainfall totals are essentially preserved with enhanced greenhouse forcing, the intra-seasonal distribution, how-

ever, points to more accentuated conditions with increased precipitation mainly from January to February and somewhat less rainfall at the beginning and to the end of the rainy season, especially concerning the central parts of Namibia during March.

Résumé: Changements de précipitations régionales en Namibie suite à l'effet de serre anthropogène
Des changements de précipitations régionales en Namibie, qui peuvent s'établir en cas d'une hausse de température globale suite à l'émission continue des gases d'effet de serre, sont estimées par le downscaling statistique. Des dates de géopotentiel des niveaus de 1000 hPa, 500 hPa et 300 hPa, qui représentent la circulation atmosphérique en grande dimension, sont corréllées avec les dates de précipitation mensuelle des stations namibiennes par des analyses de regression pour une période de calibrage de 30 ans (1968-1997). Après une sélection qualitative des modèles de régression dans une période de vérification indépendante (1951-1967) et à l'aide du remplacement des prédictoires actuels de circulation par des dates d'un cours GCM, elles sont utilisées pour une éstimation des précipitations futures. Le cours GCM simule la circulation sous un effet de serre renforcé (simulation transiente avec le modele océan-relié de Hamburg ECHAM4). Les resultats montrent qu'un effet de serre renforcé la repartition spatiale des précipitations et aussi les précipitations d'été restent les mêmes, mais la repartition des précipitations intrasaisonnière va s'accentuer, avec plus de précipitation en janvier et fevrier, et des précipitations réduites au début et à la fin de la saison des pluies – et cela surtout en Namibie centrale au mois de mars.

1. Introduction

According to its latitudinal position Namibia experiences rainfall as a limiting factor for man and his environment implying that future changes in climate, precipitation and water availability are of primary importance for a sustainable development of this country. Present conditions are characterized by decreasing rainfall from East to West as well as from North to South with lowest annual mean values (< 200 mm) in the southwestern region and highest ones (> 600 mm) in the northeastern part. Distinctly arid conditions across widespread areas of Namibia are due to subtropical high pressure influence and to strong upwelling off the coast of southwestern Africa in context with the cold Benguela current moving towards lower latitudes eastward of the anticyclonic centre of action above the South Atlantic Ocean. Rainfall in the southern part of Namibia is mainly caused by cyclonic disturbances of the midlatitudinal westerlies occasionally penetrating far to the north (mostly between May and September). In contrast to that, northern Namibia gets rainfall mainly during summer (from November to April) linked to tropical disturbances of high convective activity. Thus, both tropical and extratropical circulations influence Namibian rainfall conditions including highly important interactions between these dynamical systems (Tyson 1986). Further basic aspects concerning circulation dynamics of Namibian summer rainfall are discussed elsewhere (e.g. Engert & Jury 1997), as well as related objectives like interannual variations (e.g. Jury & Engert 1999), dynamical teleconnections (e.g. Philipp & Jacobeit 1999) and distinct anomalies (e.g. Schinke & Jacobeit 2002).

Rainfall changes on a regional scale are to be expected if global warming should continue due to man-made enhanced release of atmospheric trace-gases absorbing outgoing longwave radiation from the earth's surface. This enhanced greenhouse warming has recently been assessed to amount between 1.4°C and 5.8°C until the end of the 21st century depending on different scenarios concerning emission rates, reduction efforts and particular reactions of the climate system (see the Third Assessment Report of the Intergovernmental Panel on Climate Change: IPCC 2001). The 'best estimate' considering a simultaneous cooling due to man-made sulphate aerosols gives a warming rate of approximately 0.2°C per decade resulting in a further temperature increase of about 2°C until the end of this century. Concerning different regions of the African continent, temperature is expected to increase until the year 2050 between 1 and 3°C (Houghton 1997). Assessments of regional precipitation changes in the context of global warming are much less reliable. Since rainfall is highly dependent on small-scale dynamical and geographical factors, general circulation models (GCMs) characterized by relatively coarse spatial resolutions of some hundred kilometres are not able to reproduce regional rainfall variability sufficiently close to reality. Assessments of precipitation changes on a regional scale thus require further techniques which may be distinguished between modelling approaches (nesting highly resolved regional models into large-scale GCMs, see for example Hastenrath et al. 1995; Murphy 2000) and various empirical methods deriving transfer functions between variables on different spatial scales. Within the postgraduate program "Joint geoscientific research in Africa" funded by the German Science Foundation (DFG) the statistical downscaling technique (see next section) has been successfully applied to the prominent case of Namibian precipitation changes (Beyer 2000), leading to a comprehensive investigation (Beyer 2001) whose main results will be conveyed by some of their most significant components.

