Analysis of the Influence of the Namelist Parameter dt_conv on Convective Precipitation, Vertical Wind, and Relative Humidity Simulated in ICON

Convective events from June 3, 2021 to June 6, 2021

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2022-07-06

Abstract: Study has helped to better understand the event's regional implications and convective parameter `dt_conv` of the ICON model. The model has been run for three different configurations using `dt_conv=900` (control run), `dt_conv=600`, and `dt_conv=300` for a period of ten days. Results of control run were compared to observational data and scenarios of the "`dt_conv`" parameter were analysed among configurations in order to assess the influence of convection parameter in the ICON model. The ICON run with control run and the observational data were examined for total precipitation, maximum temperature at 2m, average temperature, and average surface pressure for the relevant area. Effect of convection parameters was also compared to each other for convective precipitation and vertical wind speed. Convective event increases as `dt_conv` is decreased from 900 to 300 s.

Contents

1 Introduction

Convection and the form it is organised are crucial to the dynamics of the climate system. Deep convection is responsible for the majority of the world's precipitation over land. In addition to moisture fluxes from condensation and rainfall, it has a significant impact on the movement of energy and momentum in the global circulation. Convection can be weakly or substantially organised depending on the forcing mechanism and environmental factors like wind shear or instability[1]. The latter category includes phenomena that exist on greater time and space scales and are associated with significant forcing and increasing wind shear. Large hail, strong winds, and tornadoes or heavy rainfalls are all connected with supercells, squall lines, and other mesoscale convective events. Therefore, it is crucial that convection and the degree of organization it exhibits are accurately represented in numerical weather and climate prediction systems[3]. Many convective processes are explicitly resolved, and numerical weather prediction models' resolution has recently risen significantly (grid spacing = 1–10 km). Convective parameter (`dt_conv`) is still a major topic of debate and is responsible for significant uncertainty in climate prediction models. The issue of whether and how convective parameters affect meteorological conditions is a critical element of current research. Therefore, different convective parameter configurations need to be set. In this study, the ICOsahedral Non-hydrostatic model (ICON) is run three times in the cases of `dt_conv` = 900s (control run), `dt_conv` = 600s, and `dt_conv` = 300s for the convective event which mostly affected France, the Benelux region, and Germany on 3-6 June, 2021. The aim of this study is to assess how the convection parameter affects the event. Whereas the outputs of control run, which are daily average and maximum temperature, total precipitation, the average surface pressure, relative humidity, were compared to observational data, the variable of convective precipitation, vertical wind speed, and relative humidity were also compared to different configurations of convective parameters as `dt_conv` = 900s, `dt_conv` = 600s, `dt_conv` = 300s. The study's findings suggest that although the ICON model is not perfect at forecasting all variables for the convective event, it can simulate the meteorological variables included in the study with high accuracy, and that `dt_conv` = 300s is more likely to trigger convective events and indications.

2 ICON setup

The ICON model setup is according to the ICON model tutorial from November 2020[4]. The model is run three times, to simulate the weather from June 3 to June 6, 2021 in Europe. Initial conditions are given by ERA5 reanalysis data for June 1, 2021. During each of the three runs, all namelist parameters are kept constant, except `dt_conv`, which is the time interval of convection and cloud-cover call. This slow-physics parameter is set to 900 s, 600 s, and 300 s. The remaining slow-physics time steps `dt_rad`, `dt_sso`, and `dt_gwd` are kept at 900 s. It should be noted, that it is advised to set `dt_rad` to an integer multiple of `dt_conv`, so that radiation and convection are called at the same time. This is only the case for the 300 s and 900 s runs.

3 Validation of ICON simulation results

Before an analysis of the convective event can be conducted, the ICON results must be validated by comparing them to observational data[2]. The comparison includes the temporal evolution of the daily mean temperature, the daily maximum temperature, the total daily precipitation, and the daily mean surface pressure. The respective visualizations are given in figs. 1 to 4.

ICON simulates the temperature and precipitation evolution very well. In both the observation figures and ICON figures in fig. 1 it can be seen, that there is a warm air region on June 3 with average temperature over 20 °C, namely in France, the Benelux, and Germany. Over the following days the warm air moves eastward and the air over France, Germany, and the

Benelux cools down to an average temperature of approximately 15 °C. This evolution is also represented in fig. 2, where on June 3 the maximum temperature reaches up to 35 °C in France, Germany, and Benelux, however decreases over the course of the following days. It is to be noted, however, that the maximum temperature given by ICON is by approximately 2 °C to 3 °C lower than given by observations.

The cooling of the discussed region can be due to the onset of precipitation, as seen in fig. 3. On June 3, precipitation is observed on the west coast of France. The following day, almost all of France records precipitation. June 5, high precipitation is mainly observed in Germany and on June 6 it has moved to southern Germany and eastern Europe. While the ICON results are able to simulate the regions of precipitation, the simulated precipitation is much more concentrated at individual grid points. The maximum precipitation given by ICON is also significantly higher (approx. 50 mm/d), than what is given by the observational data (approx. 40 mm/d).

