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Upscale feedbacks through microphysics fields at nesting domains of the MM5 model

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A B S T R A C T

Multi-scale interactions and associated physical processes are common features of the atmospheric flow. Their spatial and temporal behaviour presents a challenge to understand and predict the state of the flow at finer and broader scales. The objective of this study is to focus on capabilities of various parameterisation schemes in the MM5 model to simulate interactions and feedback system at nesting domains. Two-way nesting allows us to track the occurrence and consequence of affecting smaller scale processes explicitly produced at a finer resolution domain to larger scales at a coarser resolution. The quantitative estimations of model errors in two-level nesting domains are compared against the similar ones in a single-level domain. Various combinations of parameterisation schemes for cumulus, PBL, moisture and radiation are used to identify the one that provides the least difference between the model state and reanalysis ERA40 that is considered as the reference state. Basic attributes of model errors are measured to determine spatial structures, vertical profiles and synoptical patterns. The results show that feedbacks from finer to larger scales usually lead to better behaviour in the simulated state. However, this is mainly true for the atmospheric properties characterized by smooth patterns with large scale structure functions such as geopotential and temperature. On the contrary, the humidity model error in the nesting mode is sensitive to the choice of a parameterisation scheme. In some cases feedbacks from finer scale processes simulated in the nesting domains toward larger scales lead to an increase in the model error. This effect is especially remarkable for humidity fields in the middle troposphere.

1. Introduction

The spatial-temporal structure of meso-scale atmospheric fields is among the most complex phenomena known in meteorology, being both highly related and separated for different variables and scales. For example, temperature and geopotential are correlated with each other at ranges of the large scale flow, while non-hydrostatic pressure perturbations and velocity fluctuations are rather sporadic. The precipitation and cloudiness fields additionally show their discontinuity, which does not allow for clear comparison with other variables. Insufficient attention is also being given to dynamical properties of microphysics processes. In particular, the passage of available potential energy released in clouds into kinetic energy of large scale motions is not completely quantitatively evaluated. Such an upscale cascade of energy (Shutts and Gray, 1999) is forced by convective processes at scales from a few to about 100 km.

The meso-scale features considerably complicate the study of atmospheric phenomena. Results of meso-scale numerical modeling are highly sensitive to physics and dynamical parameters in models. Mittermaier (2007) studied inconsistencies between high-resolution precipitation forecasts, which can vary considerably from run to run. He found that the time-lag ensemble performs better at or near the grid scale, and that there is a strong case for recalibration. Termonia and Hambi (2007) reviewed the physical-dynamics coupling in the core of spectral models and generalized the relation between physics parameterisations and model structures. They classified reasons that lead to the deviating

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of the model state from the real atmospheric state. Among them are the physics parameterisations, dynamical cores of models and a space–time location of the physics coupling on a Lagrangian trajectory. Minder et al. (2008) pointed out that while the model shows excellent skill in simulating small-scale patterns at a seasonal time-scale, major errors exist for individual storms. Gray and Dacre (2008) studied the impact on banded frontal clouds of model representation of convection. Experiments using the standard or modified schemes for convective processes demonstrated known problems with the use of parameterisation schemes at the 4 km grid length. Hohenegger et al. (2008) explored cloud-resolving ensemble simulations for cases of heavy precipitation. In general, the resolution-induced differences tended to be smaller than typical member-to-member variability. Differences between ensembles can be tied to forms of precipitation (stratiform or convective) located within the particular synoptical pattern and meso-scale interaction of the flow with orography. Zangl (2007) investigated the factors which control the structure and amplitude of the small-scale precipitation variability and found that the ambient wind direction had the largest impact on those patterns. The correlation of simulated patterns with the observational data degraded when the ambient wind speed diverged from its real value, but impact is not as large as for the wind direction. A less systematic impact was found for temperature. When choosing large scale flow conditions that approximately match the real observations, the pattern correlation with the observed rain-gauge data becomes as high as for the best simulation.

