Hindcast experiments of the derecho in Estonia on 08 August, 2010: Modelling derecho with NWP model HARMONIE

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A B S T R A C T
On August 8, 2010, a derecho swept over Northern Europe, causing widespread wind damage and more than 2 million Euros in economic loss in Estonia during its most destructive stage. This paper presents a modelling study of the derecho-producing storm utilising the Hirlam Adalin Research for Mesoscale Operational Numerical Weather Prediction in Europe (HARMONIE) model. The model setup is chosen to mimic near-future, nearly kilometre-scale, operational environments in European national weather services. The model simulations are compared to remote sensing and in situ observations. The HARMONIE model is capable of reproducing the wind gust severity and precipitation intensity. Moreover, 2.5-km grid spacing is shown to be sufficient for producing a reliable signal of the severe convective storm. Storm dynamics are well simulated, including the rear inflow jet. Although the model performance is promising, a strong dependence on the initial data, a weak trailing stratiform precipitation region and an incorrect timing of the storm are identified.

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1. Introduction

On August 8, 2010, a derecho hit Northern Europe. The storm moved over Belarus, Lithuania, Latvia, Estonia and Finland. The convection formed before 09 UTC on August 8 in Belarus, and the storm reached Central Finland at 02 UTC on August 9 (Tömä et al., 2013). The storm formed the derecho near the border between Lithuania and Latvia; the strongest wind gusts (up to 36.5 m/s) were measured in Estonia. The Former Estonian Meteorological and Hydrological Institute (EMHI), now the Estonian Environment Agency (EtEA), issued only a general thunderstorm warning because the numerical weather prediction (NWP) model guidance did not suggest a severe storm of this magnitude. Fig. 1 shows the NWP guidance available operationally in EtEA during the derecho event. Operational High Resolution Limited Area Model (HIRLAM) in EtEA forecasted about 5 mm precipitation in Estonia and wind gusts only up to 12 m/s were forecasted (Fig. 1). Stronger wind gusts (up to 20 m/s) were forecasted in the area to the east of Estonia. In reality more than 15 mm precipitation was measured in several ground stations (Fig. 7) and wind gusts more than 30 m/s were observed in Estonia (Fig. 8).

Today’s definition of derecho is derived from Johns and Hirt (1987) who defined criteria to indentify derecho events. The path length of wind gusts must have a major axis length of at least 400 km and no more than 3 h can elapse between successive wind damage (gust) events. The convective storm on August 8, 2010, met the criteria to be classified as a derecho. The word derecho refers to the straight-line winds caused by a mesoscale convective system (MCS) where downbursts are present. Severe wind gusts produced by a derecho are associated with certain type of MCSs: typically, the radar echo is either a line or bow echo. Johns and Hirt (1987) categorised derechos into progressive and serial types. The derecho that moved across Estonia was progressive, meaning that only one wind system advanced in space. Severe, derecho-type thunderstorms are rare in Northern Europe.
Europe. There has only been one previously documented derecho event in Northern Europe, occurring in 2002 in Finland (Punkka et al., 2006). However, there have been several documented derecho events in Central, Western and Southern Europe (e.g., Gatzen, 2004; Gatzen et al., 2011; Hamid, 2012; López, 2007; Pučík et al., 2011; Gospodinov et al., 2014, 2015; Celiński-Mysław and Matuszko, 2014). Atmospheric conditions during derecho events and climatology of derechos have been widely studied in the United States (e.g., Evans and Doswell, 2001; Coniglio et al., 2004; Coniglio and Stensrud, 2004).