Significant information about atmospheric features is provided by surface pressure. Surface pressure data on the mesoscale are used to determine where and how intense mesohighs and mesolows are caused by convection. The figure 4 includes observational data on the left side and the control run (`dt_conv=900s`) of ICON on the right side. Observational maps show that most of Europe is above 1000 mb, with the exception of a few mountainous locations like the Swiss Alps and the Pyrenees Mountains on the borderline between Spain and France. For all maps, the model underestimates the average daily surface pressure. ICON greatly undervalues mountainous areas like the Meseta in Spain and the Dinaric Alps. It's especially interesting that neither the observational nor the ICON maps show any obvious variations in effective surface pressure between the days. The variable of surface pressure must be taken into consideration when developing the model.

The simulated daily average temperature, daily maximum temperature, total daily precipitation, and daily average surface pressure from ICON are very similar to the observational data. This means, that ICON is a reliable model regarding the convective event in Europe from June 3 to June 6, 2021. Therefore, the influence of the namelist parameter `dt_conv` can be analyzed.

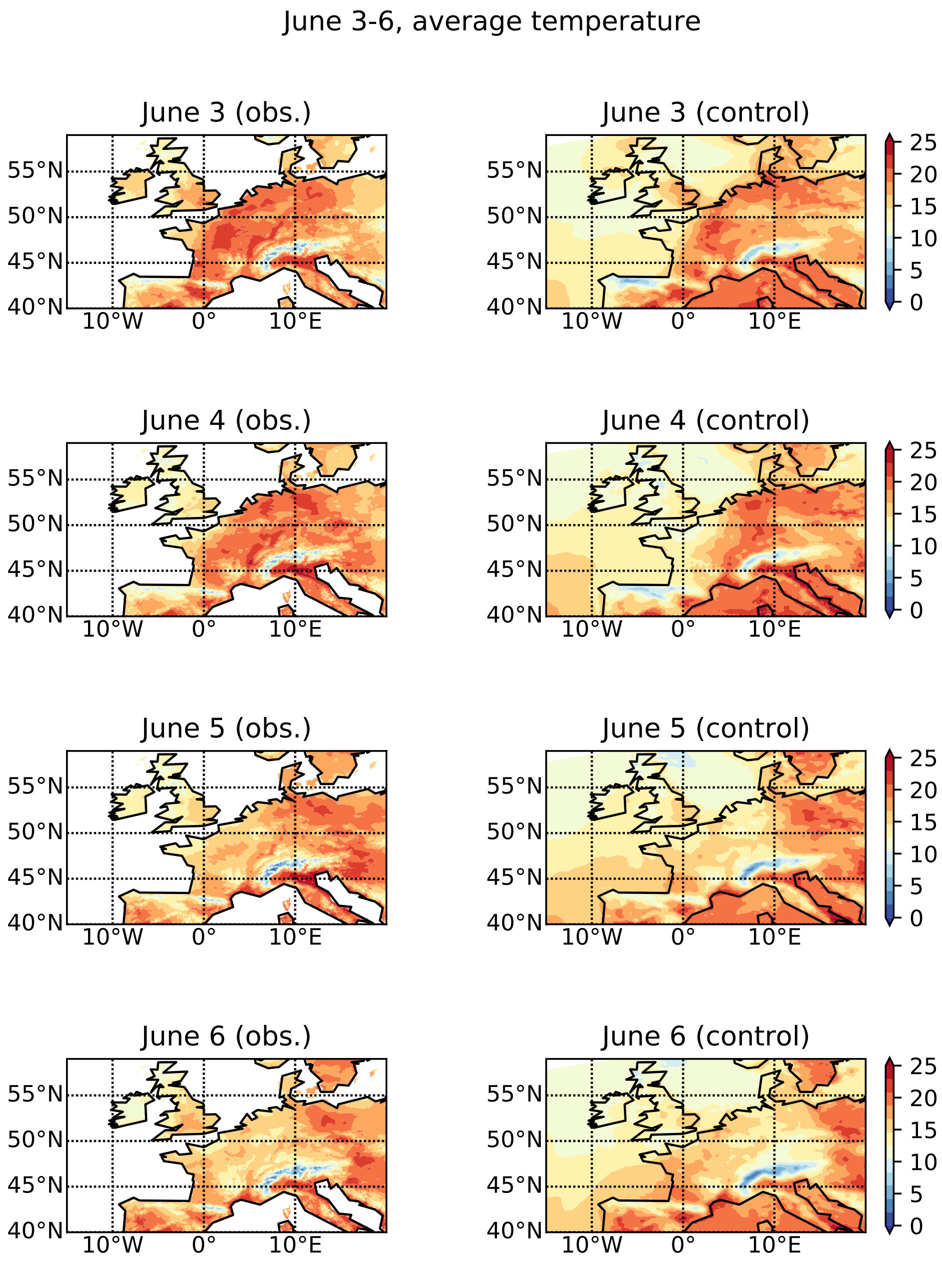

Figure 1: Daily mean temperature in °C from June 3 to June 6, 2021. Left from observations, right from ICON

