GEOFIZIKA VOL. 31 2014

DOI: 10.15233/gfz.2014.31.4
Original scientific paper
UDC 551.509.313.1

Influence of soil moisture and dynamic vegetation coupling on numerical simulations of surface temperature, precipitation and evaporation over the Europe

Irena Ružić and Ivana Herceg-Bulić

University of Zagreb, Faculty of Science, Department of Geophysics,
Andrija Mohorovičić Geophysical Institute, Croatia

Received 12 May 2014, in final form 19 June 2014

In this paper we explore the impact of vegetation cover and soil moisture coupling on climate simulations over the Europe. For this purpose, the International Centre for Theoretical Physics (ICTP) atmospheric general circulation model (AGCM) is used. The analysis is based on three targeted simulations for the period 1981–2010: a control experiment (with a simple land-surface model that mimics interaction of soil and atmosphere); an experiment with land-surface temperature and soil moisture coupling, and an experiment with both soil moisture and interactive vegetation coupling. The amplitude and interannual variability of surface air temperature, precipitation and evaporation for summer and winter seasons are examined. Compared to the control experiment, increasing of surface temperature over the continental Europe is found for the experiment with soil-moisture model for both, winter and summer seasons. However, when ICTP AGCM is coupled with the dynamic vegetation model, increasing of surface temperature is simulated only during the summer, while it is reduced during the winter. Generally, the dynamic vegetation model reduces total precipitation over the observed domain, and areas with the most pronounced decrease of the total precipitation coincide with areas of reduced evaporation. The results indicate substantial impact of soil moisture and vegetation coupling on amplitudes of simulated surface air temperature, precipitation and evaporation with predominant contribution of the soil moisture coupling. Contrary, the impact on the interannual variability of analyzed variables is rather weak.

Keywords: ICTP AGCM model, soil moisture model, dynamic vegetation model, surface air temperature, precipitation, evaporation, interannual variability

1. Introduction

Vegetation, as a part of the biosphere, includes all plants, from evergreen and deciduous forests, to various species of grasses and crops. The climate has strong impact on spatial distribution of vegetation types on a global scale, while on smaller scales, secondary factors such as soil type, topography and human activity are also important. Likewise, a strong correlation between vegetation and climatic zones is noticeable (Woodward, 1987). Vegetation variability is associated with gradients of humidity and temperature. Soil moisture and root depth also determine the possibility for different plants to survive in certain areas. Therefore, in some areas of the world, shrubs and grasses dominate over trees, while on the other hand, there is no vegetation cover in extremely dry regions (Whittaker, 1975).

Vegetation also affects climate, both on global as well on regional scales. The vegetation-climate interaction is a dynamic process with many feedbacks which include entire group of non-linear processes (Xue et al., 2010). Vegetation cover affects climate directly through energy, moisture, momentum exchanges with the atmosphere, via modification of the physical characteristics of the land surface (e.g. albedo, roughness), and indirectly affects the biochemical processes that change atmospheric gas composition (e.g. O_2, CO_2,...) (Pielke et al., 1998; Bonan, 2002). Vegetation cover impacts energy absorption via alteration of the surface albedo. The average value of albedo for most plant species is 5-20% (Oke, 1987; Rosenberg et al., 1983). Evapotranspiration, which is determined by evaporation (from the soil) and transpiration (through the plants), affects heat balance. Transpiration depends on the density of vegetation cover and physiology of plants and crops. Stomata openings and closings regulate water loss to the atmosphere (Pollard and Thompson, 1995).

The density and height of vegetation also affects the mixing of air near the surface soil. Differences in soil roughness alter wind speed, moisture convergence, turbulence and thickness of boundary layer (Sud et al., 1988; Buermann, 2002).

