Sensitivity Study of Cloud-Radiation Feedbacks in a Regional Climate Model Simulation Over Europe

M. Vavritsa, E. Katragkou, S. Kartsios, I. Pytharoulis and Theodore S. Karacostas

Abstract In this work the sensitivity of the Weather Research and Forecasting (WRF) model to a choice of parameterization modulating the cloud-radiation feedbacks is assessed. Two 5-year (1990–1994) climate simulations covering Europe were conducted using WRF-ARW v3.6.1 with 0.44° spatial resolution. In the base-case, WRF does not consider cumulus cloud feedbacks to radiation, while in the modified case the subgrid-scale cloudiness associated with convection, is taken into account. The results are compared with the base case and the differences for shortwave downward radiation at the surface, total cloud cover and convective available potential energy (CAPE) are discussed. Our analysis indicates that including subgrid-scale cumulus clouds in the radiation scheme leads to a decrease of shortwave radiation at the surface and convective precipitation. The behavior of CAPE is more complex and can be either decreasing (southern Europe) or increasing (northern Europe).

1 Introduction

The most important processes that determine the climate and its variability are the interactions between atmospheric radiation, clouds and aerosols. In climate modeling clouds are crucial because affect the climate through interactions with the Earth's radiation budget and the hydrological cycle, influencing in this way several meteorological fields. However, until recently, these feedbacks processes were not traditionally included in subgrid-scale convective parameterizations used in regional climate models. As a consequence, the radiation passed through the atmosphere nearly unimpeded, resulting in simulations with excessive radiation, convective precipitation and available potential energy, but with little cloudiness especially during the summer.

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The objective of the present study is to investigate the impact of subgrid-scale cloud/radiation feedbacks on radiation at the surface, cloudiness and CAPE during summer. This feedback process incorporated into a convective parameterization and a radiation scheme in the Weather Research and Forecasting model. Alapaty et al. (2012) found that the simulation of meteorological parameters, such as shortwave and longwave radiation, CAPE and cloudiness is affected, when the sub-grid scale cloudiness is taken into account. In our study we want to investigate the impacts of subgrid-scale cloud/radiation feedbacks over Europe.

2 Data and Methodology

2.1 Data

In the present study the two different climate simulations were performed with WRF-ARW (version 3.6). The simulations cover Europe with a horizontal resolution of 0.44°. Both simulations were forced by the ERA-Interim reanalysis data (Dee et al. 2011). The configuration of both simulations is presented in Table 1. The numbers in parenthesis correspond to the selected option according to the namelist input of WRF3.6.1. Activation of the cumulus radiation feedback option (cu_rad_feedback = true) in the modified case allows for sub-grid cloud fraction interactions. The analysis includes mean surface temperature (T2), convective precipitation (Prc), shortwave downward radiation at the surface (DSW), available potential energy (CAPE) and total cloud fraction (CF).

2.2 Methodology

The Kain-Fritsch (KF; Kain 2004) convective parameterization is modified to provide feedbacks to RRTMG radiation schemes in WRF. Two different regional climates simulations are performed. In the first one (hereafter "base" case), WRF does not consider cumulus cloud feedbacks to radiation, while in the second (hereafter

Table 1 Configuration of the regional climate simulations

	Base	Modified
Microphysics	WSM6(6)	WSM6(6)
Radiation (SW-LW)	RRTMG(4)	RRTMG(4)
Sfc layer	MO(1)	MO(1)
Cumulus	Kain-Fritsch(1) with cu_rad_feedback	Kain-Fritsch(1) without cu_rad_feedback
PBL	YU(1)	YU(1)
LSM	NOAH(2)	NOAH(2)

"modified" case) the subgrid-scale cloudiness associated with convective clouds, is taken into account. All variables were averaged for the time period of interest (1990–1994). Both simulations used one year (1989) as spin-up time. Summer months are June to August (JJA). All seasonal averages were calculated based on mean monthly values and include all hours for each day. Only cells over land are taken into account. The analysis was performed over the whole European domain and over the following subregions: Alps (AL), British Isles (BI), Eastern Europe (EA), France (FR), mid-Europe (ME), Mediterranean (MD), Iberian Peninsula (IP) and Scandinavian Peninsula (SC).

