REGIONAL CLIMATE CHANGE
INFERRED FROM GLOBAL-SCALE ESTIMATES:
WINTER RAINFALL ON THE IBERIAN PENINSULA

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It is generally accepted that General Circulation Models (GCM) are the adequate tool to predict global-scale climate changes caused by an increasing atmospheric greenhouse-gas concentration. These models operate with a numerical discretization so that spatial scales of the order ≥ 3000 km are, at least potentially, reliably simulated. Regional scales (typically ≤ 500 km) cannot, however, be described skillfully, and it is on this scale that users of climate change forecasts, such as hydrologists, request information. It is therefore necessary to apply a consistent method to infer regional information from global-scale information. One method [1] is to drive a regional dynamic model with large-scale information provided by a global GCM. In the present paper we show an alternative statistical approach, relating empirically the global and regional scales, may be applied successfully. The regional parameter studied is northern winter Iberian rainfall, the global-scale information is the seasonal mean atmospheric-pressure distribution over the North Atlantic; the statistical model is used to reconstruct Iberian rainfall patterns from the first half of this century and to estimate changes in Iberian rainfall by a climate change experiment [2].

The statistical model was obtained by a Canonical Correlation analysis (CCA) [3] of anomalies of winter mean Iberian rainfall and North Atlantic sea-level pressure from 1950 to 1986 [4]. Given two random vector time series, CCA identifies pairs of patterns whose coefficients are optimally correlated. The rainfall is given at a number of irregularly distributed meteorological stations, while the pressure data is on a regular grid.

The CCA identifies one dominant pair of patterns (Fig 1). The pressure pattern, representing 40% of the interseasonal variance, is that of the North Atlantic Oscillation (NAO), the dominant mode of large-scale variability in the North Atlantic sector (e.g. [5]). The rainfall pattern accounts for 65% of the variance. The correlation of time coefficients of the two patterns is 0.75.

The relative position of the anomalous pressure-pattern and of the anomalous rainfall-pattern indicates a physically consistent mechanism [4]: a southward shift of the westerly winds is associated with an increase of Iberian rainfall, and a northward shift is associated with a decrease in rainfall. The effect is strongest in the mountainous northwest part of the peninsula.

The result of the CCA provides a method for estimating from a given anomalous large-scale pressure field a regional anomaly of rainfall that is consistent with the pressure field. Mathematically, this is accomplished by projecting a North Atlantic pressure anomaly field onto the CCA pressure pattern, and by multiplying the resulting coefficient with the CCA precipitation pattern. This procedure is, of course, capable of describing only the 65% of the precipitation variance that can be traced to the NAO. The implicit assumption is that the observed interannual NAO-Iberian rainfall relationship can be extrapolated to longer time scales, which is reasonable as long as the climate variations are considered small. We will later see (Fig. 2) that this condition is fulfilled.

The reliability of the suggested statistical relationship is tested by reconstructing the patterns of Iberian rainfall from the beginning of this century. As noted in [6], the North Atlantic pressure field has undergone significant changes during this century. Note that the data prior to 1950 have not been used to perform the CCA and, thus, represent independent samples.

The area-averaged rainfall, obtained indirectly from the pressure fields and from the in-situ meteorological observations are displayed in Fig. 2. The two time series, both smoothed with a 5-year-running mean filter, vary coherently on all resolved time scales. There is a marked variability on the inter-decadal time scale and an upward trend of approximately 10 mm/month in 80 years.

Fig. 2 leads to two conclusions: firstly, that the proposed procedure operates properly and, secondly, that the trend, as well as the inter-decadal variations, are real. This follows since the two data sets, rainfall and pressure, are from independent sources.

We then applied the proposed statistical procedure to interpret the output of a climate change experiment on the regional scale. The climate change experiment [2], conducted at the Max-Planck-Institut für Meteorologie in Hamburg, consisted of a pair of two 100-year integrations which are identical except for the imposed CO_2 loading. In the "control" run the greenhouse gas concentration was kept constant whereas in the "Scenario A" run the concentration was continuously increased as specified by the IPCC Scenario A ("business as usual").