2. Statistical Downscaling

This technique tries to link large-scale variables (e.g. hemispheric pressure data with a low spatial resolution) and small-scale variables (e.g. regional rainfall data with a high spatial resolution) by means of statistical transfer functions (e.g. resulting from multiple regression or canonical correlation analyses). According to the physical relationship the large-scale variables represent the statistical predictors which determine the dependent predictands (small-scale variables). Since GCMs are able to reproduce the large-scale atmospheric circulation rather realisticly – in contrast to the small-scale regional precipitation – this technique offers a favourable way for estimating future rainfall changes: once reliable relations between circulation and rainfall have been established based on available observation data, we may replace the actual predictors within these relations by circulation data from an appropriate GCM simulation with enhanced greenhouse forcing thus obtaining assessments of future regional precipitation for these modified boundary conditions of an advanced global warming.

However, since relations between circulation and rainfall are transferred from a recent observation period to another simulation period, two fundamental aspects have to be considered: i) these relations must prove to remain valid if used for another period independent from the particular period for which they have been established. Thus, the available observation data are mostly split up into a calibration period for deriving these downscaling relations and an independent verification period for evaluating their validity outside the calibration period. These extensive procedures concerning the case of Namibia have been discussed in detail by Beyer (2001) and need not be reproduced for this selected exercise. ii) Future rainfall assessments are based on the assumption that downscaling relations between circulation and rainfall would be essentially the same under conditions of an enhanced greenhouse warming as for the recent situation. This necessary assumption is not strictly provable but quite tenable at least as far as climate differences remain smaller than the interannual variability (Jacobeit 2000) which is recorded (confirmed) by downscaling relations derived for (applied to) a calibration (verification) period.

Statistical downscaling further described in detail for instance by Hewitson & Crane (1996) is increasingly used within climate research since the 1990s. Among many investigations during the last decade it has been applied for example to assessments of future rainfall during Mediterranean winter (v. Storch et al. 1993; Jacobeit 1994), of maximum and minimum temperatures in Argentina (Solman & Nunez 1999), of daily precipitation in the Balkans (Cavazos 2000) or of daily to seasonally resolved rainfall in South Africa (Hewitson & Crane 1996; Mason 1998; Landmann & Tennant 2000). Non-climatic parameters may be assessed by downscaling techniques as well, e.g. sea levels (Hupfer et al. 1998), landslide activity (Dehn

1999) or river discharge (Bertacchi-Uvo et al. 2000). An extensive overview of downscaling applications is given by Beyer (2001).
Results discussed below are derived by means of stepwise multiple regression analyses applied to monthly resolved data selected and processed as described in the following section.

3. Data Processing

The dependent small-scale variables are the Namibian monthly rainfall data provided for 84 stations (see Fig. 1) during the 1951-1997 period by the Meteorological Service of Windhoek. They will be used for the summer rainy period from November to March.