Current non-hydrostatic NWP models have been successful at resolving convective processes; the explicit treatment of convection enables the models to simulate organised convection and MCSs (Done et al., 2004). According to Weisman et al. (1997), 4-km horizontal grid spacing is often sufficient for realistically simulating deep convection. However, the quality of modelled dynamics can still be improved with increased horizontal resolution (e.g., Bryan and Morrison, 2012). The system averaged fluxes of heat, moisture and momentum are realistically resolved with the explicit treatment of convection with 4-km horizontal grid spacing and in the system averaged sense MCS structure is more successfully resolved by the explicit configuration (Weisman et al., 1997). However, as shown by Bryan et al. (2003), resolution in order of 100 m provides more realistic perspective on the processes that occur in deep moist convection and is needed to have more realistic simulation. For example, 100 m resolution may be needed to enable the physical process of cloud turbulence and cloud entrainment.

An important aspect of MCS evolution is the development of a cold pool. In order to successfully simulate derecho producing MCS, the cold pool needs to be resolved by the model. Models in which deep convection is parameterised perform poorly in simulating cold pools, which is important for triggering new convective cells (Weisman et al., 1997). Microphysical parameterisations play an important role in simulating cold pool development. While warm cloud microphysics is able to simulate the cold pool generated by the evaporative cooling, a mixed-phase parameterisation helps to improve the simulation quality (Gilmore et al., 2004; Liu and Moncrieff, 2007). Moreover, bow echo simulations are sensitive to the graupel parameterisation through its effect on cold pools (Adams-Selin et al., 2013).

Fig. 1. EeA HIRLAM model forecast from 08.08.2010 00 UTC initialisation: a) 24 h accumulated precipitation (mm); b) wind gusts (m/s) in last 6 h at 18 UTC.

Fig. 2. Main modelling domain (elevation above mean sea level (m)).
The added value of explicitly treating convection in MCS simulations is described in, e.g., Done et al. (2004). Done et al. (2004) investigated daily convective forecasts using the Weather Research and Forecasting (WRF) model with 10-km grid spacing and parameterised convection vs. 4-km grid spacing with explicit convection. The MCS dynamics were more successfully resolved in the explicit forecasts. For parameterised convection experiments the precipitation fields often failed to show system structure whereas 4-km grid spacing enabled a better distinction of convective system attributes such as the presence of bow echoes. Furthermore, Weisman et al. (2008) concluded that 4-km explicit forecasts often realistically resolved MCS structure and evolution.

Derechos have been numerically simulated in previous studies (e.g., Bernardet et al., 2000; Bernardet and Cotton, 1998; Simon et al., 2011; Weisman et al., 2013; Evans et al., 2014; Fierro et al., 2014). Weisman et al. (2013) described successful numerical simulations of the superderecho on May 8, 2009. The WRF model with 3-km resolution and explicit treatment of convection was able to simulate important storm features.

Limited-area NWP models have been actively developed to achieve operational capabilities near kilometre scales. A major effort in European NWP community is the development of the near kilometre scale Hirlam Aladin Research for Mesoscale Operational NWP in Europe (HARMONIE) model. HARMONIE is a spectral model with a dynamical core based on the non-hydrostatic fully compressible Euler equations (Bubnova et al., 1995). Essentially the same dynamical core has been used in the operational AROME (in French Applications de la Recherche...
à l’Opérationnel à Meso-Echelle) model in Meteo-France since 2008 (Seity et al., 2011). Moreover, HARMONIE is running in an operational or pre-operational phase at many national weather services of the HIRLAM consortium.

Earlier bow echo modelling case studies running the HARMONIE (AROME) NWP model were presented by Groenland and Tijm (2011) and Roulet (2011). Groenland and Tijm (2011) modelled the bow echo event on July 14, 2010, in the Netherlands, showing that the simulated wind gusts were consistent with observations. On May 13, 2009, a bow echo was forecasted by the operationally running AROME model in Meteo-France (Roulet, 2011), providing a good example of how mesoscale model output can be useful for issuing appropriate severe wind gust warnings.

The primary goal of this study is to present the successful application of the HARMONIE NWP model for simulating a severe convective storm in the Baltic Sea region. This study presents modelling results of the derecho event using a high-resolution non-hydrostatic model, analyzes the storm evolution, investigates the effect of initial data and discusses the potential of high-resolution NWP models to forecast similar events. In Section 2, the models and the numerical experiment design are described. The results of the numerical experiments are presented in Section 3.

