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Stability of the seasonal distribution of precipitation in the Mediterranean region: Observations since 1950 and projections for the 21st century

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[1] A gridded data set of precipitation records since 1950 was used to assess how observed precipitation trends in the Mediterranean area have affected the contribution of monthly precipitation to total annual precipitation in the region. Simulations of nine AOGCMs for a control period (1961–1990) and a SRES A1B scenario (2040–2070) were also used to explore potential future changes. The results indicate that the seasonal distribution of precipitation has remained stable in most of the Mediterranean basin, and that this is expected to remain the case for the first half of the 21st century. This finding is independent of existing precipitation trends and any predicted reduction in precipitation. **Citation:** López-Moreno, J. I., S. M. Vicente-Serrano, L. Gimeno, and R. Nieto (2009), Stability of the seasonal distribution of precipitation in the Mediterranean region: Observations since 1950 and projections for the 21st century, *Geophys. Res. Lett.*, *36*, L10703, doi:10.1029/2009GL037956.

1. Introduction

[2] Precipitation is one of the principal components of the hydrological cycle; hence, significant scientific effort is being devoted to assessing its temporal evolution and predicting changes over future decades. Although total precipitation is generally used as an indicator of the water available for ecosystems and water resource schemes, the timing of seasonal precipitation is particularly important for many environmental processes [*Weltzin and McPherson*, 2000; *Pryor and Schoof*, 2008]. In hydrological processes, the distribution of precipitation throughout the year controls interception, evapotranspiration, infiltration rates and snow accumulation, and these factors have significant implications for stream discharge and flood forecasting [*Beniston*, 2003, 2006; *García-Ruiz et al.*, 2008]. With respect to the management of water resources, changes in the distribution of water inputs may lead to a mismatch between water availability and water demand. While it is likely that this can be managed in highly regulated basins, it is a problem of some concern in poorly impounded systems [*López-Moreno et al.*, 2004].

[3] Most studies of the past evolution and future prediction of precipitation have focused on total precipitation, despite the importance of seasonal shifts. References to changes in seasonality are generally inferred from trend analyses conducted on a monthly or seasonal basis, or in relation to changes in the duration of the dry and wet seasons [*Palutikof et al.*, 1994; *Pnevmatikos and Katsoulis*, 2006]. Few studies have investigated explicit changes in intra-annual contributions to total precipitation [*Pryor and Schoof*, 2008].

[4] The aim of this study was to assess whether the monthly contributions of precipitation to the annual total has changed in the Mediterranean basin since 1950, and to predict the contributions for the middle of the 21st century assuming a scenario of moderate greenhouse gases emissions (SRES A1B). Precipitation in the region is sparse and highly variable, and has been characterized by a general decrease in annual amount since the middle of the 20th century [*Hasanean*, 2004]. A number of studies have also highlighted important seasonal differences in the magnitude, and in some cases the sign, of the trend of precipitation series, although these differences are characterized by contrasting spatial patterns [*Hasanean*, 2004; *Trigo et al.*, 2005]. Most studies based on atmosphere-ocean general circulation models (AOGCMs) and regional circulation models (RCMs) in the Mediterranean region suggest a general trend of less precipitation in the next century, subject to noticeable spatial and seasonal differences [*Giorgi and Lionello*, 2008]. According to this view, changes in the contribution of precipitation in each month to annual totals may already have occurred, or could occur in the near future.

2. Methods

[5] To analyze changes in precipitation seasonality, we used the CRU TS 2.1 data set developed by the Climate Research Unit of the University of East Anglia (http://www.cru.uea.ac.uk/~timm/grid/CRU_TS_2_1.html [*Mitchell and Jones*, 2005]). These data describe the terrestrial surface climate for the period 1950–2002 at a spatial resolution of 0.5°, and are in good agreement with satellite-based precipitation data in terms of both the climatology and the leading modes of variability [*Zveryaev*, 2004]. Projections for the next decades were analyzed from monthly precipitation simulated by nine AOGCMs obtained from global circulation model (GCM) runs for the Fourth Assessment Report (AR4) data set. They cover a control period (1961–1990) and a future time slice (1940–1969), based on IPCC scenario A1B. The data can be accessed at http://www.ipcc-data.org/ar4/. The models used were: BCCR: BCM2, CCMA: CGMA3T3, UKMO: HADCM3, NIES: MIROC3HI, CNRM: CM3, CSIRO: MK3, NCAR: CCSM3, CNRM: CM3, and MPIM: ECHAM5, at spatial resolutions ranging from of 0.5 to 5°; these were subse-