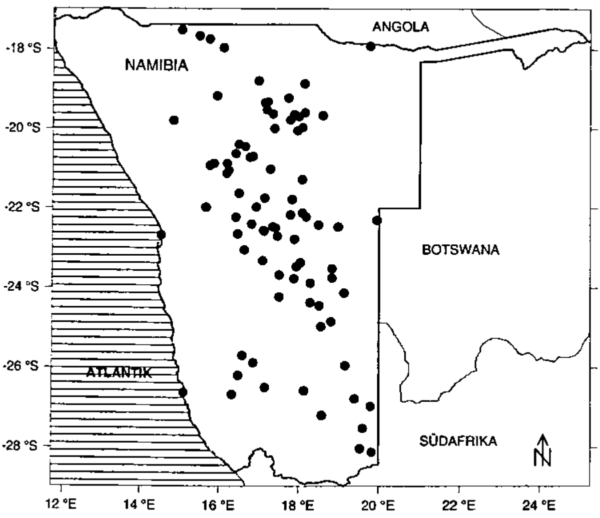

Fig. 1: Location map of the 84 rainfall stations in Namibia used for downscaling

The predicting large-scale variables describing the atmospheric circulation are given in terms of gridded geopotential height data at the 1000 hPa, 500 hPa and 300 hPa levels with a spatial resolution of 2.5° x 2.5°. These data have been generated within the NCEP/NCAR reanalysis project (Kalnay et al. 1996) and are globally available with a 6-hourly temporal resolution. For the present study the section from 50°S to 20°N and from 80°W to 100°E has been extracted (see Fig. 2) comprising the main centres of pressure variability affecting rainfall variations in Namibia; remote influences from beyond this section – e.g. in context with Pacific ENSO events

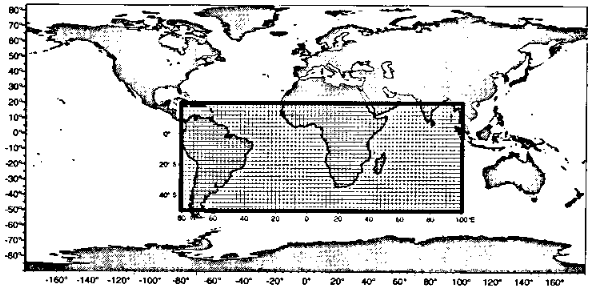

Fig. 2: Selected grid of geopotential height data used for downscaling

(Nicholson & Kim 1997) – are operating by transmissions being considered within dynamic teleconnection analyses (see Philipp & Jacobeit, this volume).

The information on pressure conditions from this restricted section still needs to be condensed for the subsequent downscaling, and this is properly achieved by s-mode principal component analyses applied separately to the geopotential height grids of each level and each month (same period as mentioned above for Namibian rainfall).

The resulting principal components from all the three levels have been used as potential predictors for each monthly station rainfall series of Namibia. Stepwise derived multiple regression models have been established for a 30-year calibration period (1968-1997) with the remaining interval (1951-1967) used for verification. The latter implied a particular quality check in terms of significance tests for the correlations between observed and regressed rainfall data during the verification period (Beyer 2001). As a consequence only about one quarter of the initial regression models were accepted for further processing implying that not the whole area of Fig.1 will be covered by assessment results (next section), but rather those parts including stations with sufficiently qualified regression models for the corresponding month.