2. Model and methods

The main derecho simulation was performed with 2.5-km grid spacing. This is the resolution that will be used in future high-resolution NWP environment of EtEA. Moreover, this resolution is sufficient to be outside the standard convective grey scale, where deep convection must be partially parameterised. Even though there are still aspects of convection that are not well resolved at this grid spacing like cloud turbulence and cloud entrainment (Bryan et al., 2003), it is often sufficient to simulate MCSs (Weisman et al., 2008).

The main modelling domain contains 540 zonal and 1200 meridional grid points, with 2.5-km grid spacing and 65 vertical levels; 20 levels are below 1 km. The time integration method employed is the two time level, semi-implicit, semi-Lagrangian scheme (Bubnova et al., 1995). The model grid is in the Lambert Conformal Conic projection, with both main latitudes at 58.5°N and the domain centre at 58.5°N and 24.5°E. The main modelling domain is presented in Fig. 2. Some simulations were performed with a smaller domain (not shown) with similar results to the main domain simulations. In Fig. 2, the Väike-Maarja meteostation and Sürgavere and Harku radars are shown with blue dots. 24-hour forecasts were computed with a 60-s time step starting at 00 UTC on August 8, 2010.

The HARMONIE model version 37 h1.1 was run with AROME physics (Seity et al., 2011) and high horizontal resolution with explicit treatment of the deep convection. In HARMONIE, twelve prognostic variables are formulated: two horizontal wind components, temperature, specific humidity, rain, snow, graupel, cloud water, ice crystals, turbulence kinetic energy and two non-hydrostatic variables associated with pressure and vertical momentum. A mass-based terrain-following hybrid vertical coordinate system is used. A mixed-phase single-moment cloud microphysics scheme is applied (Pinty and Jabouille, 1999).

HARMONIE data assimilation may have an effect on the modelling results. For example, the same storm was modelled with the AROME model at Finnish Meteorological Institute (FMI) during a satellite data assimilation study (Perttula et al., 2012). The vertical humidity and thermal profiles were assimilated from Meteorological Operational Satellite (METOP) Infrared Atmospheric Sounding Interferometer (IASI). In the simulations with and without METOP IASI measurement assimilation, similar storm geographical locations were calculated. However, assimilating METOP IASI measurements formed a more pronounced storm and stronger winds. In our study, we focus on the dynamic model aspects; data assimilation is left for further research.

No independent data assimilation was performed in the HARMONIE forecasts and HARMONIE model was nested in HIRLAM (Unden et al., 2002) output. For the main modelling results, the 0.15° resolution output from the Regular Cycle of the Reference HIRLAM (RCR), which runs as the operational model of the FMI, was used as initial and boundary conditions. Some experiments were performed using operational HIRLAM output from EtEA (EMHI-ETA) with 0.1° resolution to investigate the forecast quality dependence on the initial conditions.

Dynamic formulations of the HIRLAM models (i.e., RCR and EMHI-ETA) are similar and both HIRLAM models are nested in the European Centre for Medium-Range Weather Forecasts (ECMWF) global model. There are some technical data assimilation differences in the two HIRLAM NWP environments (Yang, 2008). In the RCR environment, unlike in EMHI-ETA,
Large Scale Mixing is used, meaning that during the assimilation step, large-scale synoptic patterns are derived from the ECMWF global model. Moreover, a four-dimensional variational analysis assimilation scheme is applied in the RCR environment and more satellite measurements are assimilated compared to the three-dimensional variational analysis scheme utilised in the EMHI-ETA environment. The biggest impact causing the differences in the initial and boundary condition

**Fig. 5.** Precipitation intensity (mm/h) from the Sürgavere and Harku radars (locations marked with filled circles) in the left panel. Simulated precipitation intensity (mm/h) in the right panel. The radar image resolution is higher (500 m) than the simulations (2500 m).
sensitivity, appearing in the results below, originates most likely from the increased amount of the satellite measurements.