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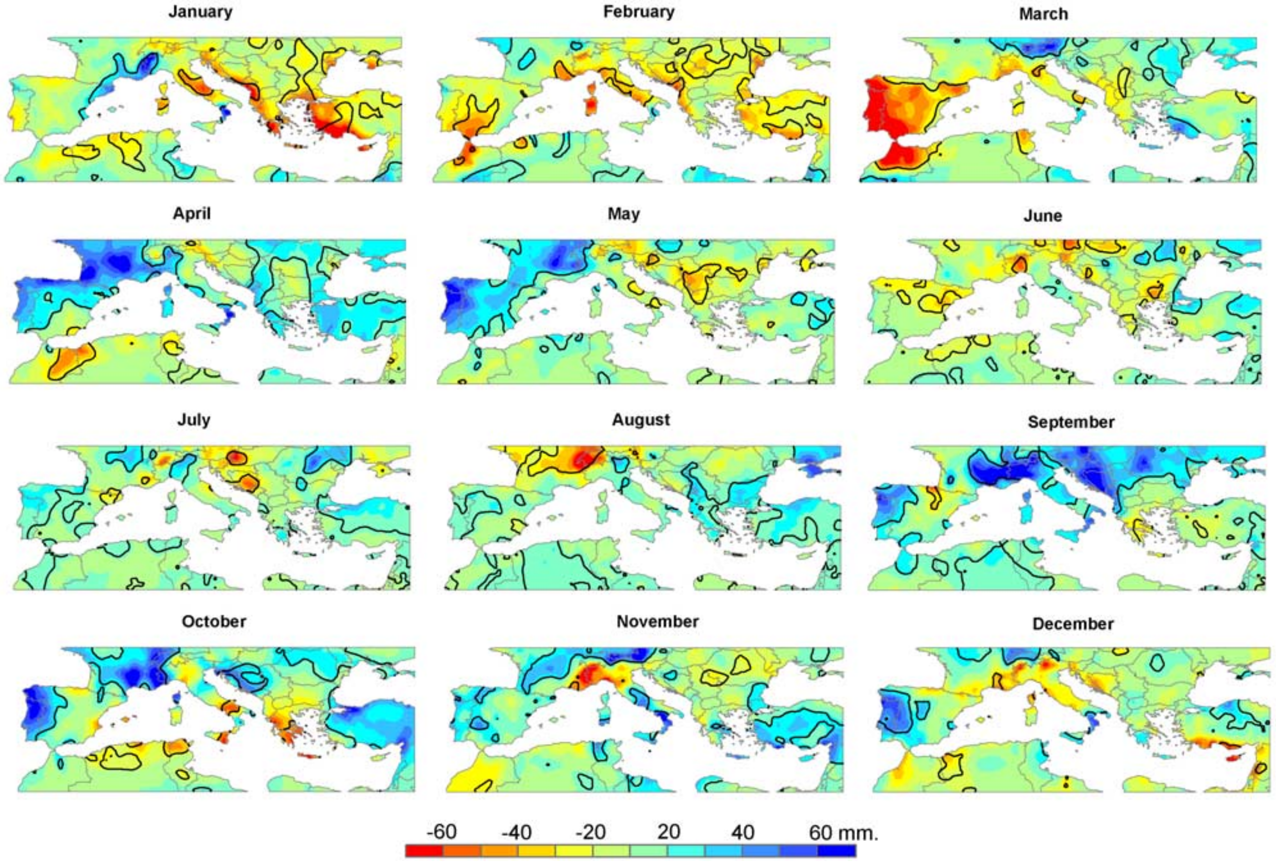

Figure 1. Trends in the magnitude of precipitation (1950–2002). The legend shows changes in precipitation for each month for the study period. The black lines indicate areas of significant change according to the Spearman-Rho test ($p < 0.05$).

quently interpolated to 0.25° by applying splines with tension.