Obviously, vegetation is an important part of a complex land-atmosphere system and is dependent on the interaction between atmosphere and soil. Soil represents a lower boundary for the atmosphere with which they exchanges energy, moisture and chemical substances (Seneviratne and Stöckli, 2007). Many studies highlight that land-vegetation-atmosphere interactions are important in climate modeling. Positive or negative soil moisture anomalies have an impact on the balance of energy and water, especially in regions where evapotranspiration is limited by water content of the soil. In the case of dry soil, radiation is balanced by convective and conductive sensible heat flux to boundary layer (Shukla and Mintz, 1982). Reversely, in the case of humid soil, the part of the incoming radiation will be used for evapotranspiration thus effecting a net cooling compared to dry surface soil. Furthermore, since vegetation is strongly tied to the climate, it is one of the most important indicators of climate change. As a response to changed climate conditions, there is spatial and temporal changes in vegetation cover, which may further affect climate (Rechid, 2009). Therefore, including of dynamical vegetation in climate modeling is an important task that may contribute to more realistic interpretation and better understanding of variety and complexity of processes that determine climate and its variability over the certain part of the world.

The purpose of this work is to examine the impact of soil moisture and vegetation cover on seasonal means of surface air temperature, precipitation and evaporation and their interannual variability over the Europe. The model and experiments are explained in next section. The results are discussed in section 3, while the section 4 provides summary and conclusions.

2. Model and experiment design

The model used in this study is atmospheric general circulation model ICTP AGCM, version 41. It is relatively simple numerical model with standard horizontal resolution of grid and with 8 vertical levels (from 925 to 30 hPa) (Kucharski et al., 2013a). ICTP AGCM is based on a spectral dynamical core developed by Held and Suarez (1994). It is hydrostatic, σ-coordinate, spectral transform model in the vorticity-divergence form described by Bourke (1974). The basic prognostic variables are vorticity (*Vor*), divergence (*Div*), absolute temperature (*T*), logarithm of surface pressure (*log*), and the only additional variable currently used is specific humidity (*Q*). The parameterised processes include short- and long-wave radiation, convection, large-scale condensation, vertical diffusion and surface fluxes of heat, moisture and momentum.

ICTP AGCM requires climatological fields of sea surface temperature (SST; Rayner et al., 2003), sea ice fraction, soil temperature in the deep soil layer (about 1 m), moisture in the top soil layer and the root-zone layer, snow depth, bare-surface albedo, fraction of land-surface covered by vegetation. To get a net surface albedo, the bare-surface albedo is linearly combined with values of sea-ice and snow albedo. Similarly, the soil moisture in the top soil layer and in the root zone are linearly combined to define a soil moisture availability index, which is used to compute evaporation over land. All climatological fields in the model are obtained by averaging data from the re-analysis ERA Interim (*European Centre from Medium-Range Weather Forecasts' re-analysis*) for the period 1979–2008 (Dee et al., 2011). The model has been used for examination of internal as well as the forced components of atmospheric variability (see Kucharski et al., 2013a and references therein). ICTP AGCM possesses a facility to be coupled to an ocean and/or vegetation model. Thus, the vegetation feedback on decadal Sahel rainfall has been investigated with ICTP AGCM coupled with VEGAS model (Kucharski et al., 2013b), and therein it is shown that decadal variability of the rainfall in Sahel region is forced by SST variability, but is also enhanced by land-surface feedbacks. More detailed description of the model as well as associated references are provided on the web-page http://www.ictp.it/~kucharsk/speedy-net.html.

The analysis performed in this study is based on three 30-year simulations for period 1981–2010. In the control experiment, denoted as CTRL, the interaction between soil and the atmosphere is simulated by simple land-atmosphere model. The available amount of water in the soil is prescribed as monthly varying climatology. In the second experiment, denoted as SOILM, the atmospheric model is coupled with a soil moisture model. In the third experiment, denoted as SOILM_VEG, ICTP AGCM is coupled with a model of soil moisture and dynamic vegetation model VEGAS (from **Ve**getation-**G**lobal-**A**tmosphere-**S**oil) (Zeng, 2003; Zeng et al., 2005). Actually, this experiment is the same as SOILM experiment, but with included interactive vegetation. Plant phenology is simulated dynamically as the balance between respiration/turnover and growth. The vegetation component is coupled to land-atmosphere system through soil moisture, temperature, radiation, and atmospheric CO_2. Model VEGAS includes four different plant functional types: broadleaf and needleleaf tree, and cold and warm grass.

