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Impact of upstream flow conditions on the initiation of moist convection over the island of Corsica

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ABSTRACT

The influence of upstream flow on the initiation of moist convection over Corsica is investigated using semi-idealized simulations. The simulations, performed with the Consortium for Small-scale Modeling (COSMO) model, are initialized with one vertical profile at all grid points and under constant boundary conditions. The upstream wind velocity and wind direction, as well as the saturation deficit and stability, are systematically varied to estimate the impact of the individual factors on the initiation and strength of moist convection. Also, the influence of radiation is evaluated. It is found that deep convection can only develop with high solar radiation. With lower radiation, thermal wind systems are weak, and only shallow convection is triggered. Results show that with strong solar radiation, a strong upstream wind velocity is less efficient in triggering deep convection than a weaker one. This is due to the dynamic effects on the flow field. A low upstream wind velocity enables thermal wind systems to become dominant and the preconvective conditions for deep convection are more favorable. This leads to more events with deep convection and precipitation. The wind direction can be the determining factor for the initiation of deep convection and also controls the location of precipitation. A change of just 15° can decide on whether deep convection occurs or not. With a high upstream wind velocity, the location is always on the lee side of the island. With a lower upstream wind velocity, two hot spots for convection initiation, one in the northern central part and one in the western part of the island, are identified. It is further found that the impact of saturation deficit is higher than the impact of stability. With increased instability, the atmospheric conditions are more favorable for the development of convection, but the high saturation deficit in the middle troposphere prevents the formation of deep convection. Through reduction of the saturation deficit, multiple convective cells can develop in the more humid atmosphere. Additionally, the integrated water vapor is larger, which means that more precipitable water is available allowing larger amounts of precipitation.

1. Introduction

During late summer and fall, several heavy precipitation events (HPE) generally occur in the Mediterranean every year. They can cause flash floods or landslides and therefore affect people and the economy. The frequency of HPE with precipitation >128 mm d^{-1} e.g. in Italy has been increasing by a factor of four since 1950 and the fraction of precipitation with over 32 mm d^{-1} has been increasing from 23% to 32% (Alpert et al., 2002). Similar results were found by Homar et al. (2009) for the Balearic Islands, where the contribution of HPE to the annual rainfall increased, whereas moderate rainfall decreased. Although a reliable forecast of HPE would be very important, its skills are still fairly limited (e.g. Ducrocq et al., 2013). To improve the forecasting skills, a better understanding of the involved processes is essential.

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Therefore, the project Hydrological Cycle in the Mediterranean Experiment (HyMeX) was initiated, including measurements in the Mediterranean area (Ducrocq et al., 2013). HyMeX aims at a better understanding and quantification of the hydrological cycle and related processes in the Mediterranean, with emphasis on high-impact weather events, inter-annual to decadal variability of the Mediterranean coupled system, and associated trends in the context of global change (Drobinski et al., 2013).

To investigate HPE in Italy and southern France, the island of Corsica serves as an ideal observational site, because it is located in the near upstream area of the flow finally leading to these events (Lambert et al., 2011). The island is also large enough to generate a significant land-sea contrast and has a high mountain chain, to initiate and modify deep convection. Therefore, the Institute for Meteorology and Climate Research (IMK) of the Karlsruhe Institute of Technology (KIT) deployed a mobile multi-sensor observing platform (KITcube) in Corsica (Kalthoff et al., 2013). IMK focuses their investigations on the impact of thermal wind systems on the development of deep convection over Corsica.