[6] The contributions of monthly precipitation to the annual total were calculated for each year and each 0.5° grid point, and trends in both parameters were determined using the Spearman's rank correlation test. To filter year-to-year variations and reveal more persistent trends we applied a 5-year Gaussian filter to the precipitation and contribution series for each month. Using linear regression we obtained the slopes of the best-fit lines of precipitation contribution for each month to annual total as a function of time, and used these as a measure of the magnitude of the changes that took place between 1950 and 2002.

[7] We then obtained a spatial classification of homogeneous areas based on changes in the magnitude of the precipitation contributions for each month, using rotated (Varimax) Principal Component Analysis (PCA) and the percentage change for each month corresponding to each grid point. The variables thus obtained were the curves of the magnitude of the change in precipitation regime, derived from the slope of the regression line for each month at each grid point between 1950 and 2002. The PCA was used in S-mode, in which the different grid points were the variables, and the twelve months of the year were the cases. The number of components was selected in accordance with the criterion of an eigenvalue greater than 1. The regions identified by each component were determined using the maximum loading rule.

[8] In the regions represented for each component we obtained the average percentage contribution change to the annual total for each month over the period 1950–2000. We present this parameter in preference to the standardized components as it has a clearer physical meaning, although both showed the same behavior. For each region we also show the average precipitation regime for two periods (1950–1975 and 1976–2002) to illustrate possible temporal differences.

[9] For the regions represented by each component we show for all nine AOGCMs the percentage change in precipitation for each month and the percentage contribution to total annual precipitation, and compare the outputs of the control and the scenario for the mid 21st century. The precipitation regimes for both periods for each of the nine AOGCMs were also calculated for each region.

3. Results

[10] Figure 1 shows the spatial distribution of precipitation trends for each month in the Mediterranean region between 1950 and 2002. The trends exhibit high spatial variability in terms of both magnitude and sign. Among the most significant patterns was a general decrease in precipitation in the western part of the basin in March and an increase in April and May, a decrease in precipitation between January and March in most of the Balkans and Turkey, and a general increase in precipitation in September