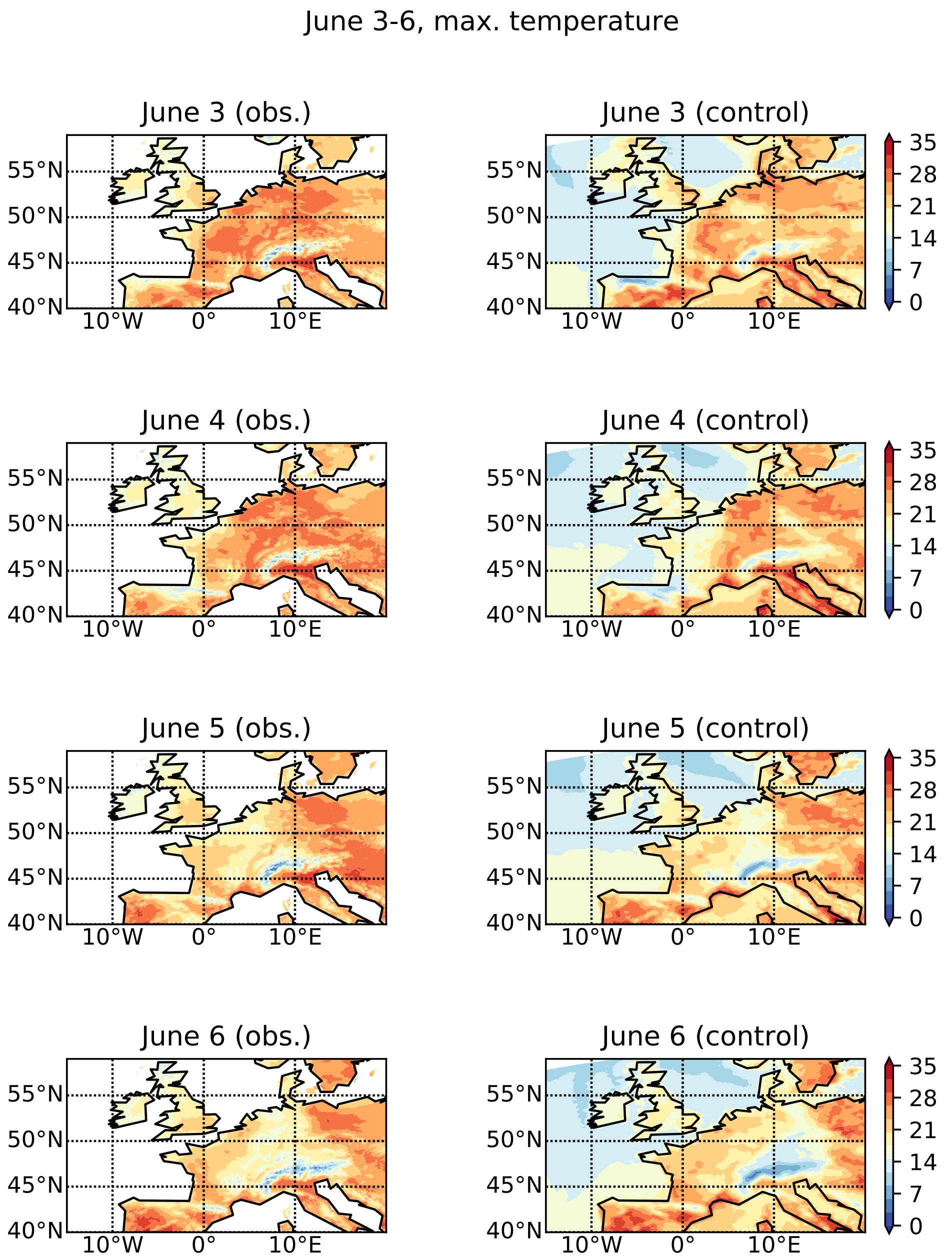

Figure 2: Daily maximum temperature from June 3 to June 6, 2021. Left from observations, right from ICON

