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European rain rate modulation enhanced by changes in the NAO and atmospheric circulation regimes

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Abstract

The aim of this study is to classify the circulation patterns in the Atlantic-European sector and to reveal linkages between anomalies in the pressure field over the North Atlantic (e.g. North Atlantic Oscillation (NAO)) and its respective circulation pattern occurrence over continents on the one hand and rain fields on the other hand. Changes in atmospheric circulation over Europe during the past 50 years were examined using both objective (modes of low-frequency variability inferred by regression analysis and objective cluster classification of circulation types—fuzzy logic) and subjective (Hess–Brezowsky classification of weather types) methods. The grid monthly geopotential (H700), wind zonal and meridional velocity components (U850 and V850) as well as the surface atmosphere pressure (SAP) and precipitation fields acquired from the NCEP/NCAR reanalysis dataset (for 1948–1998) were employed in this study. Joint regression analysis and fuzzy logic classification of these fields was a basic tool for finding major circulation regimes. The fuzzy set analysis of these fields revealed that the major circulation regimes over eastern North Atlantic and Europe were determined in summer by three vorticity poles: (1) North-western (Scandinavia), (2) Western Mediterranean and (3) Caucasian. It is worth noting that an anticyclone occurred in the western part of the North Atlantic for both seasons. The Scandinavia cyclone area explains rain rate maximums located in the 50–60° latitude European area and the lower rain rate in Southern Europe because of hot and dry African air inflow. In late fall and winter the vorticity system consists of three other poles: (1) North-western, (2) Northern Africa and (3) Northern Russia (Kara Sea). A zonal circulation type dominates in this case and more precipitation is delivered from the Atlantic. Rain rate is more uniformly distributed in the winter in various latitude belts across Europe than in summer, but more intensive precipitation occurred in Southern Europe because of strong moisture transport into this area from Atlantic NAO as well as the substantially larger their magnitude of Arctic Oscillation (AO) indexes in the late 1980s and 1990s during global warming. The atmospheric circulation patterns, which transported very wet Atlantic air, moved northward during last two decades. As a consequence, the climate in Southern Europe became drier and respective rain amounts reduced primarily in the warmer part of year. In contrast, the rain rate increased here in the colder part of the year. This leads to more frequent floods and a wetter climate in autumn/winter.

Keywords: Monthly vector wind and precipitation fields; Atmospheric circulation regimes; Low-frequency oscillation; Fuzzy classification

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1. Introduction

Changes in stream flow patterns over Europe have serious consequences for a wide range of

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human activities in this densely populated region. An appearance of extreme events such as floods or droughts is caused in many cases by persistence of certain circulation type(s). The climate of the European-Atlantic area exhibits considerable variability on a wide range of time scales. A substantial portion is associated with the North Atlantic Oscillation (NAO), a hemispheric meridional oscillation of atmospheric mass with centers of activity near Iceland and over the subtropical Atlantic. NAO-related impact on the winter climate extends from the East coast of the United States to Eurasia and from Northern Africa and the Middle East to the Arctic regions (Wallace and Thompson, 2002a, b; Trenberth et al., 1998; Hurrell, 1995, and references therein; James and James, 1989). An analysis of proxy data of the NAO shows phases of enhanced (active) and reduced (passive) decadal variability (Appenzeller et al., 1998). The growing interest in the NAO is partly explained by the fact that the spatial signature of the observed climate warming during the last century (with a significant increase over the last three decades) resembles the surface temperature anomalies associated with the NAO.

The current climate trend could be partly explained by human activities and by their related increase of concentration in greenhouse gases (Raible et al., 2001). The understanding of the mechanisms sustaining the NAO and their link to global climate change is thus crucial to detect and clearly identify the signature of the latter (Halliwell, 1997; Raible and Blender, 2004). In addition, climate fluctuations at shorter timescales (from week to season) that are related to the NAO (in terms of temperature, precipitation anomalies or preferred storm tracks) affect a large number of human activities, such as the management of energy and water resources and the agriculture and fisheries industry. Therefore, understanding the origin of the NAO and predicting its temporal fluctuations also fulfill a social and economical need.

The aim of this study is to classify the atmospheric circulation patterns in the Atlantic-European region and to reveal linkages between anomalies in the pressure field over the North Atlantic (e.g. NAO) and it respective circulation patterns over continents on the one hand and rain fields on the other hand. Changes in atmospheric circulation over Europe during the past 50 years were examined using both objective (modes of low-frequency variability by regression analysis and objective cluster classification of circulation types—fuzzy logic) and subjective (Hess–Brezowsky classification of weather types) methods.

2. Methodology and data

Statistical analyses provide an empirical knowledge that can lead to more skillful forecasts in the absence of explicit physical understanding. Additionally, acquired information may provide guidance towards identification of the physical process that contributes to or limits the predictability. The choice of using an empirical approach reflects the fact that both simple and complex general circulation models (GCMs), either with prescribed boundary conditions or with actual oceanic coupling, currently do not adequately reproduce the processes of the real atmosphere in the mid and high latitudes at the lead times and averaging periods of concern here. It is not surprising that the seasonal skill score of GCMs may not be the best (Van den Dool, 1994).

One of the main difficulties is actually validating GCM forecasts since a large number of independent prediction cases (al least, equal to a number of the independent grid variables in the model) is required to fully assess their skill. We hope and assume that eventually, with advances in physical understanding, dynamic prediction approaches will outperform statistical ones. Prediction of time-averaged surface climate has received considerable attention over the last two decades. First, the potentially predictable portion of the total variability of a given predicand has been empirically estimated using ratios of predicand variability at different frequencies (Trenberth, 1984). Second, direct attempts at forecasting and verification have been made using analog approaches (Wallace and Gutzler, 1981) and linear statistical approaches with either several preselected predictor elements or whole predictor fields (Barnett, 1987).

The empirical orthogonal functions (EOFs) and singular value decomposition (SVD) are the most commonly used techniques (Fraedrich and Wang, 1993; Vautard et al., 1999) to build a phase space. EOFs are the eigenvectors of the covariance matrix obtained from calculating covariances of time series at different spatial points. EOFs are optimal in explaining as much total variance as possible with any specific number of spatial patterns. The first EOF explains most of the temporal variance in the dataset among all possible spatial fields. The subsequent EOFs are mutually orthogonal (in space