All three experiments are forced with prescribed monthly varying but interannually constant climatological sea surface temperature. The concentration of carbon dioxide was kept constant. The domain under the study covers the whole European continent, extending from 35° N to 75° N, and from 30° W to 60° E. The results are shown for two extreme seasons: winter season (January, February and March – JFM) and summer (the growing season, or period of increased vegetation activity; July, August and September – JAS).

Climatological fields of examined variables are calculated as 30-year seasonal averages. The difference between experiments provides an estimation of the impact of soil moisture and vegetation coupling on examined meteorological variables. A two-sided t-test is performed in order to determine statistically significant values at a significance level of 95%. Interannual variability of analysed variables is estimated by standard deviation.

3. Results

Here, we are presenting the impact of soil moisture and dynamical vegetation models on climatology and interannual variability of surface air temperature, precipitation and evaporation for JFM and JAS seasons. Also, obtained changes are analysed in connection with changes in net-surface radiation and sensible heat fluxes. In the figures, statistically significant areas are bordered by dashed line. Beforehand, the changes in soil wetness availability (SWAV) and vegetation cover are briefly analysed.

3.1. Soil wetness availability and vegetation cover

SWAV is expected to be the main driver of possible changes in results of simulations. Generally, coupling with soil moisture model as well as coupling with vegetation model reduces SWAV over the Europe in both JFM and JAS seasons (Fig. 1). The reduction is somewhat more pronounced for JAS season

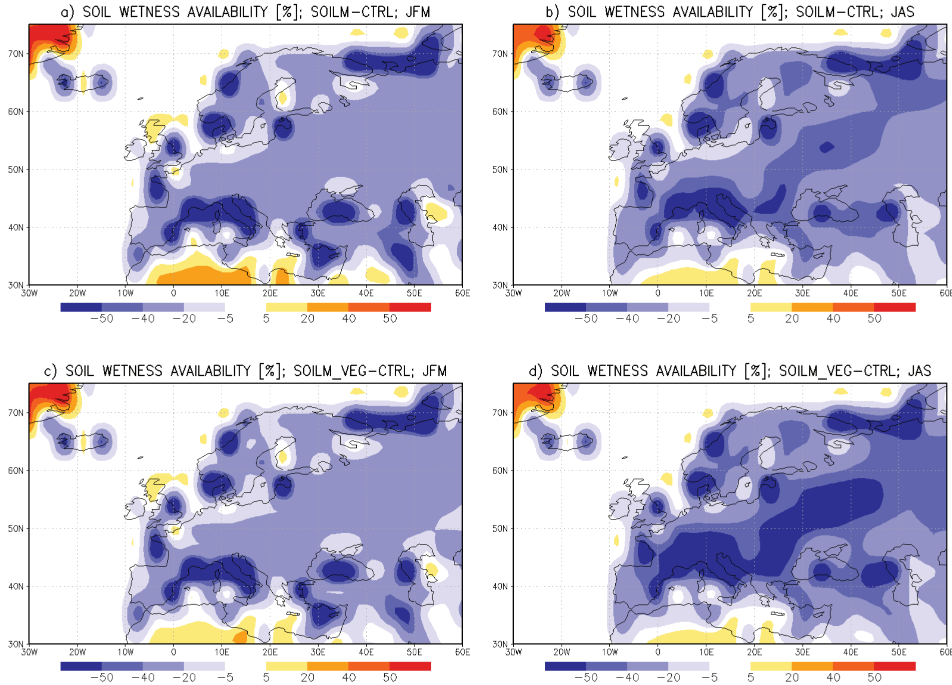

Figure 1. Differences between experiments for climatological soil wetness availability for: (*a*) SOILM-CTRL, JFM season; (*b*) SOILM-CTRL, JAS season; (*c*) SOILM_VEG-CTRL, JFM season and (*d*) SOILM_VEG-CTRL, JAS season.

over the central part of domain (Figs. 1b, d). While there is no discernible change in SWAV between SOILM and SOILM_VEG experiments for JFM season (cf. Figs. 1a and c), vegetation in SOILM_VEG experiment additionally depletes moisture from the soil (cf. Figs. 1b and d). Obviously, the main moisture reductions are associated with soil moisture coupling, while during the summer season vegetation additionally extracts moisture from the soil.