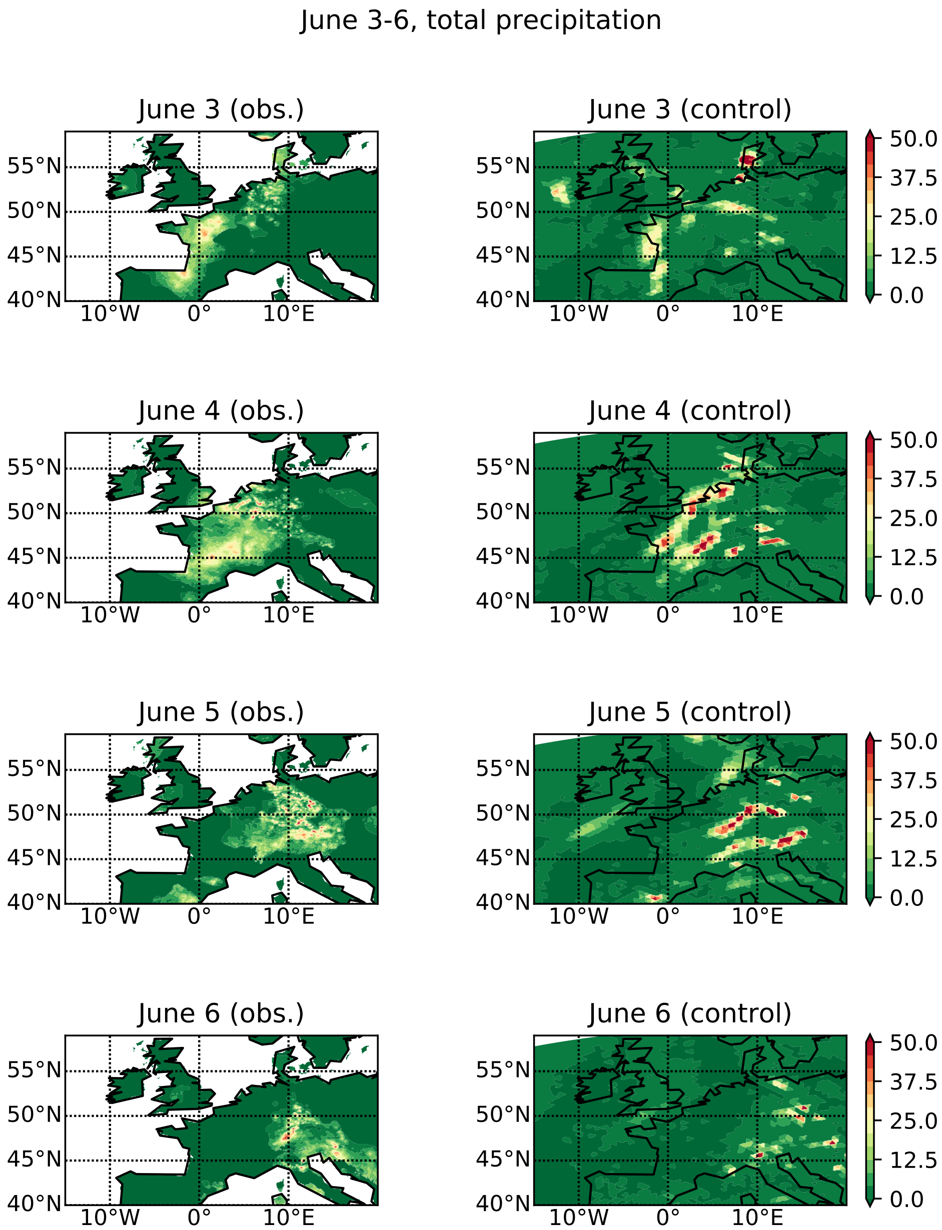

Figure 3: Daily total precipitation from June 3 to June 6, 2021. Left from observations, right from ICON