In Fig 3 we show two curves representing the Iberian winter area-averaged rainfall. One curve is the averaged simulated rainfall anomalies relative to the control experiment at the four grid points that can be connected with the Iberian Peninsula. The other curve represents the rainfall anomalies as indirectly derived from the simulated North Atlantic sea-level pressure anomalies. The variations in Fig. 3 are of the same order as in Fig. 2, indicating that our implicit assumption of small variations is applicable in the climate change experiment.

Clearly there are marked differences in the amplitudes of the grid point rainfall and the estimated rainfall curves, but they vary coherently on the interdecadal time scale. The high-frequency variations, however, are not in agreement, resulting in a correlation coefficient of only 0.40. Both curves have a downward trend, with -9 (mm/month)/(100 years) in the grid-point data and with -7 (mm/month)/(100 years) in the estimated data.

We note that the evaluation of another climate change experiment, namely on the equilibrium response to a doubling of CO_2 concentration [2], leads to a similar conclusion. A climate change experiment will yield considerably different implications on the regional scale if the grid-point information is evaluated simplistically or, in contrast, a dynamically consistent statistical approach is pursued.

Our statistical "down-scaling" strategy offers three advantages: its technical simplicity, its degree of dynamic consistency and its applicability, for example, to economic or ecological parameters. There is, however, a severe limitation to this statistical strategy: it can be applied only if there is a direct relationship between the global-scale atmosphere state and the regional parameter being considered.

