Posible modificación del régimen pluviométrico en la zona mediterránea a causa del cambio climático

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Abstract

The study uses a GCM (ECHAM-OPYC3) and the association between the atmospheric circulation at 925 and 500 hPa and the distribution of daily precipitation for Mediterranean Spain (from earlier analyses) to give estimates of the probable annual precipitation for the late 21st century. A down-scaling technique is used which involves the matching of daily circulation output from the model for a sequence of years in the late 20th century (1971-90) and for a corresponding period in the late 21st century (2080-99) to derive probable regional atmospheric pattern (AP) frequencies for this latter period, and thence to estimate likely changes in annual precipitation. Model days are classified by searching for the closest analogue amongst 19 previously identified APs from an earlier study.

Marked decreases in frequency are indicated for many near-surface circulations with a westerly or northerly component. For APs with an easterly component, some are shown to increase, others to decrease. Increases in inter-decadal variability are strongly indicated for most APs, though for some easterly situations there is no clear signal. A significant annual precipitation reduction of between 6 to 14% is indicated for Andalucía and the upland parts of Cataluña, but in contrast, with an increase in annual totals of up to 14% along parts of the coast between Almería and the French border. All the details of this study may be found in Sumner et al. (2002).

Introduction

Many General Circulation Models (GCMs) are available which permit the prediction of climates to the end of the current century. Most agree that with at least a doubling of CO_2, the most significant GHG, during the rest of this century, marked global warming will occur in the coming decades. Models may be used to indicate future trends in precipitation as well as predicting probable future temperatures. Many results indicate, for example, that the Mediterranean region as a whole may experience a general increase in aridity (Met Office, 2001; Watson and Zinyowera, 2001), but that trend may not necessarily be consistent across the region. For example, any reduction in the frequency and strength of westerly flows in the temperate North Atlantic, linked to changes in the North Atlantic Oscillation (NAO) and generally predicted for the coming century (Watson and Zinyowera, 2001), may result in decreases in precipitation receipt generally in the Mediterranean basin, particularly in the extreme west, where significant precipitation is often the result of major incursions of Atlantic flows and their embedded disturbances, mostly during the winter. But a reduction in the incidence of westerly flows may allow for an increase in the frequency of flows from other directions, in turn increasing the incidence of mesoscale disturbances which initiate local changes in the amount, frequency, intensity and seasonal and spatial distributions of precipitation.

In the western Mediterranean therefore, as in other regions of the world, there is an urgent need for a down-scaling of the results from GCMs so that they can be made more directly relevant in the national, regional and local contexts. This study uses atmosphere-ocean coupled ECHAM-OPYC3 GCM model predictions of atmospheric circulation frequencies for the last two decades of the 21st century to provide a first estimate of likely annual precipitation amount and variability for Mediterranean coastal Spain. The model, run for the period 1860-2099, was forced with historical greenhouse gas concentrations starting in 1860 and ending in 1990, and after this year the concentrations were assumed to evolve according to the projections envisaged by the IPCC in Scenario A (IPCC 1992).

Methodology

The used down-scaling technique is underpinned by earlier research, which established a sequence of 11 typical daily rainfall patterns (RPs) (Romero *et al*. 1999a; Figure 1), and derived 19 characteristic regional atmospheric patterns (APs), based on flow at the 925 and 500 hPa levels for 'rainfall days' during the decade 1984-93 for Mediterranean coastal Spain (Romero *et al*. 1999b; Figure 2) using European Centre for Medium-

Range Weather Forecasts (ECMWF) data. A close statistical relationship has been demonstrated between the RPs derived from the first study and the APs identified in the latter (Romero *et al*. 1999b), so that a first guess of the general spatial distribution of future mean precipitation along the Spanish Mediterranean coast may be obtained from matching model predicted 925 and 500 hPa daily circulations against one of the 19 APs.