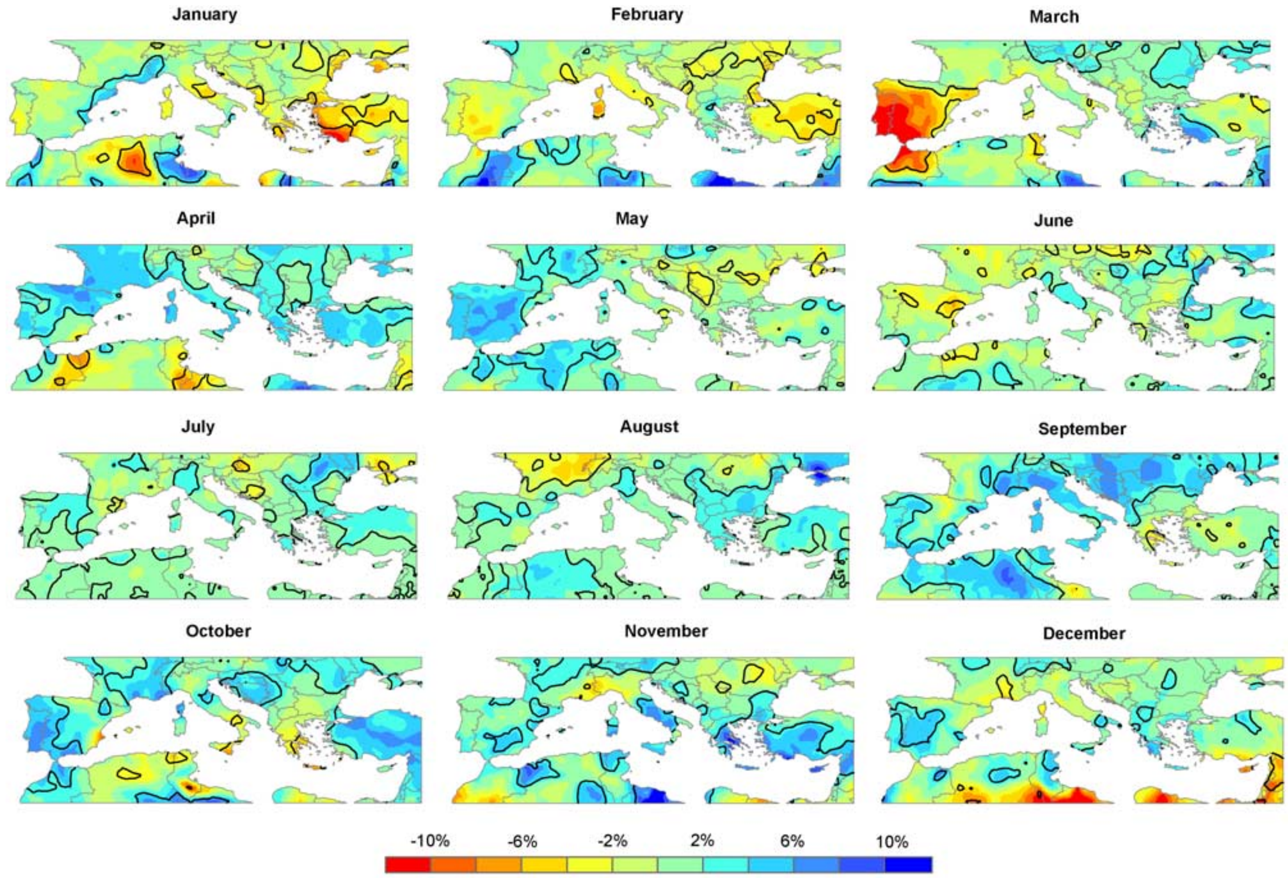

Figure 2. Trends in the contribution of precipitation (1950–2002). The legend shows changes in the contribution in relation to the total annual precipitation for each month over the study period. The black lines indicate areas of significant change according to the Spearman-Rho test ($p < 0.05$).

and October over large areas of the northern part of the basin. The observed trends in precipitation were reflected in the trends in the contributions of each month to the annual values. Figure 2 shows that a smaller contribution to the total annual occurred in January and February in Turkey, the Balkans and some parts of North Africa, and that the contribution to precipitation in March decreased noticeably in the western Mediterranean. In the autumn months (September, October and November) there was a widespread marked increase in contribution, which was even more generalized than the changes observed for total precipitation.

[11] Figure 3 summarizes changes in the precipitation regime throughout the Mediterranean region, based on PCA. The spatial distribution of the component loadings revealed highly defined regions based on the change in precipitation regime between 1950 and 2002. Component 1 represents most of the Iberian Peninsula and the area north of Morocco, where the most obvious trend was a sharp decrease in the contribution of February and March to precipitation (particularly in March, where there was an average decline of 8%between 1950 and 2002), an increase (3%) in the contribution in April and May, and a slight increase in the months from August to December. The curves of the precipitation regimes in this region show some differences between the 1950–1975 and 1976–2002 periods, but the characteristic Mediterranean precipitation regime remains clearly visible in the series. However, in the last 25 years of the 20th century, the autumn contribution increased somewhat. Component 2 represents Turkey and some areas of the Balkans and Italy. In this region the contribution of autumn precipitation also increased, whereas the contribution of winter precipitation (in January and February) decreased. Despite these differences, the Mediterranean regime can be identified clearly in both periods. In the Balkans (Component 3), there was a decrease in the precipitation contribution in the winter months, and an increase in the contribution in the months from August to October. Nevertheless, the changes were not sufficiently intense to cause noticeable alterations to the main precipitation regime. Some very slight changes were also observed in the Middle East and some North African areas (Component 4), in which only a displacement of the contribution from December to the autumn months was observed. In southern France and northern Algeria (Components 5 and 6) the changes were also minor, and the curves showing the precipitation regime remained largely unchanged throughout the second half of the 20th century. In southern Italy and the area to the north of Tunisia (Component 7), there was a decrease in the precipitation contribution in September and October, and an increase in the contribution of the early winter months. The opposite pattern was found in Romania (Component 8), where the contribution decreased in the winter months, but increased in the summer and autumn months. In summary, despite the observation of several