REFERENCES

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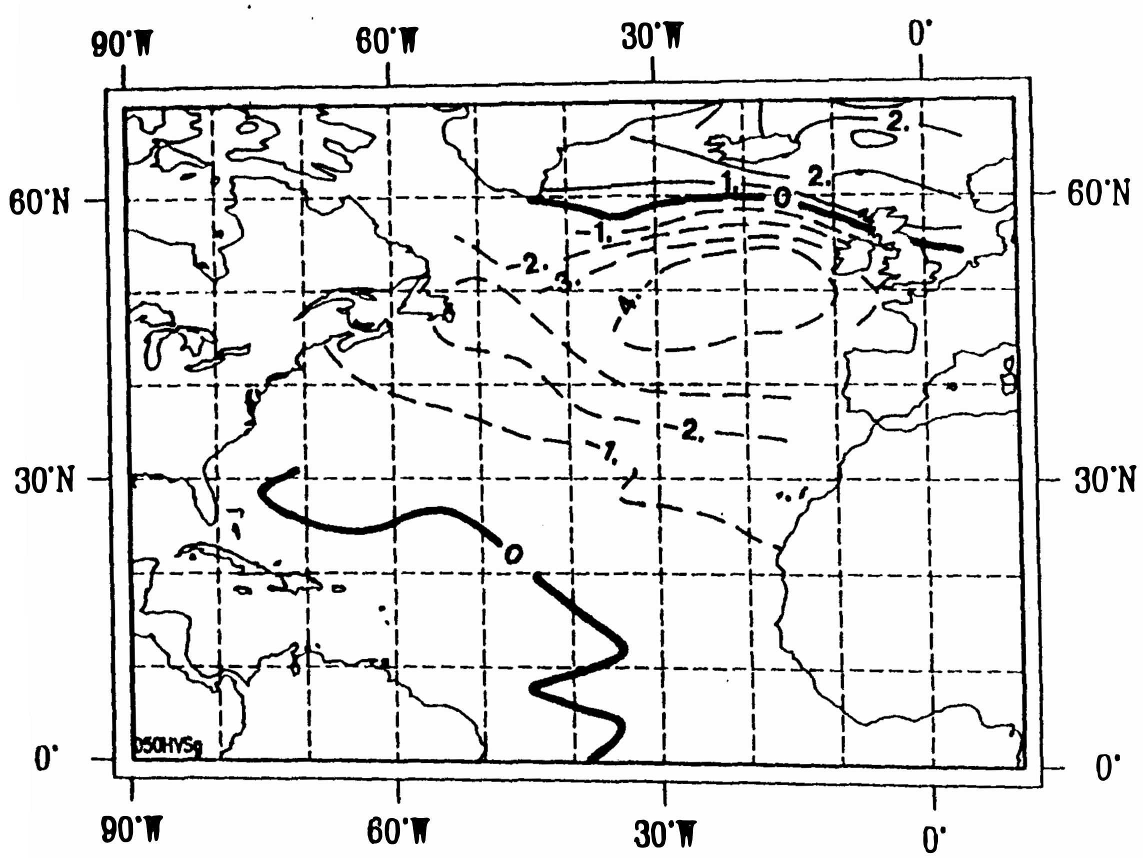
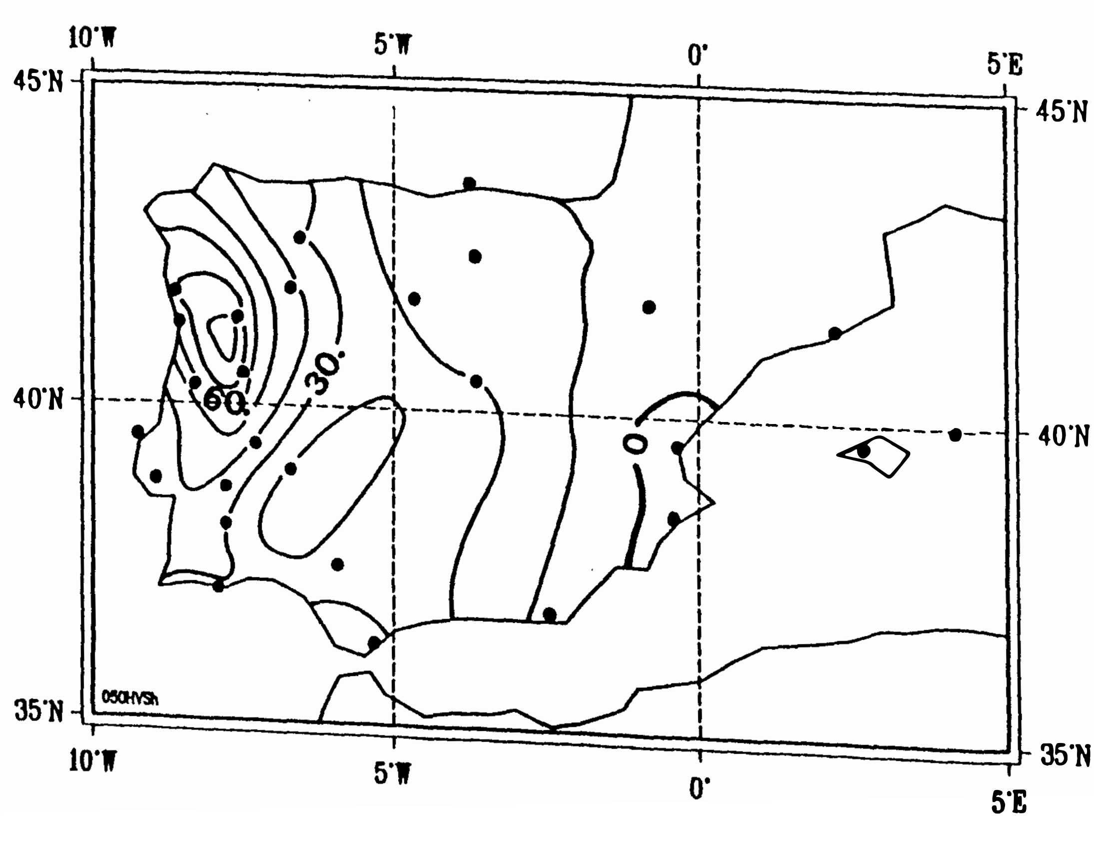
Figure 1.

Canonical correlation patterns of observed winter (DJF) Iberian rainfall and simultaneous sea-level pressure field in the North Atlantic area. The correlation between the time coefficients is 0.75. They explain about 65% and 40% of the inter-seasonal total variances.