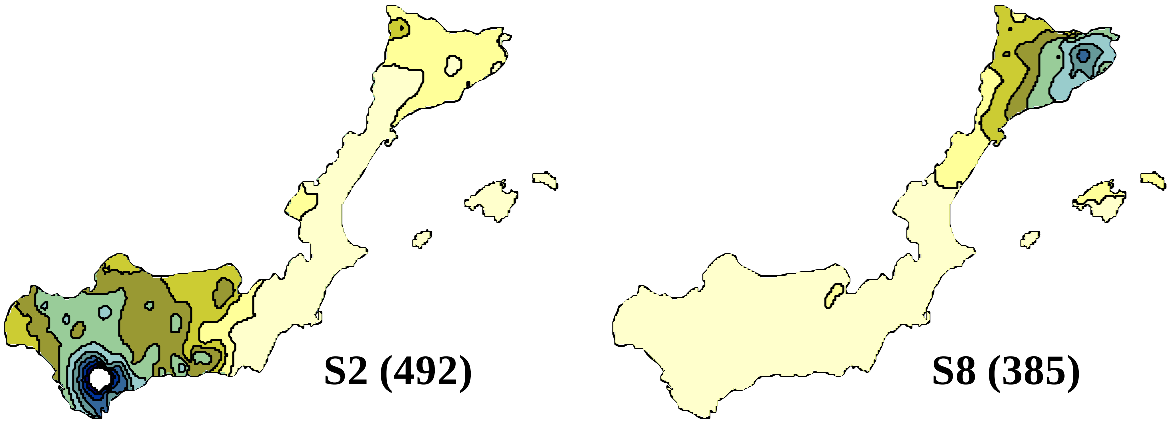

Figure 1. Daily rainfall composites for 2 of the 11 typical patterns of rainfall (RPs) in Mediterranean Spain.

Daily circulation results from the ECHAM GCM for the North Atlantic/European region for the late 20th century (1971-90), representing 'the present', and for the period 2080-99, representing 'the future', were both classified following an analogue procedure: the circulation for each model day was matched with the closest observed day within the 1984-93 ECMWF data set. If the matched day within the ECMWF set was not itself classified within one of the 19 APs then the day was rejected and was not included in the ECHAM AP classification. The comparison between ECHAM AP classification for 1971-90 and empirical data for 1984-93 permitted an assessment of the reliability of the ECHAM model output, and also the derivation of a correction factor to moderate indicated future ECHAM AP frequencies. Such derived future AP frequencies were then used to deduce RP frequencies, up-scaling the percentage results to compute a map of estimated annual total rainfall for the period 2080-99. Since the above procedure was applied on a decadal basis using a moving 10-year window along the two 20-year model periods, 1971-90 and 2080-99, measures of inter-decadal variability of AP frequencies and down-scaled future rainfall could also be obtained.

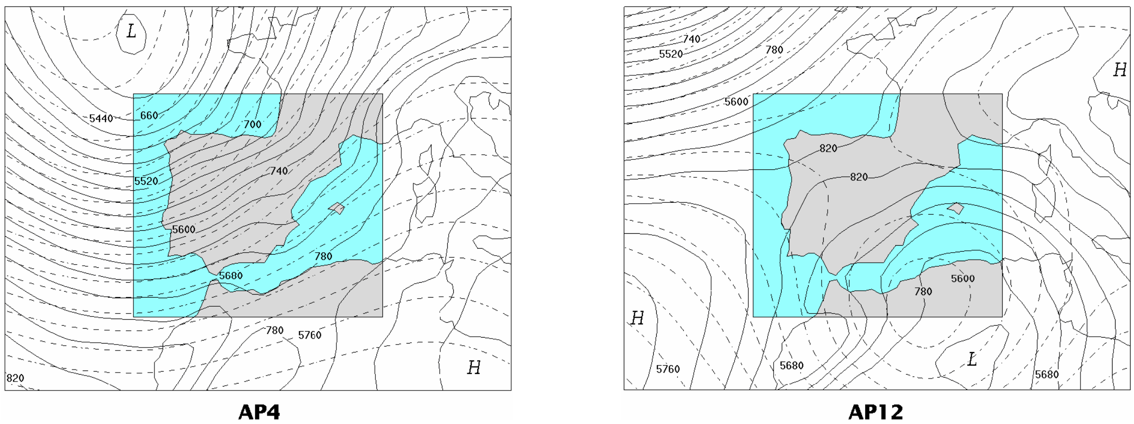

Figure 2. Composites for 2 of the 19 atmospheric patterns (APs) associated with rainfall in Mediterranean Spain. The continuous lines represent the geopotential field at 925 hPa (contour interval, 10 m), and the dashed line that at 500 hPa (contour interval, 20 m). The interior rectangle represents the geographical window used for the pattern classification.