The storm location and timing were detected from Meteorological Satellite (METEOSAT) instrument Spinning Enhanced Visible and Infrared Imager (SEVIRI) visible channel images and radar images from Estonia. Moreover, storm intensity and kinematics were compared with wind and precipitation measurements from automated ground observations in Estonia and the Sürgavere and Harku dual polarisation Doppler radars. The Sürgavere and Harku radar locations are shown in Fig. 2. For precipitation intensity and wind comparisons, Constant Altitude Plan Position Indicator images at 500-m altitude were used.

3. Modelling results

3.1. Modelled life cycle and intensity of the storm

Realistic storm evolution was simulated by the HARMONIE model starting the simulation at 00 UTC on August 8, 2010, and using the RCR environment analyses of FMI output as boundary conditions. In this section results from simulation with NWP analyses from RCR environment as boundary conditions are presented. However, the simulation with RCR environment forecasts as boundary conditions shows very similar results.

To provide an overview of the temporal evolution and geographical path of the storm, location of the storm is shown on visible channel satellite images together with the pseudo visible satellite images simulated by the HARMONIE model in Fig. 3. Moreover, the storm locations in the simulation, determined by the simulated 10-m wind gust area (simulated gusts are stronger than 20 m/s during last 30 min) in every 2 h, are presented in Fig. 4. The simulated geographical storm path corresponds rather well with the observed path described in Törmä et al. (2013) until the storm reaches the Gulf of Finland. Clouds associated with the storm are seen at 07 UTC at the border of Belarus and Ukraine in both satellite image and model output (Fig. 3). At 17 UTC the storm is at the northern coast of Estonia on satellite image and at the southern border of Estonia according to simulation. Wind gusts stronger than 30–35 m/s are observed from 14 to 18 UTC in simulation (Fig. 4). This appears to be the most intense stage of the storm, coinciding well with the description in Törmä et al. (2013). However, after crossing Estonia, the simulated results and observations disagree as the simulated storm dissipates over Southern Finland. According to the observations, the storm reached 66°N latitude in Central Finland at 02 UTC on August 9, 2010 (Törmä et al., 2013).

To compare the simulation results with observations, precipitation intensity measurements from the Sürgavere and

![Fig. 6. Precipitable water (mm) at 12 UTC a) in HARMONIE simulation and b) in RCR HIRLAM analysis.](image)

![Fig. 7. Simulated 24-h accumulated precipitation (mm) in Estonia on August 8, 2010 (shaded). Ground-based measurements are shown with numbers if the precipitation exceeds 2 mm.](image)
Harku Doppler radars are plotted with the model output in Fig. 5. Fig. 5 describes the precipitation intensity at the storm’s most destructive stage. On radar images bow echo (width 150–200 km) associated with progressive derecho is detected. Convective line and expanding stratiform precipitation region behind it are observed. The precipitation intensity appears

![Radar Images](image)

**Fig. 8.** Sürgavere and Harku radar (locations marked with filled circles) radial Doppler winds (m/s) in the left panel. Simulated 10-m wind gusts (m/s) during the last 30 min (shaded) and observed maximum 10-m wind gusts at ground stations during the last 60 min (numbers) in the right panel.

Fig. 5 shows that the modelled instantaneous convective precipitation rate is between 1 and more than 9 mm/h near the convective line; the radar reflectivity-derived precipitation rates exceed 20 mm/h. Moreover, the simulated trailing stratiform precipitation, a precipitation region behind the main convective line with precipitation intensity less than 1 mm/h in the simulation, is weak compared to the radar observations.