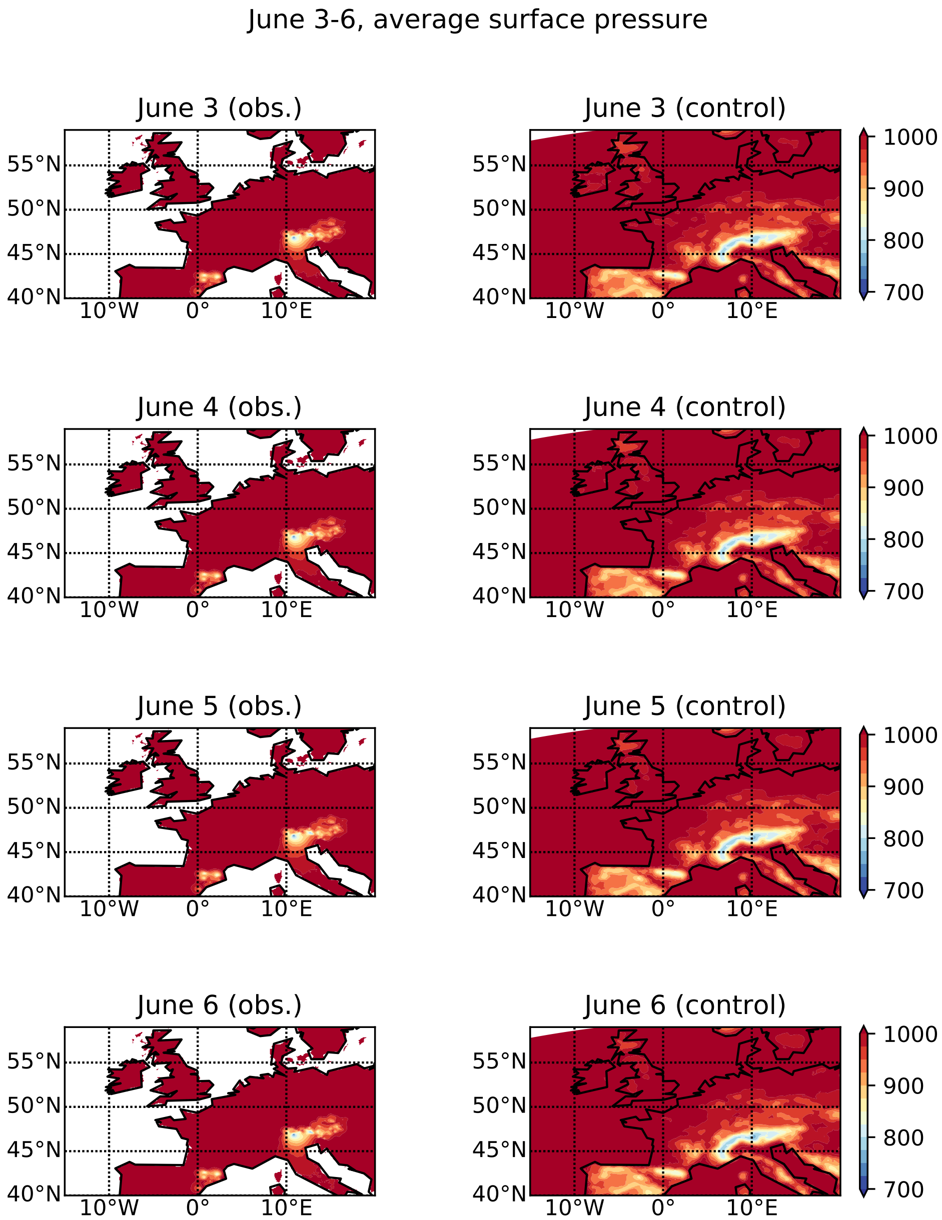

Figure 4: Daily average surface pressure from June 3 to June 6, 2021. Left from observations, right from ICON

4 Results and Discussion

The influence of the namelist parameter `dt_conv` is analyzed, by comparing convective precipitation, vertical wind, and relative humidity results from ICON runs with `dt_conv` = 300 s, 600 s, and 900 s, where `dt_conv` = 900 s is the control run from section 3. The analysis is conducted on these variables, as they are associated with and linked to convection and convective motion.

4.1 Convective precipitation

As a first analysis of the convective precipitation, the total precipitation over the four day period, June 3 to June 6, 2021, is discussed. The total convective precipitation is illustrated in fig. 5, where fig. 5(a), (c), and (e) give the precipitation for `dt_conv` = 900 s, 600 s, and 300 s, respectively. When comparing the 900 s run with the 600 s run, there seems to be a decrease in precipitation when decreasing `dt_conv`. This can be seen in fig. 5(d) which illustrates the difference between fig. 5(a) and (c). Especially near Denmark (10 °E,55 °N), the 900 s run gives higher precipitation results. On the other hand, the 300 s run gives higher precipitation than the 900 s run, as can be seen when comparing fig. 5(a) and (e). While both runs give higher precipitation near Denmark, the 300 s run also gives higher total precipitation in the North Sea, near the coast of Germany (5 °E, 55 °N) and the English Channel (0°, 50 °N). This becomes clear when regarding fig. 5(f), where the difference between the total convective precipitation of the 900 s run and the 300 s run is illustrated. In the discussed regions, the 300 s run gives higher precipitation over the four day period than the 900 s run. For a comparison of all three runs, a boxplot of the convective precipitation is given is fig. 5(b). Here, only grid points with total convective precipitation above 0.0 mm/4d are considered. As discussed, decreasing `dt_conv` from 900 s to 600 s results in a decrease in convective precipitation, here visible when comparing the median precipitation (orange line). A further decrease of `dt_conv` to 300 s leads to an increase of median precipitation. However, for both runs with decreased `dt_conv` the extreme precipitation values (given by the vertical line extending to the horizontal line) are similar to each other and significantly higher than for `dt_conv` = 900 s. Additionally, the maximum quartiles, represented by the upper boundary of the box around the median, is larger for the 900 s run than for the other two runs.

However, the influence of decreasing `dt_conv` from 900 s to 600 s has significantly less influence on the convective precipitation than the decrease to 300 s, as can be seen in figs. 6 and 7, where fig. 6 illustrates the temporal evolution of the total convective precipitation in Europe and fig. 7 gives the temporal evolution of the mean convective precipitation in Europe. For both plots, the curve for `dt_conv` = 600 s is only slightly higher than for `dt_conv` = 900 s, while the `dt_conv` = 300 s run results in significantly higher total convective precipitation and higher mean convective precipitation for all days. These results however are not represented in the temporal evolution of the maximum convective precipitation value, given in fig. 8. The 300 s run maximum precipitation is higher than for the other two runs from June 4 to June 6, yet is lower on June 3 than for the 900 s run. The 600 s run gives lowest maximum values from June 3 to June 5, and only reaches a value above the 300 s run's value on June 6.

Overall, while a decrease of `dt_conv` from 900 s to 600 s doesn't lead to a significant difference in simulated convective precipitation, a decrease to 300 s causes a large change and increase in simulated convective precipitation. As previously discussed, it is advised to set `dt_rad` to an integer multiple of `dt_conv`, so that radiation and convection are called at the same time. This is only the case for the 900 s and 300 s runs, and not the 600 s run. Therefore, a decrease from 900 s to 300 s only changed one aspect of the ICON run and differences in convective precipitation can be directly traced back to the change in `dt_conv`. However, for the 600 s run, not only was the namelist parameter `dt_conv` changed, but also the frequency at which `dt_conv` and `dt_rad` are called at the same time. Every 1800 s, both parameters are called simultaneously, yet for the other two runs it's every 900 s. This should also be considered and therefore a careful analysis of the 600 s with respect to dt_conv is necessary.