The accepted downscaling models are finally used to assess future rainfall amounts by replacing the actual circulation predictors by corresponding data from a GCM run simulating conditions of enhanced greenhouse warming. Results of the following section have been obtained with geopotential height data (same levels as mentioned above) from a transient simulation – i.e. with time-dependently increasing concentrations of greenhouse gases in the atmosphere – performed by the ECHAM4 GCM that has been developed at the Max-Planck-Institute for Meteorology in Hamburg (Roeckner et al. 1999). This model couples atmosphere and ocean and additionally considers the tropospheric sulphur cycle which partially reduces further greenhouse warming. The spectral T42 resolution corresponds to an approximate 2.8° grid point spacing which has been transformed to a 2.5° x 2.5° grid according to the reanalysis data discussed above. The simulation run extends from 1860 to 2099 with observed trace-gas concentrations until 1990 and continuously increasing greenhouse forcing afterwards with a doubling of the equivalent CO_2 concentration (compared to pre-industrial times) around 2030 and final values at the end of the 21st century exceeding 1150 ppm. The following results have been obtained by assessing Namibian rainfall with these simulated circulation data and the corresponding downscaling models for two different 30-year periods (GCM years 1890-1919 and 2070-2099, respectively). These clearly separated periods have been selected to get enhancing greenhouse signals as strikingly as possible (the first three decades being ignored on account of initial model balance requirements). Mean values for these 30-year periods have been subtracted thus giving indications of possible rainfall changes on a climatic time-scale.

4. Results

The estimated rainfall changes are specified for each month of the summer rainy season (Figs. 3-7) depicting quite different changes both in time and space. Altogether, they would not alter the general spatial distribution with declining rainfall from East to West as well as from North to South. Thus, we get rather a gradual modification of the Namibian climate known from present conditions.

At the beginning of the summer rainy season (November) moderate rainfall decreases are indicated (Fig. 3). Only to the southwest a minor increase appears whereas the highest negative values are reached in the northeastern part. The strong gradients within the central region are quite artificial resulting from an irregular local estimate compared to its complete surroundings. The prevailing decrease in November precipitation may point to a later onset of the rainy season. At this time, however, short-term isolated rainfall events are decisively important which might not be adequately represented by downscaling models on a monthly scale.

Results for December (Fig. 4) imply another change from lower to higher latitudes with increasing values in the northern part (culminating around 21°S) and nearly constant rainfall conditions farther south (negative values within the central region are restricted and insignificant). Thus, after a late onset, the rainy season tends to develop more efficiently than nowadays, but still concentrating to the northern parts.

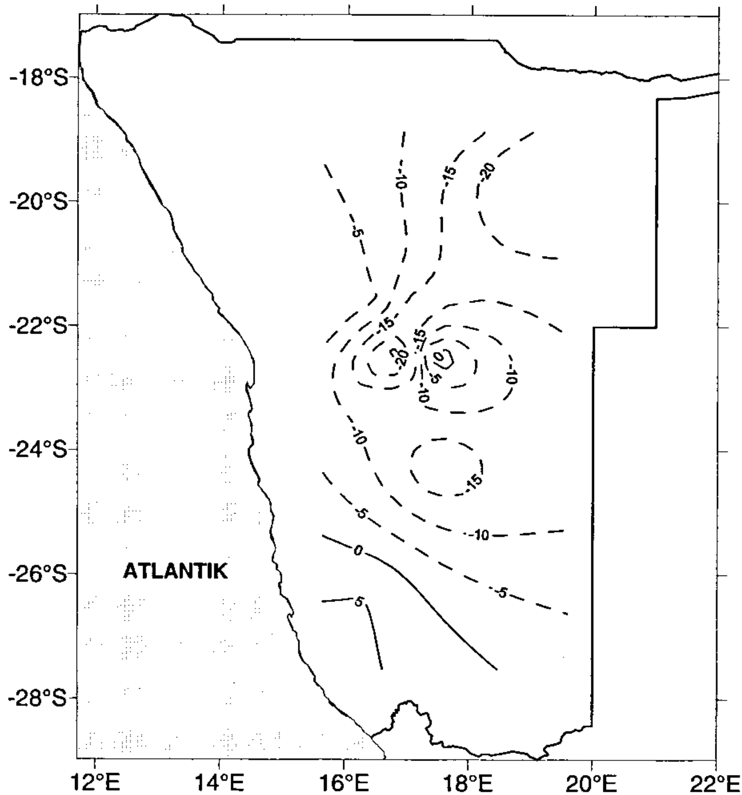

Fig. 3: Precipitation changes (mm) in Namibia for November resulting from mean-value differences between 2070-2099 and 1890-1919 according to statistical down-scaling assessments with atmospheric circulation predictors extracted from a transient ECHAM4 simulation run with continuously increasing greenhouse forcing (interpolated from local estimates by qualified multiple regression models; dashed lines for decreasing precipitation)