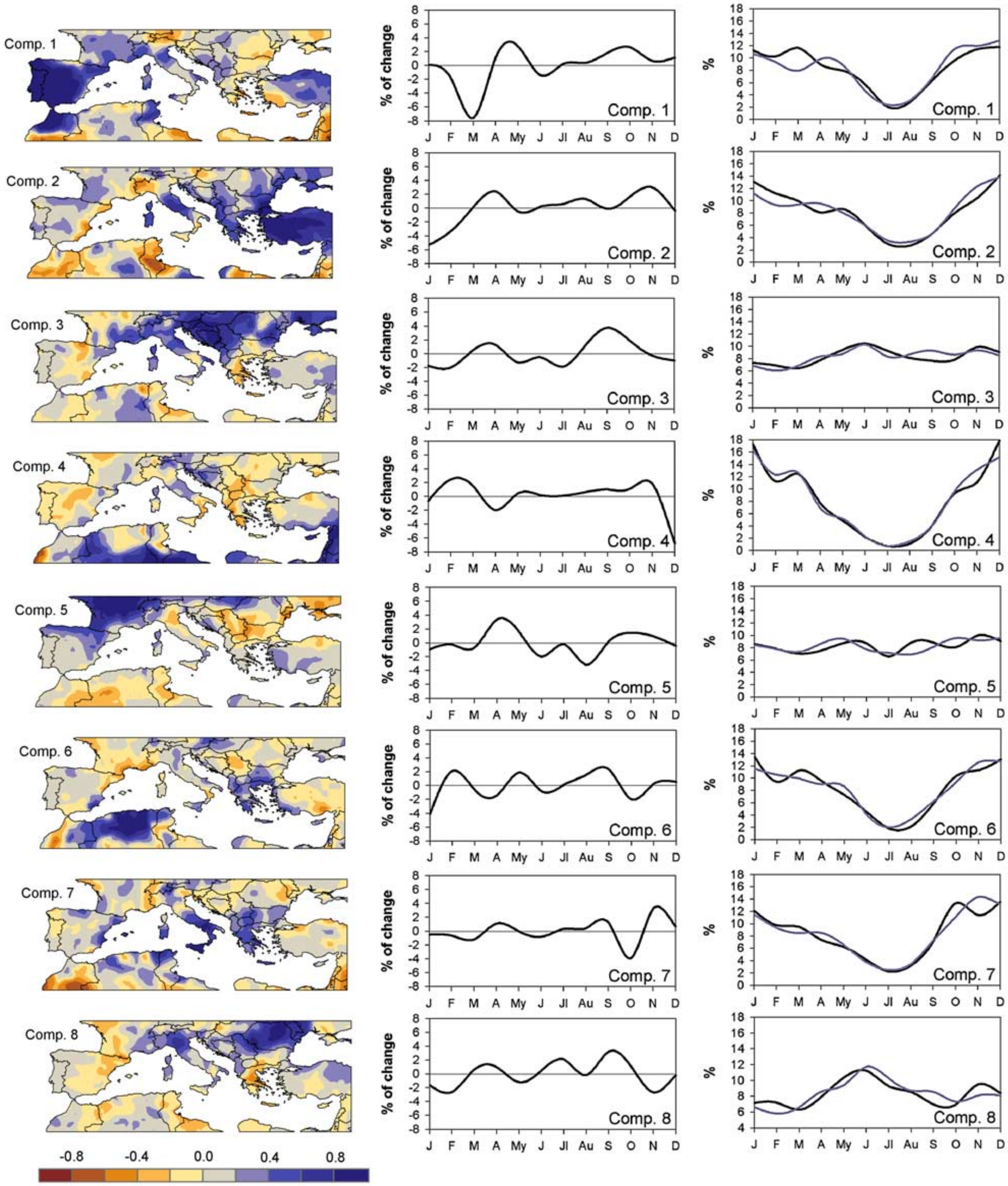

Figure 3. (left) Spatial distribution of component loadings corresponding to each principal component, (middle) percentage change in the areas represented by each component, and (right) precipitation regimes for each region in two different periods. Gray, 1976–2002; Black, 1950–1975.

important trends in precipitation magnitude, no noticeable changes were apparent in the seasonality of precipitation during the second half of the 20th century.

[12] With respect to future decades in the same 8 regions, Figure 4 shows the differences in precipitation regimes between the control period (1960–1990) and the middle of the 21st century (2040–2070), obtained using the nine AOGCMs under the A1B scenario. Figure 4 suggests that the GCMs reasonably reflect Mediterranean precipitation regimes because they accurately reproduce the observed