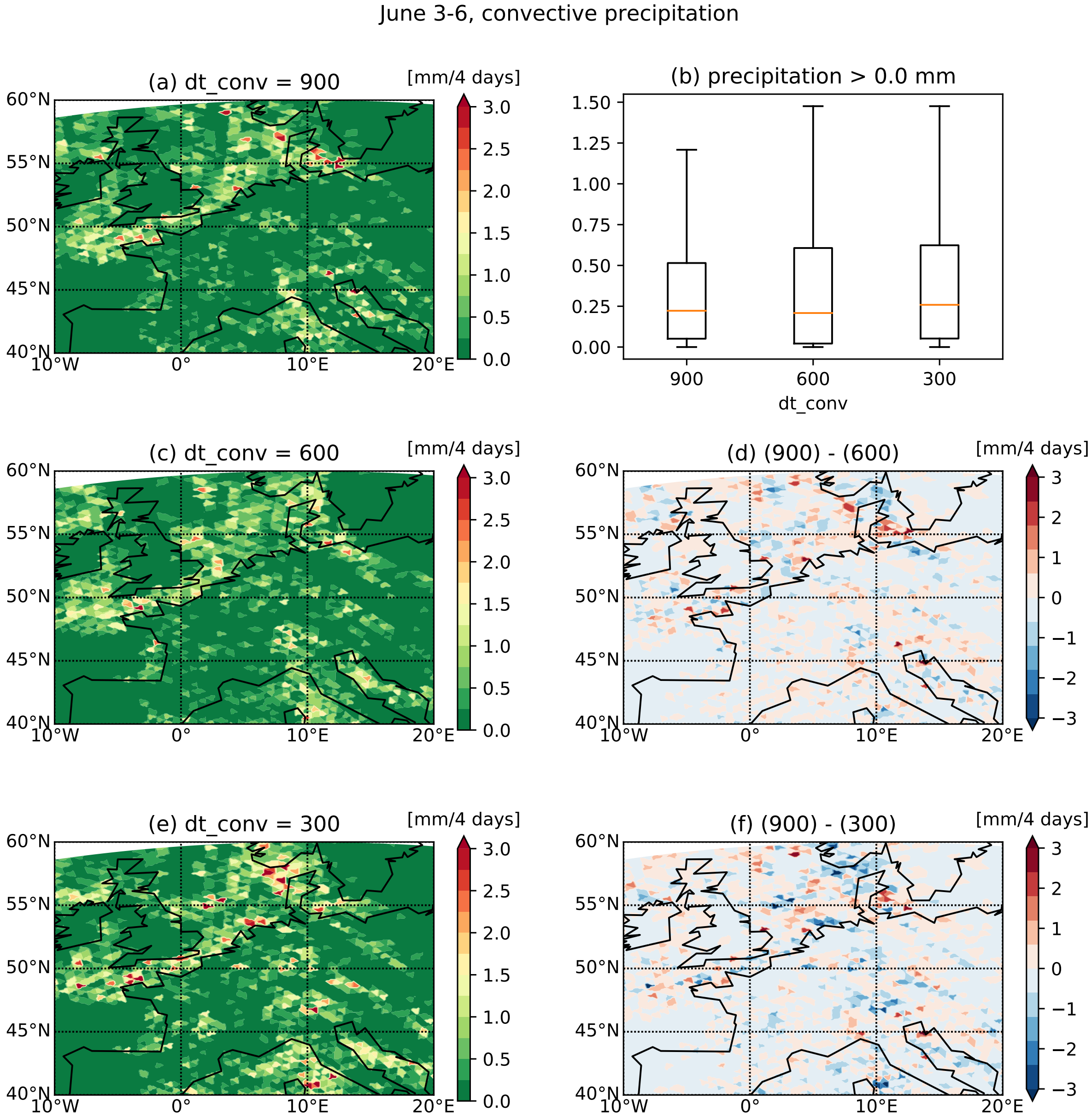

Figure 5: Total convective precipitation from June 3 to June 6 for dt_conv = 900s (a), 600s (c), 300s (e). Comparison of all three precipitation results in (b) only considering grid points with values above 0 mm/day. Difference between dt_conv = 900s and 600s (d) and dt_conv = 900s and 300s (f).

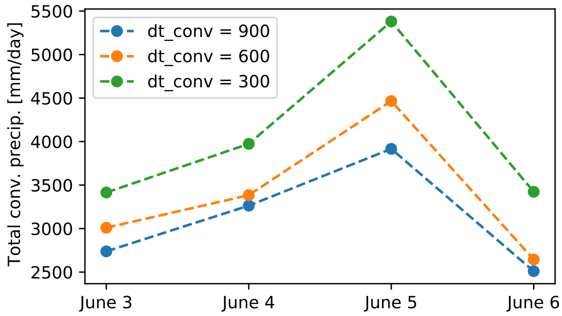

Figure 6: Total convective precipitation for entire region over time.

