PRACE GEOGRAFICZNE, zeszyt 107

Instytut Geografii UJ
Kraków 2000

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DEVELOPMENT OF A DOWNSCALING MODEL FOR ESTIMATION OF AN 'ARTIFICIAL ICE CORE' DERIVED FROM LARGE SCALE PARAMETERS OF A 1000 YEAR GCM RUN

Abstract: Object of our work is the creation of 'artificial ice cores' by means of GCM data. Regression models for 3 Greenland ice core accumulation rates are presented which use the first 5 EOF time series of seasonal mean large scale 500 hPa stream function fields as predictors. The fitting data are the monthly NCEP Reanalysis data and real yearly ice accumulation time series from 1948 until 1992. The explained variance of the estimated ice accumulation lies between 56% and 74%. The regression model has been applied to a 1000 year coupled ocean/ atmosphere control run (ECHAM4/HOPE) to estimate accumulation. The spectra of the real and the estimated accumulation are nearly 'white'. For the estimated accumulation there is a reduction of variance.

Key words: ice cores, reanalysisd data, GCM data, linear regression.

1. Introduction

Many ice cores drilled from the Greenland and Antarctic ice sheet were taken to investigate features of the past climate. Much effort has also been done to perform GCM runs over hundreds of years, varying the underlying parameters like the CO_2 content or the solar radiation in order to eliminate the anthropogenic or natural impact on climate. Here, the ice accumulation rates are consistently estimated from GCM output and 'artificial ice cores' are constructed. These 'artificial ice cores' are compared to the real cores and used to estimate the natural variability and anthropogenic influence of ice accumulation rates. For the creation of 'artificial ice cores' one has to search for empirical relations between ice accumulation and GCM data. Since local features, especially precipitation is not well simulated by GCMs it is not possible to use this obvious predictor for our purpose (Fischer 1997). Therefore a statistical downscaling relation is derived which describes the local ice accumulation by means of well simulated large scale atmospheric parameters such as geopotential, temperature or horizontal velocity fields. For developing a reliable downscaling relation the monthly NCEP Reanalysis data (Kalney et al. 1996) and three north and central Greenland ice core accumulation data sets from 1948 until 1992 are used (Fischer 1997; Schwager 1999). In Fig.1 the sites of the ice cores are shown. Their elevations lie between 2100 m (B21) and about 3000 m (B16, B29).

2. Regression Model: Statistical Technique, Parameters and Results

A simple downscaling method is a multiple linear regression using the EOF time series of the large scale field as predictors. This way the small scale noise is eliminated, while the main patterns are described by the EOF analysis, which are well simulated by GCMs. The EOF time series of the large scale field G(x,t) result from a development in EOFs (v. Storch, Zwiers 1999):

$$G(x,t) = \sum_{i=1}^{n}, G_i(x) A_i(t) \qquad (1)$$

The $G_i(x)$ are the spatial patterns which are independent of time, whereas $A_i(t)$ are the EOF time series. Because the $A_i(t)$, $A_j(t)$ are orthogonal, the equation for multiple linear regression is:

$$A_{cc}(t) = K_1 A_1(t) + K_2 A_2(t) .... + K_i A_i(t) \qquad (2)$$

With $A_{cc}(t)$ as local accumulation[1] and K_i as regression coefficients.

The three ice cores are described best using the first five EOF time series of the 500 hPa streamfunction. Using the temperature or the geopotential fields or combining them yields worse results in this set-up.

In the final form the three regression models use slightly different areas covering the northern hemisphere from the east American coast to east Asia in west/east direction and to the central Sahara in the south. The main differences of the models are the different periods which have to be considered by the regression models. B21 is best described using only the mean May/June field. The B16 model uses the mean streamfunction field from August until October and the B29 model from June until February.

Fig. 2 shows the ice accumulation anomalies for the real ice core and the estimated accumulation obtained by applying cross-validation (v. Storch, Zwiers 1999). The explained variance for the accumulation of B16 is 56%, of B21 69% and of B29 74%.

[1] Because of uncertainties of ice accumulation measurements and dating a weighted running mean (with weights 1-2-3-2-1) has been applied to the accumulation time series. In order to relate the yearly ice accumulation rates to the atmospheric data the date of the spring signal is set to May 1st.