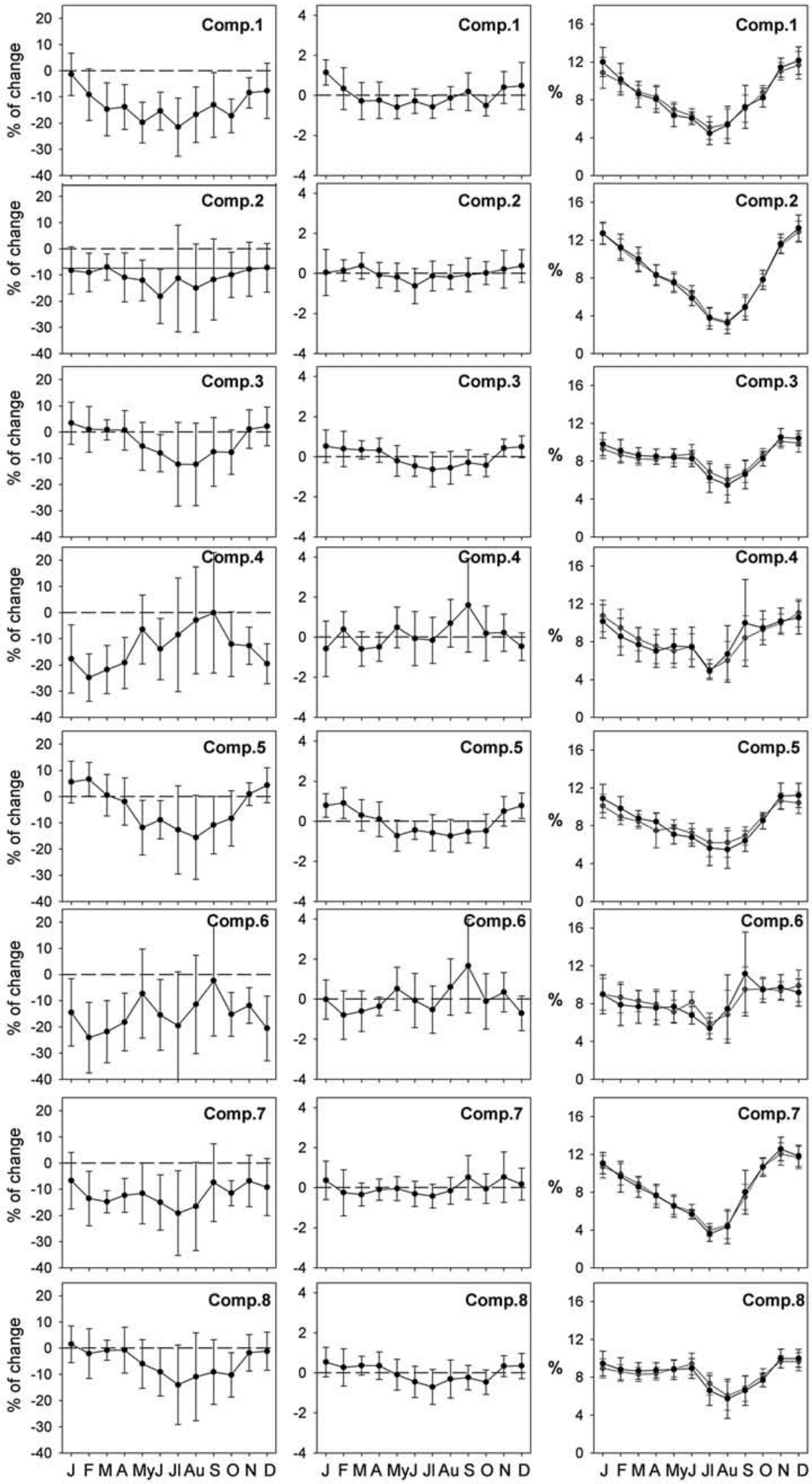

Figure 4. (left) Change in monthly precipitation and (middle) the contribution of each month to total precipitation, and (right) precipitation regimes for each region for the control (black, 1960–1990) and SRES A1B scenario (gray, 2040–2060). The dots represent the intermodel average. The error bars represent the standard deviations for the nine AOGCMs used.

regimes from the CRU TS 2.1 data set, in terms of both the percentage changes and the distributions for each month. The unique exceptions were for Components 4 and 6 (North Africa and Middle East, respectively), in which the observed and modeled regimes show some disagreement.

[13] Despite moderate variations among model outputs, all projections point to a consistent decrease in precipitation in all the regions. The largest predicted decrease is in spring and summer; the exception is most of North Africa and the Middle East, where the main decrease is predicted for winter and spring. Nevertheless, the contribution of the total precipitation to the annual total is not predicted to vary markedly between the control period and the A1B scenario. Only in Africa and the Middle East can any significant changes be expected, as a result of increases in the contributions to precipitation of July, September and the winter months. Thus, there are very few differences in the precipitation regimes for each region between the control period and the A1B scenario, regardless of the predicted decrease in precipitation. Such stability in the precipitation regime is supported by a high level of agreement among the nine models used, as suggested by the low intermodel standard deviation.

4. Conclusions