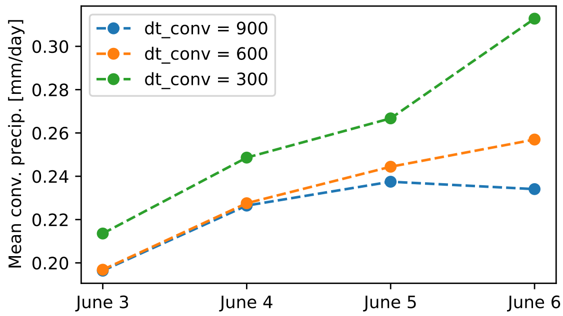

Figure 7: Mean convective precipitation of entire region over time. Only considering grid points with values above 0 mm/day.

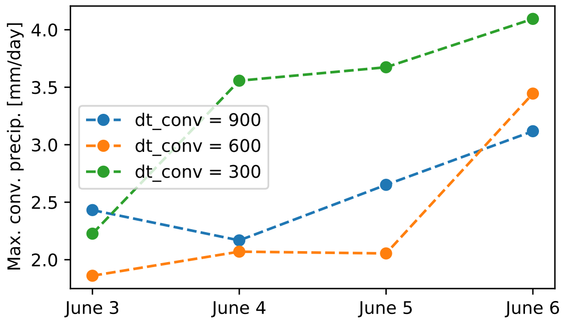

Figure 8: Max convective precipitation of entire region over time.

4.2 Vertical wind

In order to understand the variables that affect convection's intensity and structure, and in particular to determine whether the how severe the activity happens in various situations, a modeling research is carried out. From June 3 to 6, figure 9 covers local atmospheric motions. The severity of the various convective cases and the direction of the vertical wind shear at 850 mb across the area were shown to be strongly correlated. Updraft motion in the atmosphere is crucial variable in order to forecast a convective phenomena. Therefore, vertical wind speed is the one of the most important parameters to examine the updraft motions. The maps in figure 9 indicates the anomalies in wind speed between `dt_conv` = 900s and `dt_conv` = 600s, `dt_conv` = 600s and `dt_conv` = 300s, and `dt_conv` = 900s and `dt_conv` = 900s correspondingly. There appears to be a decrease in the absolute value of anomaly when comparing the `dt_conv900-dt_conv600` run. The run provides both colors combined, especially over Germany. Additionally, it demonstrates that area's atmospheric circulation is less orderly than other areas. The map shows more neutral values for the `dt_conv600-dt_conv300` run, with the exception of southern Norway. The map that highlights the differences between `dt_conv900-dt_conv300` includes the break point. In comparison to the case of `dt_conv` = 900s, it shows more negative values, which means higher updraft motions and a less stable atmosphere. Convective phenomena would hence likely become more frequent and intense. As a result, the figure makes it simple to understand how the `dt_conv` option works.

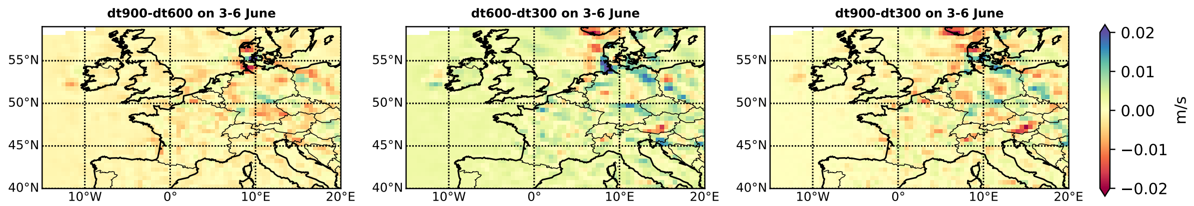

Figure 9: Average vertical wind speed at 850 mb for over the time.

4.3 Relative humidity

There are three ingredients that must be present for a thunderstorm to occur. They are: MOISTURE, INSTABILITY, and LIFTING. Since relative humidity is a part of those ingredients, relative humidity at 2 m height is going to be examined in this section. Typically stated as a percentage of the maximum amount of moisture the atmosphere can hold, relative humidity (RH) refers to the moisture content (i.e., water vapor) of the atmosphere (moisture-holding capacity). Relative humidity (RH) influences the hygroscopic development of water droplets, which modifies the physical properties. It's also crucial to look at the depth of lower tropospheric moisture and the amount of moisture convection. When there is more moisture in the lower troposphere, severe thunderstorms are more likely. Because the highest amount of total convective precipitation was simulated on 5 June, maps on the same day are illustrated in the figure 10. On every row, the same observational maps are provided. However, ICON simulations with varied convection settings are included in the second column. Here, comparing the differences between observational-simulation maps and various `dt_conv` approaches is the major objective. Let's begin by making comparisons between observational data and ICON runs. When observational maps are reviewed, the Alps, the Benelux region, the west and middle regions of Germany, and the east of the United Kingdom are found to have higher percentage values of relative humidity. Although the model runs for all scenarios predict the relative humidity over the Alps region more correctly, all simulations show a lower percentage than observed. ICON has struggled to simulate the relative humidity variable as a result. With the exception of northern Germany and western Poland, the map displays more neutral values in the `dt_conv900-dt_conv600` anomaly. This indicates that for those regions, `dt_conv600` predicted a higher moisture content. Over the same regions, the amount of anomaly may be readily seen in relation to the deviations between `dt_conv600` and `dt_conv300`. The south of Norway, however, does not have the same outcome. There is a striking similarity between the anomalies of `dt_conv600-dt_conv300` and `dt_conv900-dt_conv300` for the final anomaly map, which is `dt_conv900` and `dt_conv300`. As a result, `dt_conv600` is superior to the other two examples in terms of accuracy when displaying the relative humidity level. Particularly, `dt_conv600` simulations over inland regions are more accurate and hence more tolerable.