Weak trailing stratiform precipitation is found in the simulation compared to observations (Fig. 5), most likely resulting from the single-moment microphysics scheme (Pinty and Jabouille, 1999) used in HARMONIE. Double-moment schemes predict number concentrations in addition to the mixing ratios for each precipitation species. Morrison et al. (2009) investigated the influence of double-moment vs. single-moment microphysics schemes implemented in the WRF model (Skamarock et al., 2007). Single- and double-moment simulations were similar. However, the double-moment scheme resulted in stronger and more pronounced trailing stratiform precipitation. This was primarily caused by weaker evaporation in the stratiform region in the double-moment scheme forecast. In our simulations, the single-moment scheme may have caused excessive evaporation in the stratiform region, resulting in weak trailing stratiform precipitation.

The model simulates the storm life cycle rather well. The simulated storm is approximately 1 h late compared with the observations. However, this can still be considered to be a satisfactory result. The modelled average storm propagation speed is 25 m/s, similar to the radar observations. Only approximately 2 h is required for the storm to move from Estonia’s southern border to the Gulf of Finland. The storm turns cyclonically from a north–south trajectory at the northern Estonia coast, similarly represented in both the simulation results and radar observations.

The main shortcoming in the simulated precipitation is the early dissipation of the simulated storm visible in Fig. 5 panels c and f. In addition, the simulated convective precipitation area in simulation is situated on the western side of the storm over Estonia while on radar images it is equally present on both sides of the storm. In the western Estonia higher amount of the available precipitable water is detected similarly in the HARMONIE forecast and RCR HIRLAM analysis (Fig. 6). In Eastern Estonia HARMONIE model forecasts too low precipitable water amounts compared to the RCR HIRLAM analyses. According to RCR HIRLAM analyses precipitable water amounts were 32–36 mm and according to HARMONIE simulation 26–30 mm in Eastern Estonia. Too dry air over Eastern Estonia in the simulation may be the reason for the lower rain rates in this region.

Simulated 24-h accumulated precipitation is compared to ground observations over Estonia in Fig. 7. Fig. 7 shows that simulated 24-h accumulated precipitation associated with the storm that swept over the Estonian mainland on August 8, 2010, is mainly between 5 and 15 mm and occasionally over 15 mm in the Western Estonia. Moreover, the 24-h accumulated precipitation exceeds 10 mm at several automated stations in Estonia. In Eastern Estonia, precipitation is up to 10 mm according to the observations. However, very little precipitation is predicted in the simulation. Therefore, the exact location of the storm-associated precipitation is not precisely forecasted. The reason for low precipitation amount in Eastern Estonia may be the lower amount of precipitable water in HARMONIE simulation compared to RCR HIRLAM analyses in this region (Fig. 6).

Wind damage caused by the storm is caused by convective wind gusts. The strongest measured 10-m wind gusts exceed 15 m/s over a wide area. The width of the strong wind gust area (more than 150 km) is similar to the width of the storm on the radar. The strongest measured 10-m wind gust is 36.5 m/s at 17 UTC in Väike-Maarja; the location is marked in Fig. 1. However, the automated stations are too sparsely positioned to provide good spatial coverage of high storm-associated winds.

To compare simulated wind gusts with observations, the radial wind speed measurements from the Sürgave and Harku Doppler radars are plotted with the simulated 10-m wind gusts in Fig. 8. The parameters are not exactly comparable; however the geographical distribution of strong winds in the radar image coincides fairly well with the simulated strong wind gust area. The times in images of the radar and model data are different as the simulated storm is approximately 1 h late compared with the observations. Fig. 8 shows that the simulated storm-associated 10-m wind gusts are 25–35 m/s, similar in magnitude to the radar maximum winds at the gust front. The strongest 10-m wind gusts measured at automated stations are 25–35 m/s, which agrees very well with the model results. The area with strong gusts during the last 30 min is approximately the gust front path in that time. The geographical location of the highest measured wind speeds in Estonia at 17 UTC is in satisfactory agreement with the simulated results. The strongest modelled wind gusts are in the middle of the storm, coinciding with the strong rear inflow jet (RIJ). It appears that the RIJ is evident in the model data in Fig. 10 and possibly in the radar velocity data in Fig. 11. Strongest gusts in the middle of the storm (up to 30 m/s) are also seen on radar images.