3 Results

Figure 1 shows the differences between the modified and base case for mean summer temperature, shortwave radiation, CAPE and CF over Europe averaged for the time period 1990–1994. The introduction of the subgrid-scale cloud feedbacks to radiation changes substantially the shortwave (DSW) radiation. In the modified case the DSW radiation at the surface decreases and cloud fraction increases. The reduction in radiation at the surface, can lead to less buoyant energy, and thus in

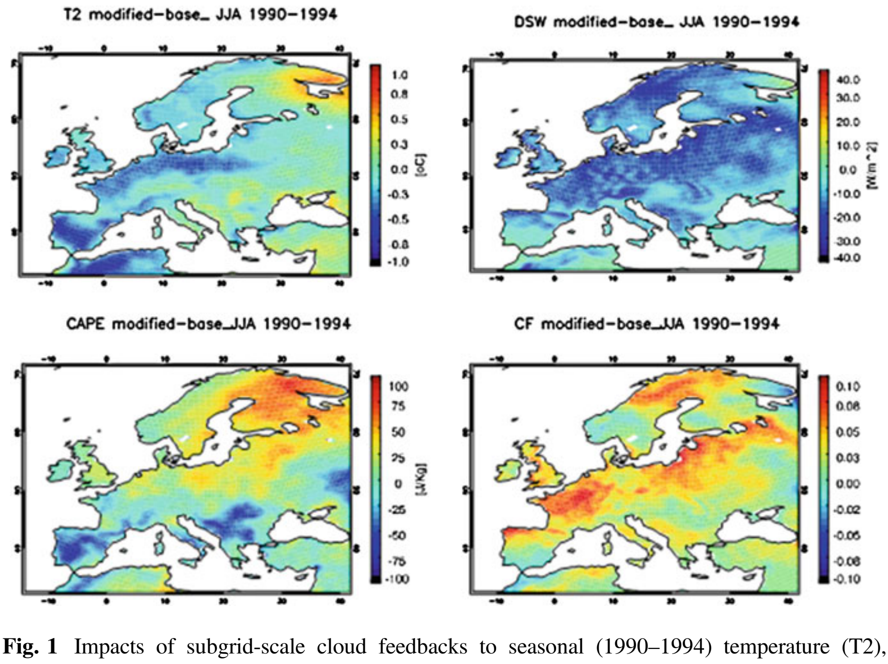

Fig. 1 Impacts of subgrid-scale cloud feedbacks to seasonal (1990–1994) temperature (T2), downward shortwave radiation at the surface (DSW), available potential energy (CAPE), total cloud cover (CF). The plots show the difference (modified-base)

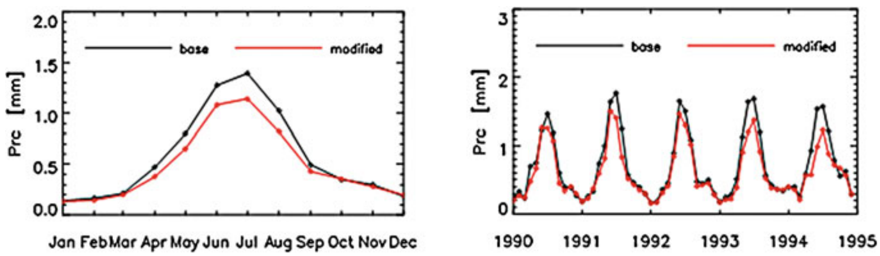

Fig. 2 Average annual cycle (1990–1994) and interannual variability of convective precipitation (Prc) over Europe

smaller CAPE, which seems to be the case for southern Europe. These finding are in accordance with the study of Herwehe et al. (2014) for North America, who showed that the impact of subgrid-scale cloud radiation interactions leads to a reduction of the DSW radiation at the surface during the summer. A different regime is seen in our simulations over northern Europe, with increased CAPE and reduced DSW radiation.

Figure 2 depicts the annual cycle and the interannual variability of convective precipitation over Europe, which is very low during the cold months and maximizes in summer, when convection is mostly active. It is clear that the implementation of subgrid-scale cloud radiation interactions in WRF produced less convective precipitation in the summer months and this is systematic. The annual cycle of CAPE, convective precipitation, DSW radiation and total cloud cover for two subregions, Scandinavian and Iberian Peninsula in the northern and southern part of Europe respectively, is depicted in Fig. 3. Over Scandinavia SW radiation, CAPE and convective precipitation maximizes in July, while at the same time the CF reaches its minimum (0.4 in July). Over the Iberian Peninsula the CAPE-maximum is higher (up to 300 J/kg) and broader compared to the Scandinavia extending from June to August. Cloud fraction ranges from 0.1 to 0.4 and reaches its minimum in July, being always lower than the CF of northern Europe.

In the modified case compared to the base case, DSW radiation at the surface decreases mostly during the warm months, when convection is more active. Convective precipitation is also affected during the summer months and decreases mostly in southern Europe and for a more extended period (March to October). CAPE has a more complex behavior, increasing over Scandinavia and decreasing over the Iberian Peninsula. It is expected to see a decrease of CAPE, when there is less SW radiation at the surface (seen over southern Europe), but less straightforward to explain the mean increase of CAPE over Scandinavia. Given the dependency of CAPE on both temperature and humidity, the complex interactions between the variables through different atmospheric processes (radiation, convection, evapotranspiration) and the multiple land-atmosphere feedbacks (temperature, precipitation and soil moisture) is not so easy to explain the behavior of CAPE, unless a more thorough analysis is performed, including components of the hydrological cycle and the energy budget. This analysis could be part of future work.