Vegetation cover in CTRL experiment is prescribed as an annual mean derived from ERA Interim dataset, and therefore represents the observed vegetation cover for both seasons (Figs. 2a, b). The same field is also used in SOILM simulation. However, vegetation cover is changing in the SOILM_VEG and is generally reduced when compared with CTRL (Figs. 2c, d). Still, there are no significant differences between JFM and JAS vegetation covers in SOILM_VEG (Figs. 2c, d). One of the key biophysical variables required for describing soil-vegetation-atmosphere system is leaf-area index (LAI), a quantity that measures foliage density. It is a dimensionless quantity that characterizes plant canopies and foliage density. It is usually defined as the half-sided green leaf area per unit ground

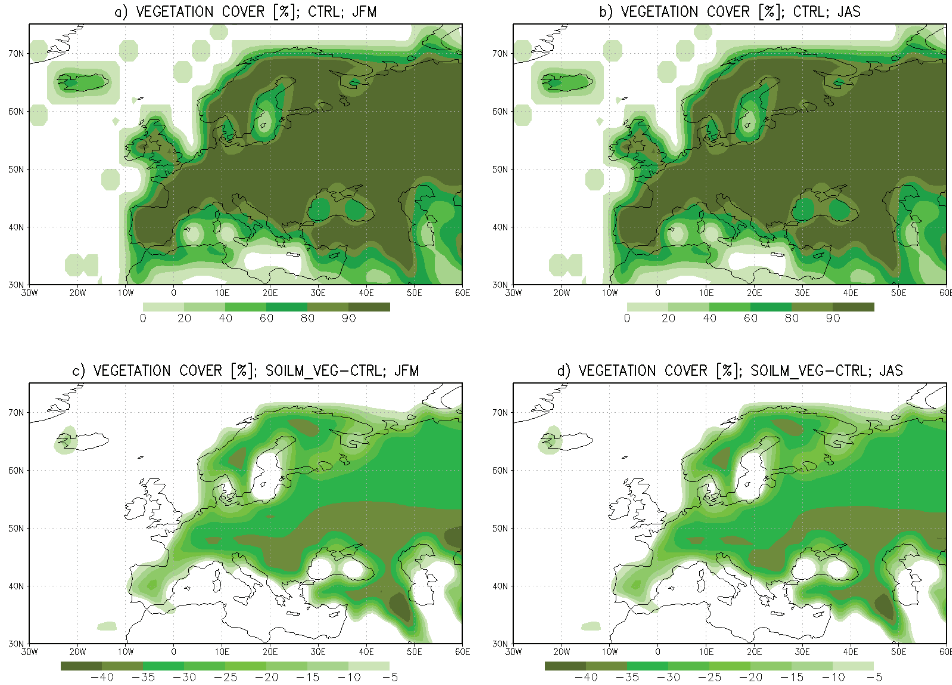

Figure 2. Climatological vegetation cover in CTRL experiment for: (*a*) JFM season and (*b*) JAS season. Differences between SOILM_VEG and CTRL experiments for climatological vegetation cover for: (*c*) JFM season and (*d*) JAS season.

surface area below the plant (Chen and Black, 1992). It is an important variable since it influences light interception and energy, water and CO_2 exchange. Here, JAS LAI is increased when compared with that for JFM season (Figs. 3a, b), what

