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Statistical and dynamical analyses of atmospheric blocking with an idealized point vortex model

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ABSTRACT

We investigate a reduced point vortex model for a statistical and dynamical analysis of atmospheric blocking phenomena. Thereby, we consider high-over-low and omega blocking as equilibria of two and three point vortices. Based on fields of the kinematic vorticity number, two novel methods, the contour and the trapezoid method, are introduced in order to identify the vortices that form the blocking pattern as well as their local positions and circulation magnitudes. Using an instantaneous blocking index a total number of 347 blocking periods were identified in NCEP-NCAR Reanalysis data for the Euro-Atlantic region during the time period 1990-2012. This procedure provides the basis to corroborate the applicability of the point vortex model to atmospheric blocking in a statistical framework. The calculated translation speed of the point vortex systems associated with the atmospheric blocking appears to match the zonal mean velocity reasonably well. This model explains the stationary behaviour of blocking patterns. A comparison between the theoretical and a statistical model further reveals that the circulation of the blocking high follows the principles of the point vortex model to a large extent. However, the low-pressure-systems behave more variable. Moreover, the stability of point vortex equilibria is analysed regarding the relative distances by considering linear stability analysis and simulations. This reveals, that the point vortex blocking model corresponds to an unstable saddle point. Also, a possible transition between high-over-low and omega blocking situations is indicated. Furthermore, we take viscosity and a Brownian motion into account to simulate the influence of the smaller, subgrid-scale disturbances. As a result a clustering near the equilibrium state emerges indicating the persistence of the atmospheric blocking pattern.

Keywords: Atmospheric blocking, point vortices, kinematic vorticity number, stability analysis, instantaneous blocking index, circulation, vortex identification, vortex pattern recognition

1 Introduction

Blocking events are large-scale, quasi-stationary phenomena that persist from several days to weeks and block the jet stream and thus the westerly flow. In general, a blocked atmospheric flow field is characterized by a mid-tropospheric high pressure system that lies polewards of one or two lows. The pattern is called high-over-low in case of two vortices and Omega blocking in case of three vortices due to the Ω-shaped geopotential height isolines. Rex (1950) was one of the first who defined and studied blocking. Since then many theories have been developed to describe blocking: Charney and DeVore (1979) for example suggested that a metastable equilibrium state can be associated with blocking situations and Shutts (1983) proposed an eddy straining mechanism for the reinforcement and maintenance of blocking. Also many indices have evolved to detect blocked situations mostly in gridded model data. Well-known examples include those from Tibaldi and Molteni (1990) based on geopotential height gradients and from Pelly and Hoskins (2003) who introduced the PV-θ (Potential Vorticity - potential temperature) approach.

The persistent behaviour of blocking often causes extreme weather situations. An example of considerable impact is the Russian heatwave in summer 2010 which was accompanied by extreme rainfall in Pakistan (Galarneau Jr. et al., 2012). Despite their large and manifold impact on our society, numerical weather prediction models as well as climate models still need to be improved to produce adequate behaviour and appearance of blocking: blocking onsets frequently coincide with low forecast skill of numerical weather prediction models (Rodwell et al., 2013; Ferranti et al., 2015) and climate models of-

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