It is proposed that precipitation at the sites investigated here is mainly a consequence of the on-flow and the forced ascent of the air by the ice sheet which lead to precipitation since the predictors are the EOF time series of the large scale streamfunction fields. The differences of the regression models concerning the seasonal means are suggested to be mainly caused by the orographic barriers which force the air to ascend (Fig.1). This way the streamfunction, averaged over different months, and its characteristic directions and intensities is associated with different precipitation rates at different sites of the slope.

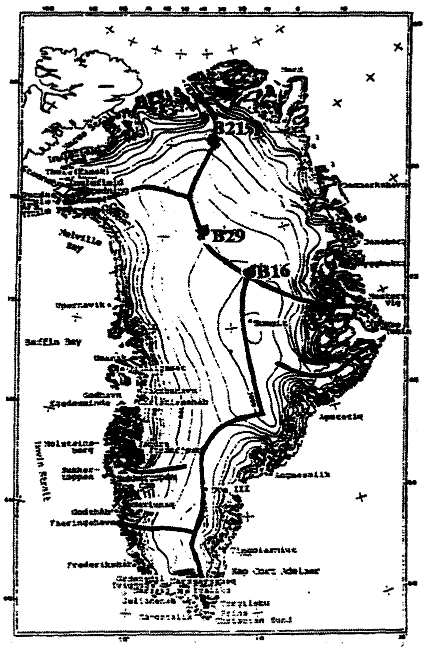

Fig.1. Sites of the ice cores and orographic barriers of Greenland (Ohmura, Reeh,1991).

Investigating the EOF patterns used by the models leads for B16 and B21 to little importance for the first patterns which explain about 85% of the streamfunction variance of the used area. For B16 the time series of the third EOF has a portion of 88%, for B21 the forth a portion of 74% of the estimated accumulation variance. Only for the B29 model the second EOF (explained variance 33%) leads to a relatively important amount of estimated accumulation variance (31%). From this features of the regression models it can be concluded that a reconstruction of large scale atmospheric characteristics using our models is possible at best for the site of B29.

3. 'Artificial Ice Cores' of a 1000 Year Control GCM Run (ECHAM4/HOPE)

The regression models have been applied to a 1000 year control run of the coupled ocean/atmosphere GCM ECHAM4/HOPE. Fig.3 shows the accumulation anomalies for B29 which is related to the mean accumulation of the real ice core of the model fitting period. As expected, there is no trend of accumulation for the control run, but the anomalies are mostly positive. The spectral analysis for the real accumulation of B29 and the estimated accumulation at the site of B29 shows that both spectra are nearly 'white' (Fig. 4). For the 'artificial ice core' a substantial reduction of variance is obtained. This is partly due to the regression model by disregarding unknown, large