Future AP frequencies

Figure 3 shows the comparison between mean ECHAM AP frequencies for 1971-90 and empirical data (ECMWF) for 1984-93. It should be noted that in absolute terms, model and empirical data sets generate very similar sample sizes, comprising about 35% of all days, suggesting that the overall precipitation-generating potential indicated using the ECHAM GCM operates well at the regional scale and for this region. However, this overall good correspondence is not carried through once AP frequencies are considered. There appears to be a degree of meteorological consistency in the degree of both over- and under-estimation of AP frequencies by the ECHAM model. The model consistently under-scores for APs 5 and 6, and 10-17 inclusive. All these have a strong easterly component at 925 hPa, and are generally of importance to precipitation generation in the Spanish Mediterranean in that they are frequently associated with significant or torrential rainfall events in that area (Romero *et al*. 1999b). By contrast, the model tends to over-score for many other circulation types, notably APs 2, 4, 7 and 9, all westerly ('Atlantic') types at 925 hPa, and APs 18 and 19, northerlies (again, essentially 'Atlantic').

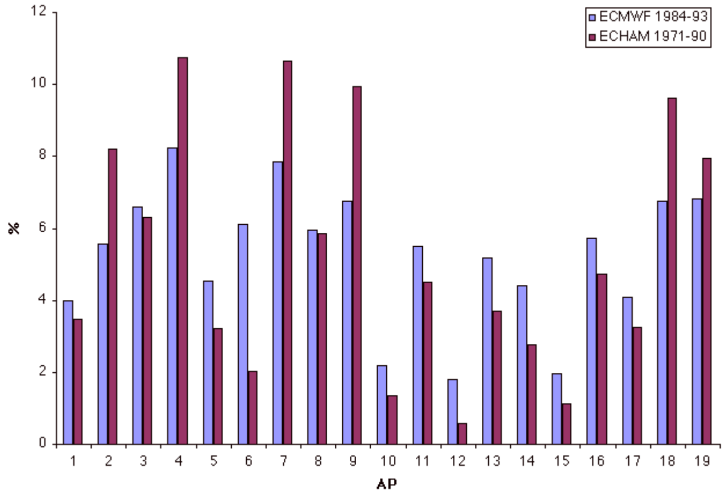

Figure 3. Comparison between atmospheric pattern (AP) frequencies for the ECHAM model-generated decades, 1971-90 (mean 11-decade sequence; see text), and those derived from ECMWF data for 1984-93.

Future AP frequencies, compensated to take into account contemporary over- or under-estimates of real AP frequencies, have been calculated for the 2080-99 period. The future increase or decrease in frequency is thus deduced by comparing the compensated future ECHAM results with those which were derived from the empirical study using ECMWF data. These results are presented in Figure 4. Notable *increases* in frequency are indicated for APs 5, 6, 10, 11, 15, and 16. In each case the percentage increase is greater than 40%. These are all examples of sustained near-surface easterly flow over the study region, or are marked by the presence of a 'flabby' near-surface low, such as a thermal low, over the Iberian Peninsula. APs 5 and 6 also possess a distinct upper level low to the south-west of Iberia. An increase of a lesser order is indicated for AP 17. Marked *decreases* in occurrence are indicated for APs 1, 2, 9 and 12, with lesser decreases for APs 3, 4, 7, 8, 13, 18 and 19. APs 12 and 13 exhibit an easterly flow at 925 hPa, but with a marked cold cut-off at the 500 hPa level over or near to Iberia, in contrast to many of the easterly types for which an increasing incidence is indicated, where no such upper cut-off feature appears (APs 5, 6, 10, 11, 15, 16 and 17). The remaining APs showing a decrease in frequency all comprise westerly-type circulations, plus the two northerly types (APs 18 and 19).

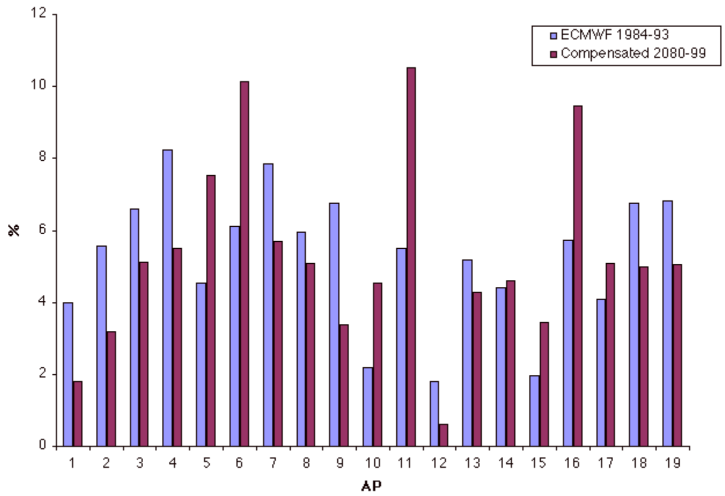

Figure 4. Predicted (2080-99; mean 121-decade sequence) and present AP frequencies. Predicted frequencies use results from the ECHAM model compensated with reference to contemporary model/empirical frequencies (see text).