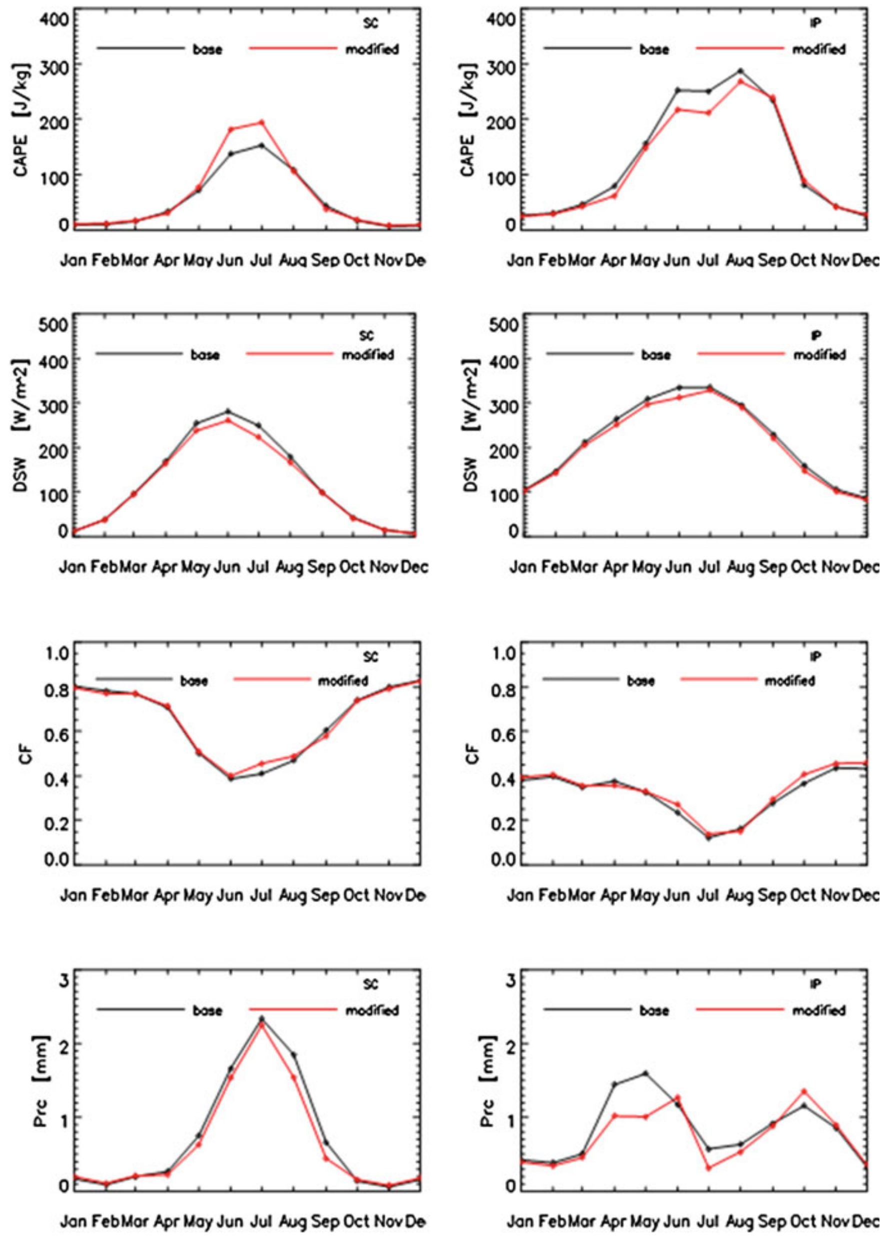

Fig. 3 Mean (1990–1994) annual cycle (from *top* to *bottom*) of CAPE, DSW, CF and Prc for two subregions of Europe, Scandinavian (*left*) and Iberian Peninsula (*right*) for the base (*black*) and modified (*red*) simulation

4 Conclusions

Two regional climate simulations were examined and compared for Europe. In the base case the interactions between the subgrid-scale clouds and radiation schemes were not taken into account, while in the modified case this feedback was included. First results indicate that including subgrid-scale cloud interactions with radiation, leads to a decrease of SW radiation reaching the surface during the warm months, when convection is mostly active. Convective precipitation decreases as a result of less active convection, especially in the south. The behavior of CAPE depends on the different European climate regimes, and can be either decreasing (southern Europe) or increasing (northern Europe). A more thorough analysis of the different parts of the hydrological cycle and the surface energy budget would be necessary in order to be able to explain in depth those finding.

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