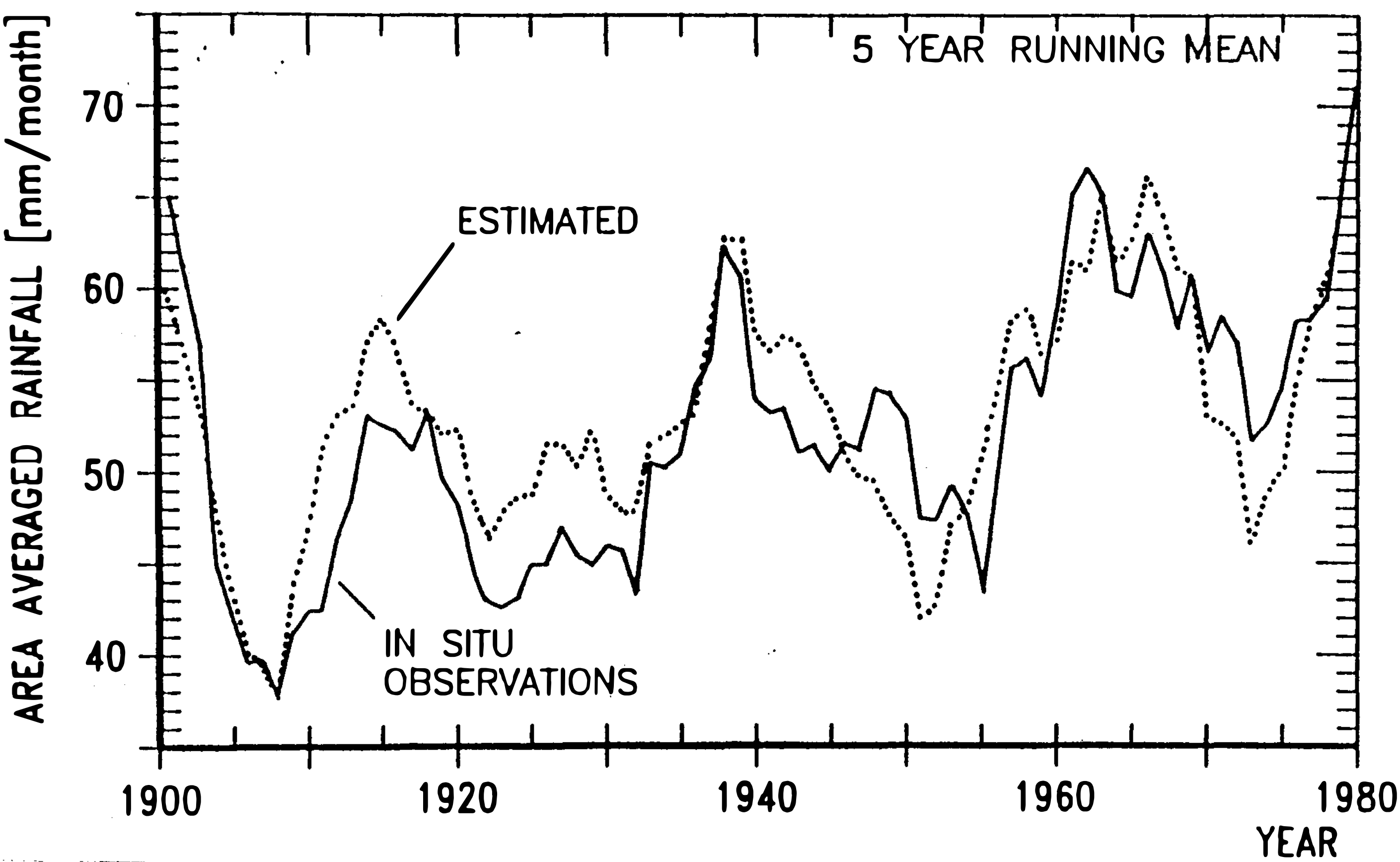


Figure 2.
Five-year-running mean time series of area-averaged winter (DJF) mean rainfall as derived from station data and from the North Atlantic sea-level pressure field.
Units: mm/month