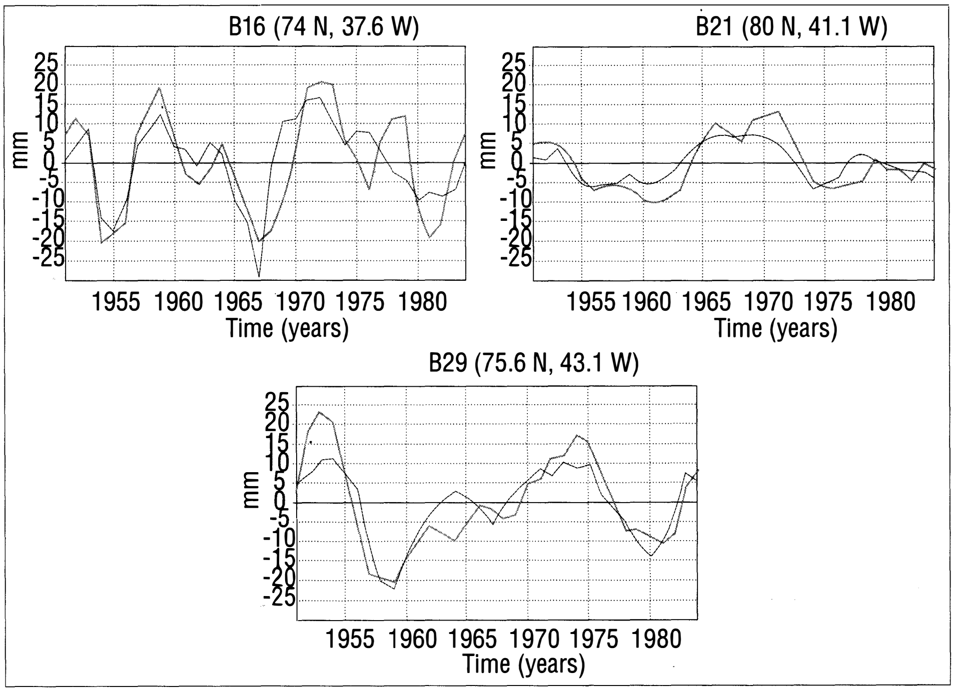

Fig. 2. Yearly accumulation anomalies; solid: real ice core; dashed: estimated

a) B16; b) B21; c) B29

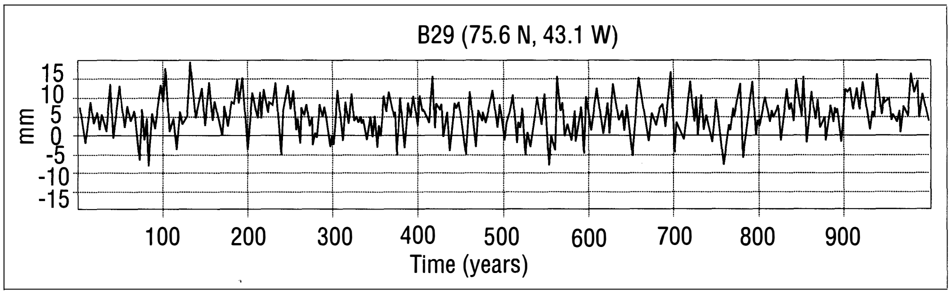

Fig. 3. Estimated yearly accumulation anomalies at B29 of the ECHAM4/HOPE control run.

scale influence factors or significant local processes. Obviously, another portion of variance reduction result from the GCM model.

For the sites of B16 and B21 the similar behaviour is obtained (not shown here).

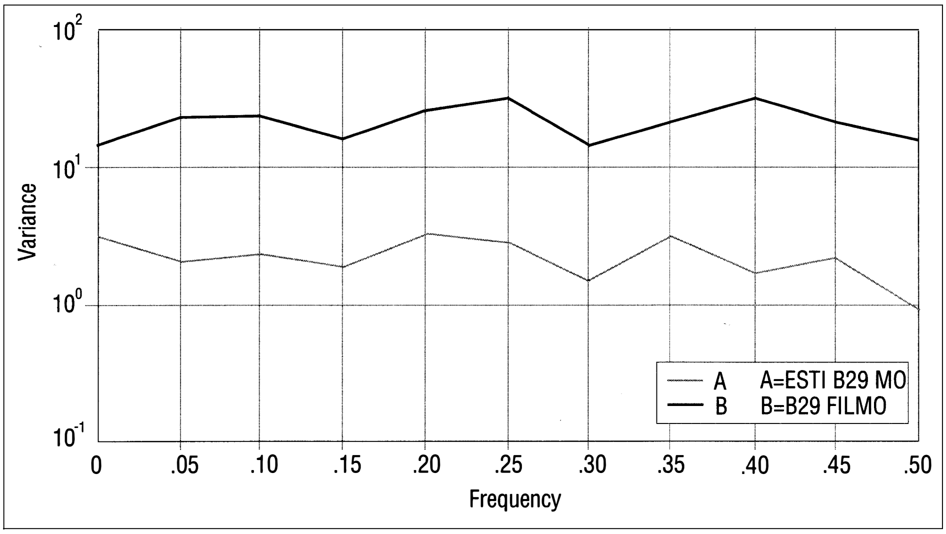

Fig. 4. Variance spectra

a) estimated accumulation of the last 500 years of the ECHAM4/HOPE control run; b) B29 yearly ice accumulation from 1495 until 1994; (frequency 0.5 represents a 10 years period).

4. Outlook

Other GCM runs with variations of solar radiation and CO_2 will be used to estimate and investigate ice accumulation. Different formulations of downscaling models will be tested for linking thermodynamic variables like humidity and temperature to accumulation rates.

Acknowledgements

This work has been done in co-operation with the KIHZ project and is financed by the 'Frauenförderung' of the University of Hamburg.

We thank the AWI-Bremerhaven for providing the ice core data, especially Matthias Schwager for helpful discussions. We also thank Stephanie Legutke and Reinhard Voss from DKRZ Hamburg for providing the GCM data.

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