5 Summary and Conclusion

The ICON model was run over several days, starting June 1, 2021 from ERA5 reanalysis data, to simulate convective events in Europe from June 3 to June 6, 2021. The precipitation, surface pressure, and temperature results are compared to observational data and validated. ICON is able to correctly simulate the temporal evolution of the parameters. Therefore, it can be assumed, that ICON can be used to analyze these convective events.

The influence of the namelist parameter and convective timestep `dt_conv` on variables, which are linked to convection, is analyzed. The parameters are convective precipitation, vertical wind, and relative humidity. To get a better insight, as to how `dt_conv` changes these variables, ICON is run three times, with `dt_conv` = 900 s, 600 s, and 300 s. The decrease in the timestep

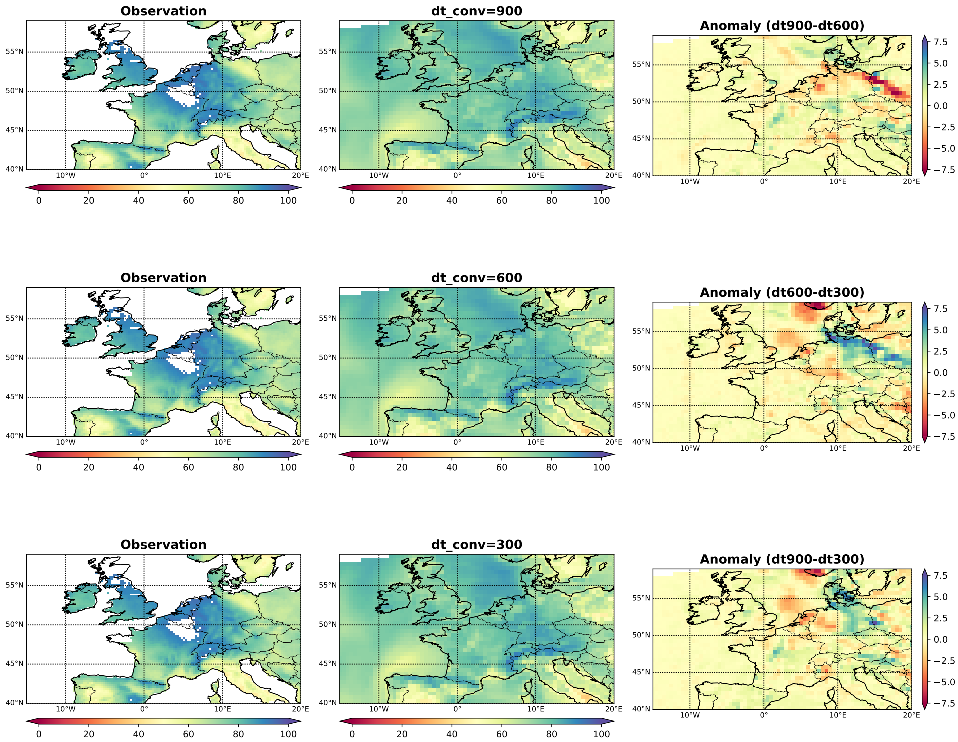

Figure 10: Daily averaged amount of 2 m relative humidity that belongs to observational data (left), ICON simulations with different `dt_conv` scenarios (middle) and anomaly (right) between `dt_conv` configurations on 5 June.

leads to an overall increase in mean and total convective precipitation. This, however, this is not the case for the maximum simulated convective precipitation. Here, the precipitation value does not correlate with the timestep size. A decrease in `dt_conv` also leads to a higher updraft motion, which is linked to stronger convection. This observation is however not made for the relative moister, where the highest values are simulated when `dt_conv` = 600 s. The 900 s and 300 s run produce similar relative humidity results. Careful analysis of influence of `dt_conv` is however necessary, as the 900 s and 300 s runs fulfill the criteria, that `dt_rad` is an integer multiple of `dt_conv`, which is not the case for the 600 s run.

Another variable influenced by `dt_conv` is cloud coverage, which is not discussed in this report but could give further insight as to how `dt_conv` influenced convection simulation in ICON. Additionally, processes like wind shear can help to reach a better understanding of `dt_conv`.

In order to determine, which of the timestep sizes gives the most accurate results, a complete comparison with observational data is necessary. In addition, it would be important to analyze, if a shorter convective timestep could lead to a long-term overestimation of convection.

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