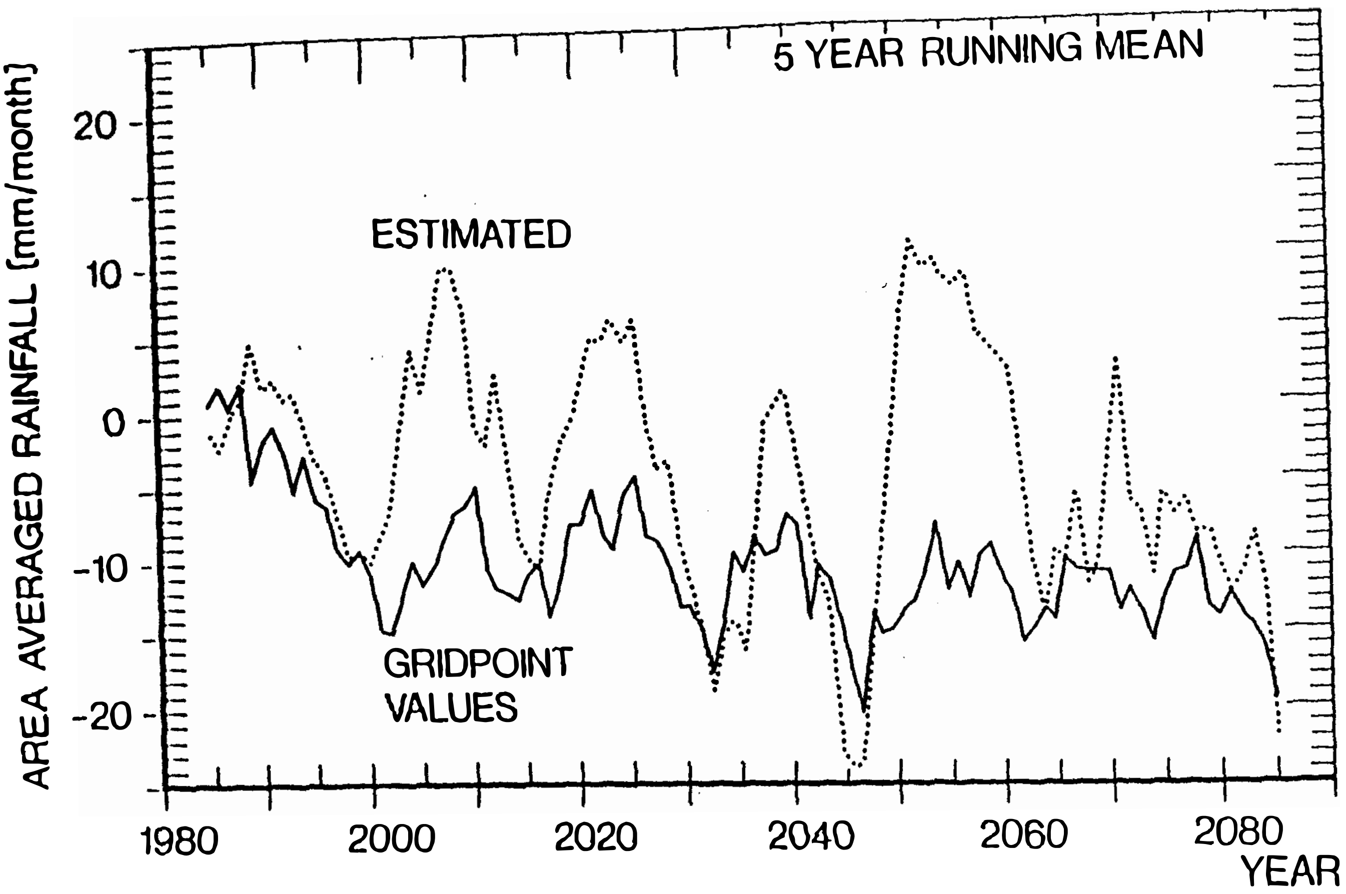


Figure 3.

Five-year-running mean time series of Iberian area-averaged winter mean rainfall in the "IPCC Scenario A" climate change experiment.

Dashed: indirectly derived from the North Atlantic sea-level pressure field.

Solid: directly derived from the grid point rainfall.

Units: mm/month