Abstract

Mesoscale numerical weather prediction models aim to analyse and forecast complex atmospheric processes on scales between one kilometre and hundreds of kilometres. On these scales, divergence becomes comparable and even dominant over vorticity. However, in spite of significant progress in mesoscale numerical weather prediction in recent years, the divergent component of mesoscale dynamics remains elusive in both observations and forecast models. Divergence is not a prognostic variable but needs to be computed from the wind components. In contrary to the global models, the computation of divergence for limited-area models is complicated because the domain boundaries are aperiodic. The present thesis deals with the issues associated with the computation of kinetic energy belonging to the divergent part of the flow (divergent kinetic energy) in limited-area models with focus on the spectral limited-area model ALADIN, which is operationally used in a number of countries including Slovenia.

The scale analysis of the divergent energy distribution is performed by the use of kinetic energy spectra, split into the rotational and the divergent part. Because obtaining the spectra over a limited domain is not a straight-forward task due to non-periodic boundaries, the impacts of several periodization methods are tested both for the ALADIN model and for simulated fields in an idealized framework.

The results with ALADIN show that, if averaging across scales smaller than 300 km, about 50% of kinetic energy in the free troposphere is divergent energy. The percentage of divergent energy increases as the scale decreases, up to the effective model resolution of $7\Delta x$ ($\sim$ 30 km). The vertical distribution of divergent energy contribution shows a maximum in the planetary boundary layer close to the surface ($\sim$ 80% of the total kinetic energy) and a secondary maximum in the mid-troposphere while the absolute maximum ($\sim$ 90%) is found in the stratosphere.

Through most of the troposphere, the kinetic energy spectrum at scales around 100 km and smaller is reasonably well characterized by the $K^{-5/3}$ power-law while in the boundary layer, the spectrum becomes more shallow. At all model levels, the divergent energy spectra are characterized by shallower slopes than the rotational energy spectra and the difference increases as the horizontal scale becomes larger.

The divergent energy quantification in the ALADIN model is compared for two different periodization methods, the extension zone, which is standardly used in ALADIN, and the detrending method. The comparison shows that although the extension zone influences the shape of the spectra at scales above approximately 50 km, a very similar vertical distribution of mesoscale divergent energy is obtained for the two methods.

The problem of achieving periodic boundaries for the purpose of spectral decomposition of variables over a limited area is further investigated through the use of a simple model. The methods under investigation are the ones applied in the ALADIN and HIRLAM models, the Boyd method, the detrending method and the discrete cosine transform. The results show that while the spectra of the last three methods match the theoretically prescribed spectrum well, the ALADIN and HIRLAM methods, which use the extension zone for periodization, introduce additional energy over a variety of scales. The amount and the distribution of the excessive energy depend on the width of the extension zone. These methods are therefore of a limited use when studying the slopes of the model energy spectra and comparing the models with observations.

Last, the spin-up process in ALADIN is presented as viewed through the rotational and divergent energy spectra. It is shown that the spin-up process occurs faster for the divergent energy. The orographic forcing plays an important role in building up the energy spectra during the first hours of the forecast, especially in the planetary boundary layer.

Keywords: kinetic energy spectrum, rotational energy, divergent energy, mesoscale, periodization, ALADIN, spectral limited-area modelling.

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