These conditions are changing for January and February (Figs. 5 and 6) showing increasing precipitation for most of Namibia (except of a small northern section during January with a disputable validity). This clearly indicates an intensification of summer rainfall with some regional differences: during January, the highest increases in rainfall are assessed for western parts of central Namibia (Fig. 5), during the following month these maxima have shifted to central and northeastern regions leaving the western part with lowest increases (Fig. 6). Obviously, some circulation characteristics important for intensive rainfall (e.g. positions of synoptic waves and cloud bands, tracks of squall lines and other disturbances) would be gradually displaced eastward in the course of this strengthened rainy season thus affecting different regions most effectively at different times during the season.

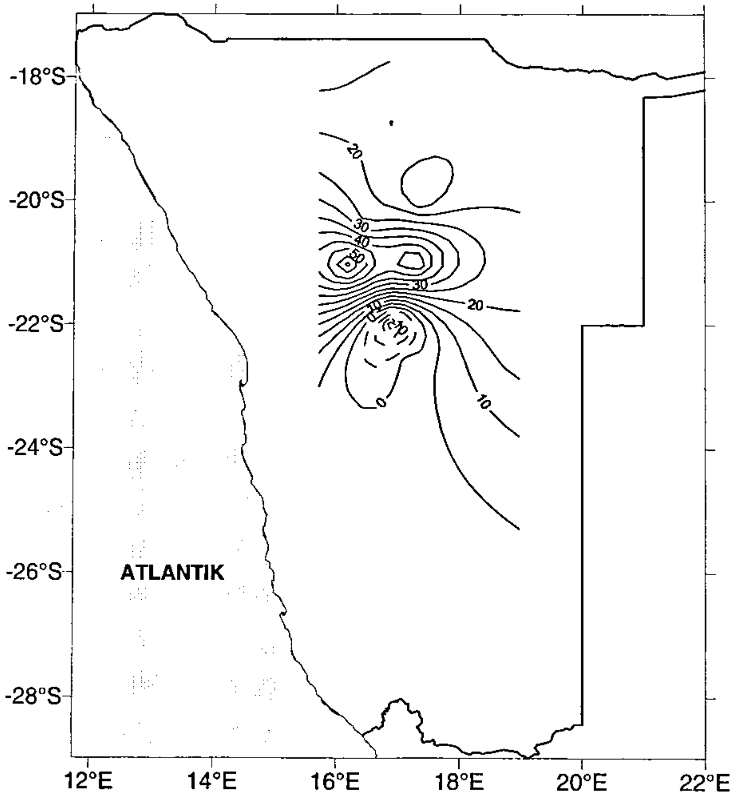

Fig. 4: as Fig. 3, but for December

Other conditions prevail towards the end of the rainy period (March) for which another decrease in precipitation is assessed at least for central parts of Namibia (Fig. 7). Farther to the northeast as well as to the south some change is indicated to increased values.