[14] Previous research has shown significant trends in precipitation across the Mediterranean basin, which is subject to marked seasonal and spatial differences [*Hasanean*, 2004, and references therein], and these are likely to accelerate during the 21st century [*Giorgi and Lionello*, 2008]. In this study we assessed the extent to which reported and predicted shifts in the temporal distribution of total precipitation could affect seasonal precipitation characteristics in the Mediterranean basin, as has recently been detected for widespread areas of the United States of America [*Pryor and Schoof*, 2008]. The results indicate that significant changes in precipitation have occurred in the region, and homogeneous areas were identified in terms of temporal evolution of precipitation. Moreover, GCMs that have reliably simulated the contrasts in seasonality of precipitation throughout the Mediterranean basin consistently predicted a significant reduction in total precipitation, which is more pronounced in spring and summer in most of the basin. Nevertheless, neither data from the recent past nor the simulations for the next decades provided evidence of any marked changes in seasonal patterns of precipitation distribution. It remains clear that the observed trends and predicted changes affecting specific geographical areas and time periods are reflected in the average contributions of each month. However, given that these changes rarely exceed 2%, they are not sufficient to alter overall patterns in the annual distribution of precipitation, despite having localized significance.

[15] Despite the evidence presented here, no immediate conclusions can be drawn about potential changes to the timing of the hydrological response and availability of water resources. Further research is necessary to assess the effect of the main observed and predicted changes in vegetal cover and/or temperature, as these may increase evapotranspiration rates, and lead to a shorter duration of snow cover and earlier melting [*Beniston*, 2003].

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