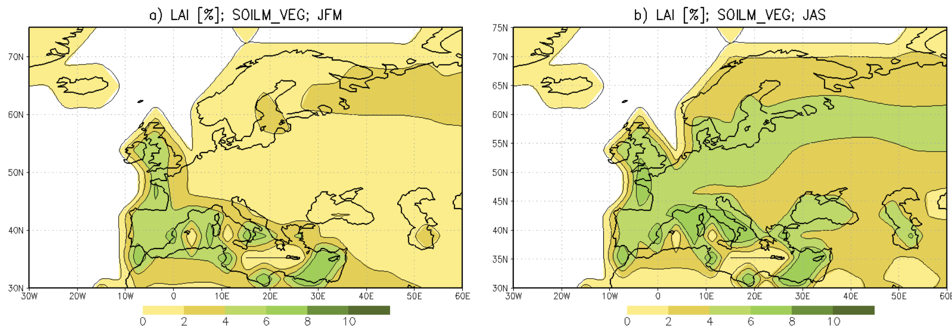

Figure 3. Climatological leaf-area index (LAI) in SOILM_VEG experiment for (*a*) JFM and (*b*) JAS season.

is most likely associated with growing season of temperate deciduous forest that prevails in that region. Therefore, although there are no substantial seasonal variations in simulated vegetation cover, LAI seasonal variations and associated physical processes may contribute to the seasonal variations of meteorological variables.

3.2. Surface temperature

Climatological fields of surface temperature simulated in CTRL experiment and that from the ERA_Interim dataset are presented in Fig. 4 (please note the different contour intervals in Figs. 4a, c and 4b, d). While the temperature pattern during the JAS season has more or less zonal form with an obvious influence of the sea (Figs. 4b, d), the impact of land and snow cover is reflected in the temperature distribution during the winter resulting in low temperatures over the north-eastern part of the domain (Figs. 4a, c). Temperature distributions simulated in the CTRL experiments correspond to the ERA_Interim data in both amplitudes and spatial patterns with high spatial correlation coefficients (0.97 and 0.98 for JFM and JAS seasons, respectively).

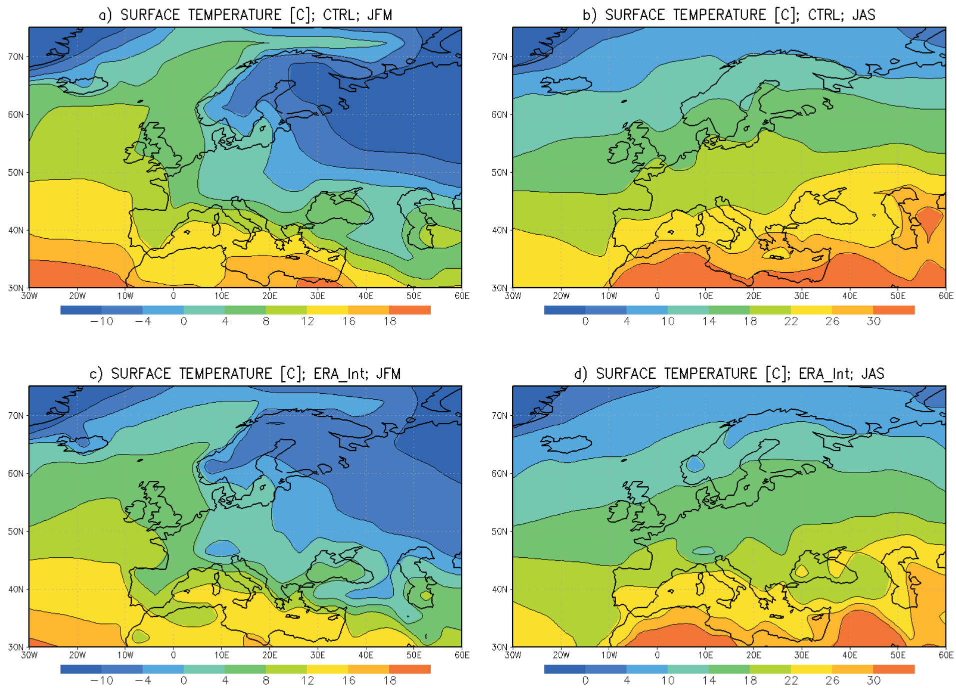

Figure 4. Climatological surface temperature for (*a*) CTRL experiment, JFM season; (*b*) CTRL experiment, JAS season; (*c*) ERA-Interim data, JFM season and (*d*) ERA-Interim data, JAS season.