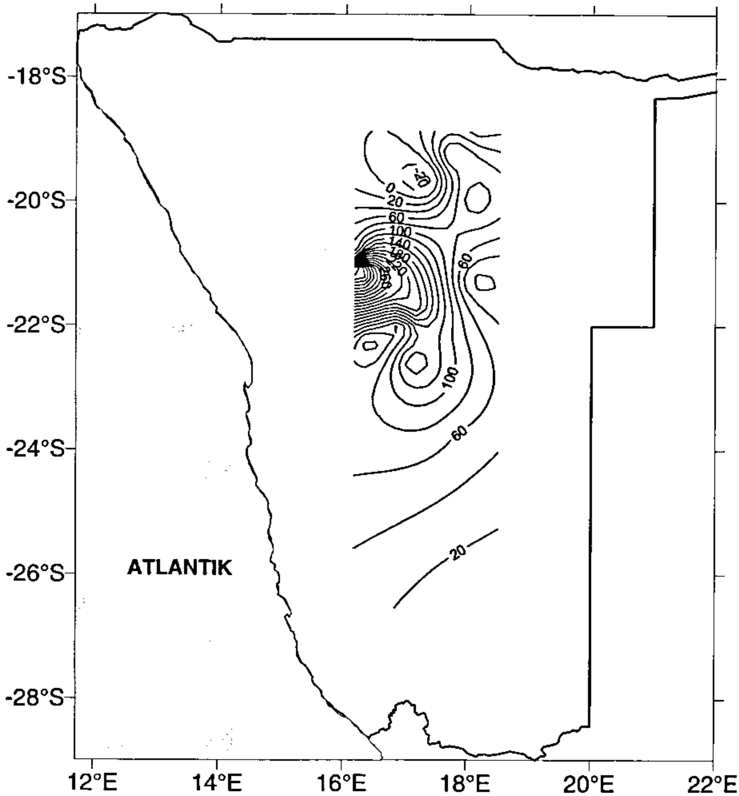

Fig. 5: as Fig. 3, but for January

Considering further assessments based on other GCM data or on modified downscaling techniques (Beyer 2001) allows the conclusion, however, that rainfall in March prevailingly tends to decrease with enhanced greenhouse forcing. This may indicate an earlier decline of rainfall activity after its strengthening during the preceding months.