The evidence of rapid growth and upscale evolution of the contaminating signal from the meso-scale to synoptical scales was shown in (Hodyss and Majumdar, 2007). After just a few hours, an amplifying signal manifests itself in locations along the midlatitude storm tracks where moist instability exists. This signal may arise from errors in the initial and boundary conditions as well as from a model formulation. Andersson et al. (2007) assessed the global analysis and forecast impact of observed humidity. They found that humidity data have a significant impact extending into the medium range (5–6 day forecasts), with a marked impact also on the wind and temperature fields. This contradicted some previous studies that have shown insignificant impact of humidity observations in general. They also reported that different humidity data sets have opposite bias impacts in the boundary layer resulting in local influence on precipitation with respect to the model.

The above evidence shows the complexity in description of cross-scale interactions and physics behind them and in the difficulty in simulating them in models. Approaches used for parameterisations of model physics are based on different assumptions and their fitness depends on particular region, season, variable and many other factors. Although numerical experiments can provide complete information about energy, heat and mass fluxes, it is actually impossible to search details of interaction between scales. This can be evaluated only implicitly, in particular through power spectra.

The main goal of this study is focused on the generalized impact from meso-scales to large scale flow. We examine model fields simulated with the same initial and boundary conditions in both the single and two-way nesting domain modes. This allows us to compare statistics of systematic model errors estimated on a single domain of a coarse resolution against statistics obtained on the same domain but with the nesting domain switched to a finer resolution, where meso-scale processes are simulated explicitly. The hypothesis is built on the suggestion that feedbacks from the nesting domain may change large scale patterns and be estimated through changes in systematic model errors. We compare various diagnostics for the errors including standard deviations, average differences and vertical profiles. The other approach used in this study is power spectral analysis and filtering. Changes of spectra on meso-scales after the explicit simulation of finer scale processes at the nesting domain are investigated. The paper is arranged in the following manner. Section 2 describes the numerical experiment design. In section 3, the results of numerical experiments and impact from the nesting domain are discussed. The conclusions are given in the last section.

2. Numerical experiments

2.1. The area and atmospheric state outline

In the present study the central part of the North Atlantic is considered. This area was selected due to the following reasons. First, the ocean surface is flat and this excludes the complicated orographic impact. Second, at this part of Atlantic there are no considerable contrasts in sea surface temperature of the global or regional scales, which may determine different regimes of air-surface interaction. This allows us to focus on atmospheric processes themselves within a particular synoptic pattern, while impact from changes on the surface has the secondary importance.

The runs have been integrated for the winter season of the year 2002. One characteristic feature of that period over the North Atlantic region was a rapid change in the atmospheric flow associated with a chain of cyclonic eddies. The cyclones moved north-eastward from the North American coast, while a strong anticyclonic ridge prevailed over the Western Europe till mid-January. In the rest of the season, particularly in February, the atmospheric flow was typically meridional, with deep, fast midlatitude cyclones (whose mean speed was about 40–50 km/h) and injections of high pressure ridge from the subtropics. As a result, the influx of warm tropical air masses to midlatitudes has generated new eddies and reinforced the existing ones. The largest and most powerful cyclone developed on 1–2 February 2002. It covered most of the North Atlantic and occupied the entire troposphere. The sea level pressure in its center dropped to 945–950 hPa. The strong interaction between the contrasting cold air mass and warm water surface supported intensive convection and developed extensive cloud fields.

Special attention has been paid to the particular synoptic pattern that occurred on 21–22 January. An extensive low pressure system accompanied by frontal systems and surface troughs affected the area during these days (Fig. 1). The intensive cyclone stretched throughout the entire troposphere and rapidly moved to the east. The central pressure value deepened from 974 to 960 hPa during 24 h. Intensive transport of warm air from the south toward the front line of the cyclone was occurring. Interaction of cold air of continental origin with the warm ocean surface supported