Implications for precipitation

The major finding of this study so far is very clear and must be stressed because of its importance for Spanish Mediterranean precipitation incidence and distribution. This is that *decreases* in AP incidence emerge for all westerly ('Atlantic') types (APs 1-4 and 7-9), for the two northerly types (APs 18 and 19), but for only two of the near-surface easterly flows (APs 12 and 13), and for one of these the decrease is small. *Increases* in incidence are indicated for most of the remaining easterly near-surface flow types, together with occurrences of a near-surface low pressure over southern or central Spain. The distinction between the two groups is thus quite clear cut, and a general important consequence for Spanish Mediterranean precipitation occurrence may be deduced at an early stage in this discussion.

The indicated frequencies of each of the 11 RPs for 2080-99 are compared with those derived from the empirical study in Figure 5. A clear basic pattern may be observed. RPs 1, 2 and 3 are characterised by rainfall concentrated on western and central Andalucía and upland Cataluña and in all cases there are significant decreases in frequency. There is also a slight decrease in the frequencies of RPs 10 and 11, characterised by a node of precipitation centred on the Balearics. This 'loss' of precipitation in the far south and north of the study area, and in the Balearics, is compensated by increases in the frequency of six of the other seven RPs (the frequency of RP 9 does not change), for each of which precipitation is concentrated on one of a number of comparatively small parts of the Mediterranean coast proper. These RPs are very often linked to the occurrence of severe storm development. The resultant trends are consistent: linking the shrinking incidence of westerly flows to reduced rainfall in Andalucía and other sensitive areas on the one hand; and increased incidence of many easterly flows to increased storm precipitation elsewhere.

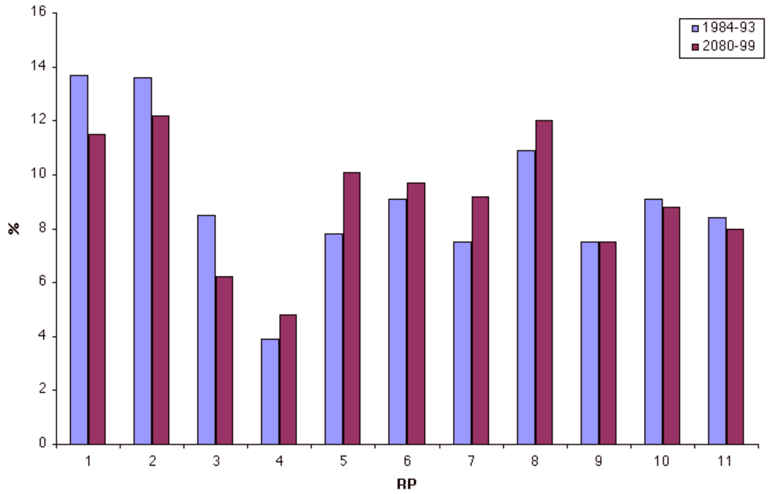

Figure 5. Rainfall Pattern (RP) frequencies from the empirical study (1984-93) and for the future (compensated ECHAM result for 2080-99 using the mean 121-decade sequence: see text).

The expected percentage change in yearly total precipitation is shown in Figure 6a, together with the standard deviation for the change in Figure 6b. Whilst a drying tendency is frequently anticipated for the whole Mediterranean region as a consequence of global warming (Met Office, 2001; Watson and Zinyowera, 2001),, it is clear that whilst some areas, notably Andalucía, the mountainous parts of Cataluña, Mallorca and Menorca in this study, will in fact become drier, others, such as the major coastal embayments along the Spanish Mediterranean coast proper, for example, Almería, Murcia, Valencia, etc., together with Ibiza, will experience an overall increase in annual precipitation. Interestingly, the division on the map between areas with increasing and decreasing precipitation also very closely resembles that illustrated by Romero *et al*. (1998) in their analysis of precipitation trends through the thirty years, 1964-93, and also that produced for the area by Guijarro (2002).

Higher uncertainty of the magnitude of change is indicated for eastern and northern parts of the study area. However, whilst the greatest changes occur in Murcia and northern Valencia provinces (increase) and for western Andalucía and upland Cataluña (decrease), the greatest degree of uncertainty concerning the magnitude of the change, as represented in Figure 6b, occurs for Murcia, the whole of Valencia province, lowland Cataluña and the Balearics. In addition, for areas close to the zero isoline (central Cataluña and eastern Andalucía) the standard deviation far exceeds the indicated mean change, so that for a quite considerable area on either side of the zero isoline (positive and negative) little confidence may be placed in either indicated increase or decrease in precipitation. Outside these areas, though, even where indicated standard deviations are high, the anticipated mean percentage change in precipitation is also high, so that considerable confidence may be placed on the indicated changes for western Andalucía, Murcia and northern Valencia provinces.