Deep convection is often triggered by thermally induced wind systems with accompanied convergence and lifting in the boundary layer (Kalthoff et al., 2009). Such thermally induced wind systems occur due to surface inhomogeneities like orography (Kalthoff et al., 2009), land–sea contrast, land use or soil moisture (Barthlott and Kalthoff, 2011). In mountainous regions, upslope winds can also trigger deep convection, because they converge over the mountain crests and moist air masses from the boundary layer may penetrate into the free atmosphere (Whiteman, 2000). Hill et al. (2010) found a connection between the initiation of thunderstorms and sea breezes, which leads to an intensive moisture transport inland. These moist air masses and the thermally induced convergence zones make islands to favored locations for thunderstorm development (Golding, 1993; Qian, 2008; Barthlott and Kirshbaum, 2013). Mountainous islands are therefore very effective in triggering deep convection, especially when valley winds and sea breezes are in phase with each other, so that they strengthen the diurnal cycle of winds and form convergence zones (Kottmeier et al., 2000). Idealized studies often served to analyze the development of thunderstorms over islands and the connected processes, like land and sea breezes. Idealized island geometry or the influence of island height were investigated (e.g. Mahrer and Pielke, 1977; Mahrer and Segal, 1984; Arritt, 1993; Robinson and Sherwood, 2008) or case studies with realistic topography for one synoptic situation (Barthlott and Kirshbaum, 2013) were performed. The results of these studies show that the island size strongly influences the strength of convection over the island and that circular islands are more effective in triggering convection than elongated ones, because they generate stronger low-level convergence and therefore stronger updrafts.

Besides supporting observational studies, the simulations discussed in this paper mainly serve to investigate the dependence of convective precipitation over Corsica on atmospheric conditions. Especially the influence of stability, saturation deficit, upstream wind velocity and wind direction is analyzed. Therefore, we perform semi-idealized numerical simulations using realistic orography and systematically vary the initial and boundary conditions. The aims addressed in this paper are: (i) The sensitivity of the initiation of deep convection on the variation of the upstream wind direction and the influence of the strength of the upstream flow on the development and strength of convective precipitation events, (ii) the comparison of governing factors like stability and saturation deficit, and (iii) the dependence of convection initiation on the strength of solar radiation.

2. Model setup

2.1. Model description

The numerical simulations were performed with the Consortium for Small-scale Modeling (COSMO) model. It is a three-dimensional, non-hydrostatic weather forecasting model based on the primitive thermodynamic and hydrodynamic equations, which is used by the German Weather Service (Deutscher Wetterdienst, DWD) and several other European weather services. We used model version 4.21, but instead of the conventional use with initial and boundary data coming from a coarser-scale model, we initialized the simulations with one vertical profile for all grid points. The profile was distributed to the simulation domain by applying the module "ARTIFCTL". This module was developed by the DWD to run the COSMO model with different idealized setups, such as idealized orography, constant thermodynamic fields, constant surface fields or artificial convection triggers.

A horizontal grid spacing of 2.8 km allowed the explicit representation of deep convection, and shallow convection was parametrized using a modified Tiedtke scheme (Tiedtke, 1989). The number of terrain-following vertical levels was set to 50. We used a multi-layer soil vegetation model TERRA-ML (Doms et al., 2011) to represent the coupling among atmosphere and land surface. Radiation was parameterized with a scheme by Ritter and Geleyn (1992). The simulation time was 24 h and after 4–5 h, spin up effects disappeared in the model data output. The model domain has a horizontal scale of 450×450 km^2 (161×161 grid points) and covers Corsica and the surrounding Mediterranean (Fig. 1a). Corsica is approximately 80×180 km^2 (1597 grid points) in size and a mountain ridge extends from northwest to southeast with a maximal height of 2249 m above mean sea level (amsl) in the model (Fig. 1b). The real maximal height of Corsica is 2706 m amsl.

2.2. Sensitivity studies

As Sardinia has an effect on the meteorological conditions in Corsica (Barthlott and Kirshbaum, 2013), this island was removed from all model runs. Soil and vegetation fields, e.g. soil temperature, soil water saturation, plant cover and leaf area index, were taken from a model run performed in a COSMO standard configuration for the 26th of August 2009, with initial and boundary conditions from a 7 km COSMO-EU analysis.

To achieve stationary conditions for comparison of the different model runs, solar radiation was set constant at the top of the atmosphere with low, moderate and high values of solar radiation, corresponding to 0, 7 and 12 UTC on the 26th of August 2009.