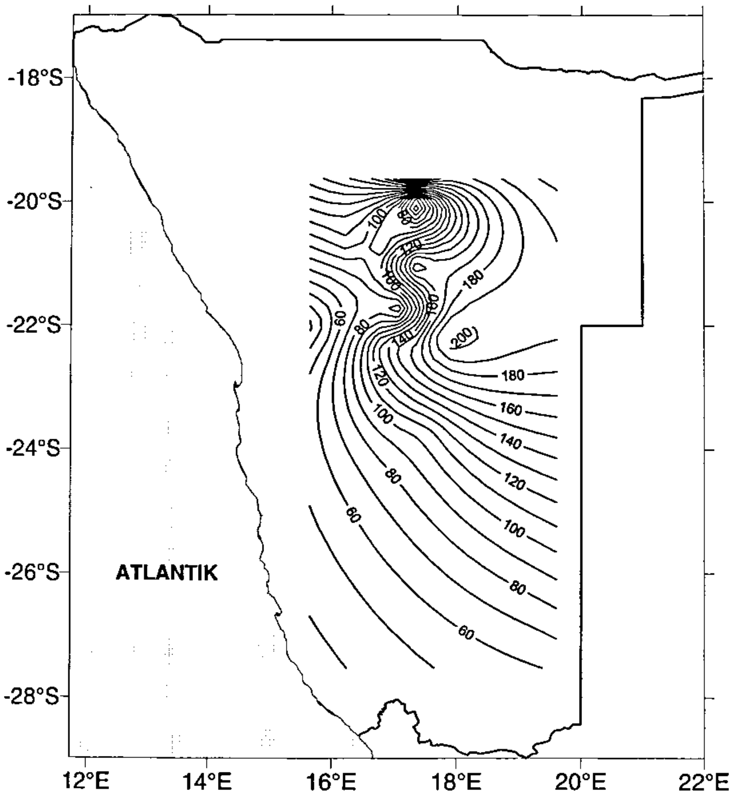

Fig. 6: as Fig. 3, but for February

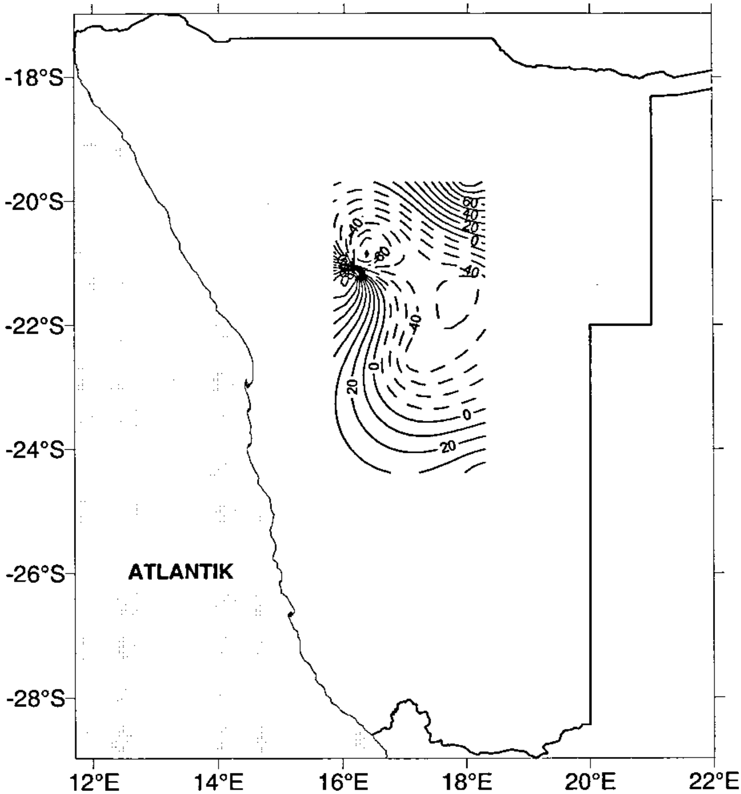

Fig. 7: as Fig. 3, but for March

5. Conclusions

Results have emphasized the importance of deriving highly resolved estimates of future climate on a regional scale since different changes, spatially and temporally, may well occur which are to be detected by some kind of downscaling techniques. With regard to Namibian summer rainfall enhanced global greenhouse warming does not seem to alter spatial distribution patterns and rainfall totals significantly, but it might induce an intra-seasonal redistribution towards more accentuated conditions with increased precipitation mainly from January to February and somewhat less rainfall at the beginning and to the end of the rainy season, especially concerning the central parts of Namibia during March. This may also be organized as a shortened but intensified summer rainy season. Results further indicate that this intensifying might start earlier (December) in northern parts of Namibia and might proceed eastward during summer with regard to maxima in rainfall increase.

Several restricting aspects, however, have to be considered. First of all, the statistical significance of the estimated rainfall changes is not continually high: thus, 95% significance levels for the signal-to-noise ratios (i.e. the quotients between an estimated change and the corresponding standard deviation of recent times) are only reached at some 40% of the stations during January to March, early summer changes being still less significant (Beyer 2001). Therefore, results from Figs. 3-7 should be understood as general tendencies that have to be further substantiated in the future. Secondly, it has to be emphasized that such kind of studies are necessarily scenario-type investigations depending on particular suppositions concerning the progress of trace-gas emissions and global greenhouse warming (IPCC 2001). Finally, the manifold uncertainties inherent to general circulation and climate models used for simulations of possible future conditions should be kept in mind (e.g. Cubasch et al. 1995). With respect to African climate change Hulme et al. (2001) have recently complained about the absence in these models of any representation of regional changes in land cover, for example, thus further extending the particular requirements for future model developments.

Concerning the statistical study domain additional assessments for Namibia have been performed (Beyer 2001) using other GCM output (DKRZ 1992), different rainfall data (New et al. 2000) and modified downscaling techniques including Canonical Correlation Analysis (v. Storch & Zwiers 1999). As to be expected results are varying somewhat, the main features outlined in this paper, however, may be seen as the most probable tendencies in Namibian summer rainfall coming along with enhanced greenhouse warming.

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