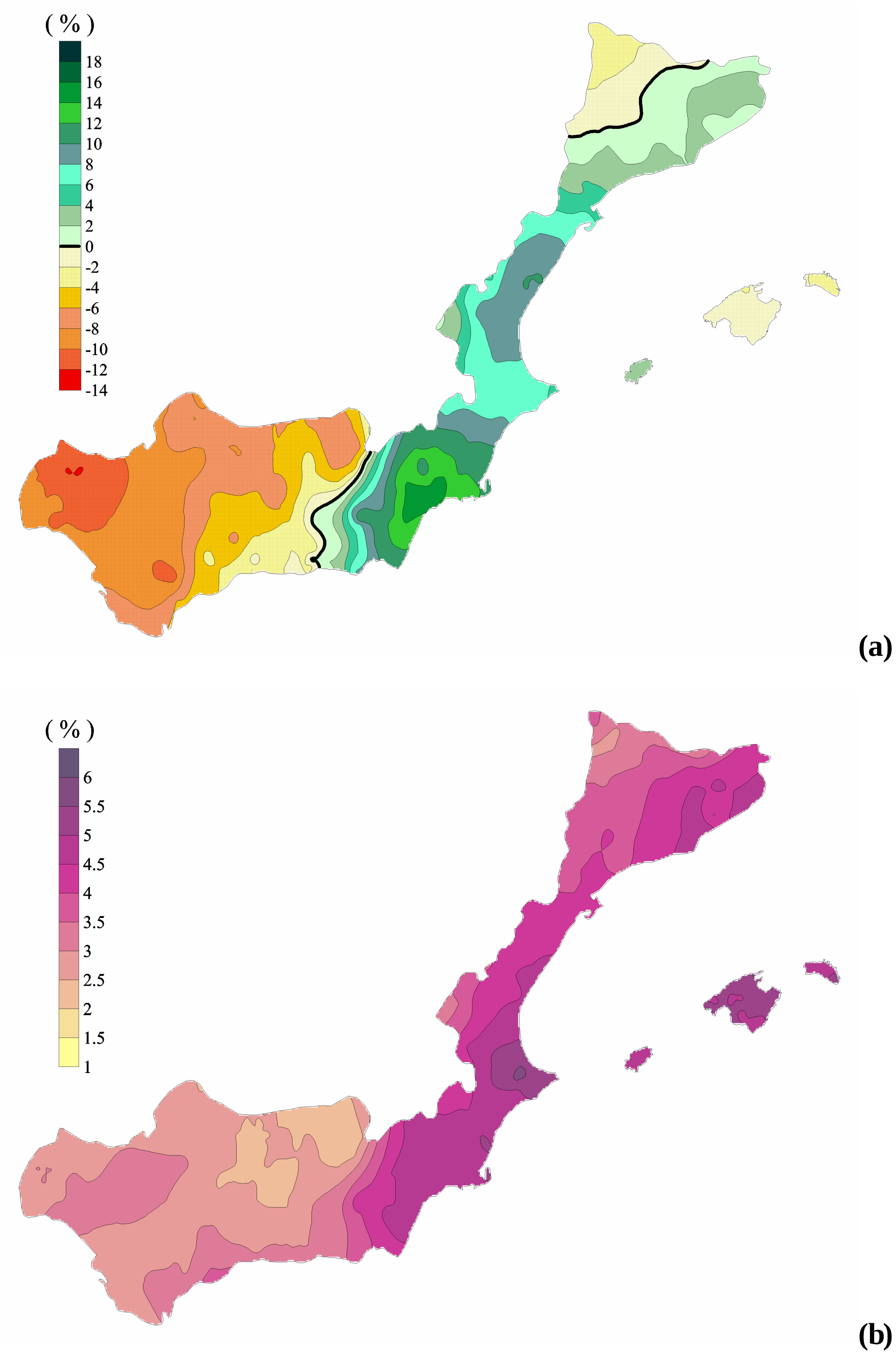

Figure 6. (a) Estimated percentage increase or decrease in mean annual precipitation for the study area, 'present' to 'future', late 20th to late 21st centuries, and **(b)** its standard deviation.

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