Fig. 9. Simulated wind shear modulus (m/s) at 18 UTC between the 700-hPa and the 1000-hPa pressure levels (shaded); wind vectors at 700 (1000) hPa are in blue (magenta).
winds image at 15:50 UTC. Therefore, the simulation can successfully predict wind gust intensity and the approximate location of the most severe gusts and gives much better forecast compared to the HIRLAM model (Fig. 1) used for the operational forecast in EtEA at the time of the storm.

3.2. Modelled storm features

Common features of severe convective storm, such as convectively driven updrafts and downdrafts, near-ground high pressure and cold pool and low pressure in the mid troposphere as well as a rear inflow jet were predicted by the model. The presence of wind shear is investigated in the simulation because the convective storm type is largely determined by the magnitude and altitude of the wind shear (Weisman and Klemp, 1982). Fig. 9 shows that the 1000 hPa level wind direction is variable, and a nearly uniform southerly flow is present at 700 hPa. Simulated mean wind speeds at the 700 hPa level are 15–25 m/s in the corridor where derecho occurred (not shown). The wind shear modulus is greater than 10–15 m/s in the south–north oriented corridor along the storm path. Simulated wind shear modulus between the 700 and 500 hPa levels is less than 5 m/s (not shown). Wind shear needed for convective organisation is typically found in the lower atmosphere during derecho events; typical wind shear is 15 m/s between 700 hPa and the ground (Weisman, 2003), which is similar in this case study.

The intensity of the storm relative RIJ is investigated in the storm vertical cross section along a south–north line. Fig. 10 shows that storm relative RIJ (5 to 10 m/s storm relative speed) is observed in the model output. The RIJ enhances the strength of wind gusts generated by downbursts. In the simulated RIJ, the highest horizontal wind speed is at 700-hPa. In front of the storm, the near-ground warm and moist air moves towards the storm with a relative speed of 20 m/s, and higher up in the atmosphere, air moves slowly or is motionless relative to the storm movement. In MCS, where trailing stratiform precipitation occurs behind the convective line, the RIJ is often formed and enhances the wind gusts induced by MCS according to Weisman (1992). To detect possible RIJ locations on radar images in Fig. 11, the Doppler wind at 15.50 UTC and 16.10 UTC is shown. There is possibly RIJ present on the radar images in the middle of the storm to the south of the radar location.

Fig. 12 shows that the 2-m temperature in the cold pool is up to 10 °C cooler than air ahead of the storm at 16 UTC. Ahead of the storm, an east–west horizontal temperature gradient is observed, which disappears as the storm sweeps across the area. The similar east–west horizontal temperature gradient is observed from in-situ measurements shown with numbers in Fig. 12. Moreover, high pressure is formed in the cold pool near the ground and low pressure is formed in the mid troposphere (not shown). The cold pool associated with the storm was also evident in in-situ measurements. Fig. 13 shows that in the simulated cold pool over Estonia temperature difference with the surrounding air was smaller than the same difference from in-situ measurements.

![Fig. 10. Vertical cross section of simulated storm relative horizontal wind speed (m/s) along a south–north line at 24.93°E at 18 UTC. The RIJ is depicted.](image)

![Fig. 11. Doppler winds (m/s) on Sürgevere radar images in Estonia a) at 15.50 UTC and b) at 16.10 UTC. RIJ is possibly present in the middle of the storm to the south of the radar location.](image)
3.3. Dependence on initial data

To investigate the sensitivity of model simulations to boundary conditions, an experiment was performed using two different boundary condition sets: RCR environment output from FMI and EMHI-ETA environment output from EtEA. Despite the relatively similar initial conditions, the modelling results differ significantly. Fig. 14 shows the simulated 850-hPa temperature and 500-hPa geopotential height at 00 UTC from the RCR initialisation together with the difference in the 850-hPa temperature between the RCR and EMHI-ETA initialisation fields. The initialised 00 UTC simulations are quite similar on the synoptic scale; the 850-hPa temperature is 1–2 °C higher over the Baltic countries and lower over Western Ukraine in the RCR initialisation. In both areas, the 1–2 °C temperature difference at 850 hPa corresponds to a 50–100 m²/s² difference in geopotential at 500 hPa.

