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Atmospheric vortex streets: structure and properties derived from large eddy simulations

Rieke Heinze and Siegfried Raasch
Institut für Meteorologie und Klimatologie, Leibniz Universität Hannover, Germany (heinze@muk.uni-hannover.de)

Atmospheric vortex streets, which are also known as Kármán vortex streets, consist of a double row of opposite rotating, mesoscale eddies and occur in the atmospheric boundary layer. Usually, they develop in the leeward region of steep islands or isolated topographies. Numerous observations reveal that the marine boundary layer is well mixed during the occurrence of a vortex street. It is further characterised by an elevated inversion which lies below the island top and by strong steady winds blowing from a roughly constant direction. For the first time, atmospheric vortex streets were simulated under the realistic meteorological situation of an elevated inversion by means of large eddy simulation (LES). In contrast to mesoscale models which were mainly used in previous numerical studies, LES models resolve the main part of the turbulence spectrum. Thus, it was possible to study the influence of turbulence on atmospheric vortex streets directly. The topography used consists of an idealised island having the shape of a two-dimensional Gaussian distribution.

As the formation and separation of eddies in the wake of large islands depends on the Froude number of the flow, the Froude number was determined by applying the concept of the dividing streamline using profile data. It is known from satellite observations that the vortices span the whole depth of the boundary layer. The high areal resolution of the simulations permits to take a step further and to examine especially the vertical structure of single eddies. Thus, the azimuthally averaged structure of single eddies in a mature state is presented. The calculation of characteristic properties of vortex streets like the distances between cyclonic and anti-cyclonic vortices requires the automatic identification and tracking of the eddies. Hence, appropriate analysis techniques, which are based on horizontal cross-sections, were developed.

The simulation results show that the properties of the vortex streets are almost constant with height and that the eddies extend throughout the whole depth of the boundary layer. The vortices are further characterised by vertical axes, warm cores and pressure minima independent of their sense of rotation. A continuous updraft in the order of 10 cm/s determines the structure of a single vortex. This is associated with a divergent outflow at the vortex' top where a maximum of potential temperature is located which originates from the lowering of the capping inversion due to the flow divergence. This may be responsible for the cloud-free centres of many observed vortices in satellite pictures. The influence of the turbulence on the vortex streets is small. Merely the mean radius of the eddies descends with increasing turbulence indicating a faster decay of the eddies. This can be ascribed to higher mixing which is associated with higher turbulence. Variations of the wind speed in the simulations affect the Froude number of the flow and therewith its character. In addition to a vortex street, a wavy wake could be simulated due to the exceeding of the critical Froude number of the flow.