Even though synoptic situation is similarly presented in the both HIRLAM models, thermodynamic differences lead to very different amounts of the simulated convective available potential energy (CAPE) available at the time when convective development associated with the derecho producing MCS begins. Fig. 15 shows that in the HARMONIE forecast using EMHI-ETA boundaries there is little CAPE available in the region where the storm formed (less than 400 J/kg) whereas in the HARMONIE forecast using RCR boundaries there is more CAPE.
available in the same region (more than 1000 J/kg). The differences in the CAPE distribution probably lead to big differences in the simulation results between the two model runs.

The HARMONIE model is not able to successfully simulate the storm using EMHI-ETA boundary conditions even though different convective systems are initiated. Fig. 16 shows that there is no storm over Estonia using the EMHI-ETA boundary conditions. Modelling results using RCR boundaries were already presented in subsections 3.1 and 3.2.

The effect of choosing boundary conditions with an initial time closer to the storm event was also tested with the EMHI-ETA boundary conditions. Fig. 17 shows modelling results using EMHI-ETA boundary conditions from simulation initialised at 12 UTC on August 8, 2010. Naturally, the updates to the initial state improve the forecast because the derecho environment is better represented when the 12 UTC observations are assimilated. Starting the forecast at 12 UTC instead of 00 UTC results in a storm over Estonia. However, the storm forms north of the observed location; the observed and simulated structures disagree considerably. Moreover, a forecast at this initialisation time (12 UTC) would have been too late for any practical use.

4. Conclusions

The dynamics of the derecho on August 8, 2010, were successfully simulated with the HARMONIE NWP model using
2.5-km grid spacing and AROME physics with explicit treatment of the deep convection. Common features of severe convective storm, such as convectively driven updrafts and downdrafts, strong wind gusts, near-ground high pressure and cold pool and low pressure in the mid troposphere as well as a rear inflow jet were predicted by the model. The simulated 10-m wind gusts (25–35 m/s) were very similar to the strongest gusts measured at automated ground stations (35 m/s) and radar maximum winds. The modelled accumulated precipitation on August 8, 2010, was greater than 10 mm in the storm area in the Western Estonia, which is consistent with more than 10 mm of precipitation measured at several automated stations in Estonia. The model was unable to capture precipitation in the Eastern Estonia.

HARMONIE model simulations with 2.5-km grid spacing showed the potential utility of this kind of high resolution atmospheric model data compared with the coarser resolution model data that was available operationally during this event. With the appropriate initial data, the realistic derecho evolution was forecasted. This finding is important because many European weather services are running in operational or pre-operational phase models with similar horizontal resolutions. The next generation high-resolution NWP environment at the ETEA will also run HARMONIE at a 2.5-km grid spacing.

It was found that trailing stratiform precipitation is weak in the simulations, possibly caused by the single-moment microphysics scheme used in the HARMONIE model. In the simulation the storm dissipates over Southern Finland but according to the observations, the storm travelled far into Finland. The cause of the dissipation is not yet clear and requires further study.

The simulations showed the capability of the HARMONIE model to predict a severe convective storm and reliably represent the storm dynamics. It is possible to forecast this type of storm with high accuracy using the HARMONIE model. Furthermore, according to this study, the wind damage caused by the storm could have been foreseen using the HARMONIE model, and a more precise warning for the storm could have been issued by the Estonian Weather Service. However, the quality of the initial data is crucial.

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References