Spatial differences in surface temperatures between the experiments are shown in Fig 5. Obviously, the impact of both SOILM and SOILM_VEG is stronger in summer season (Figs. 5b, d and f), while there is only a weak impact on the wintertime temperature (Figs. 5a, c and e). However, the impact of the soil

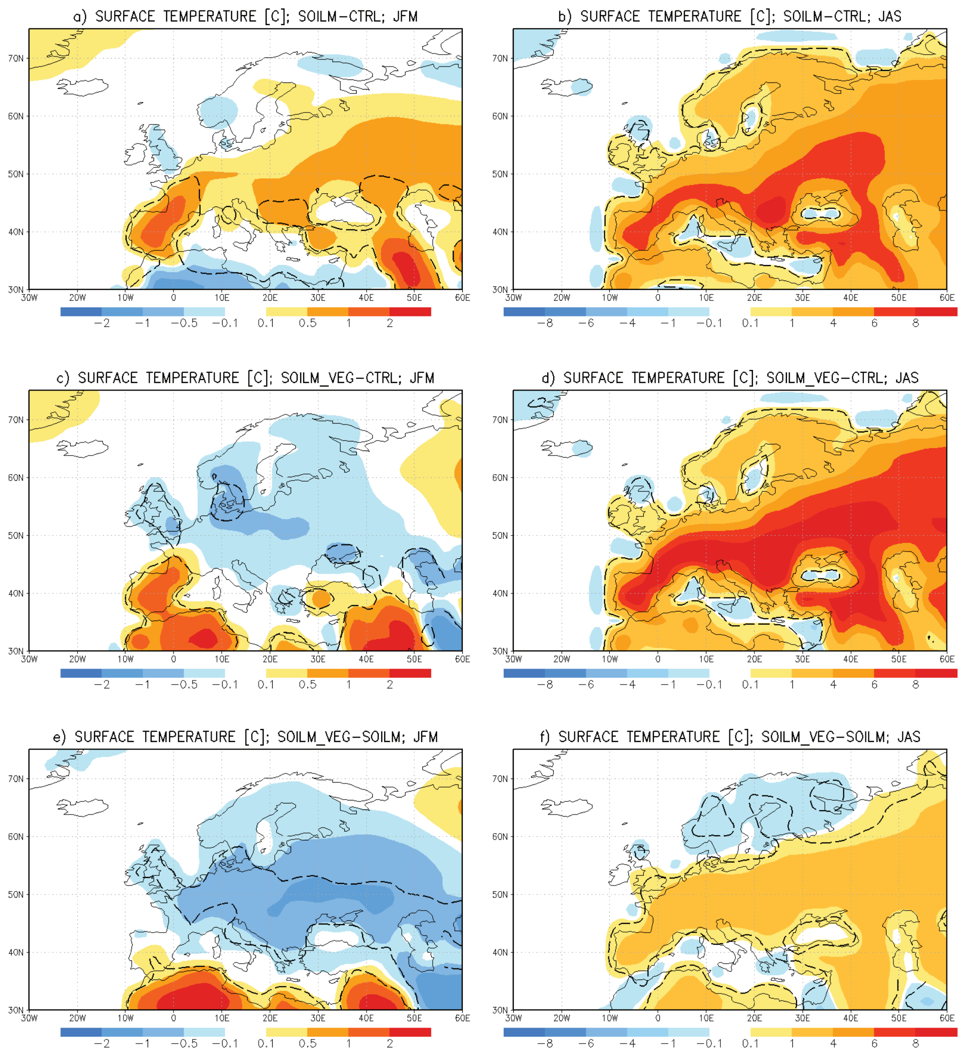

Figure 5. Differences between experiments for seasonal climatological surface temperatures for: (*a*) SOILM-CTRL, JFM season; (*b*) SOILM-CTRL, JAS season; (*c*) SOILM_VEG-CTRL, JFM season; (*d*) SOILM_VEG-CTRL, JAS season; (*e*) SOILM_VEG-SOILM, JFM season and (*f*) SOILM_VEG-SOILM, JAS season. The areas with statistically significant differences at 95% confidence level are encircled by dashed line.

moisture model and vegetation model differs one from another in a sense of a sign of temperature change. In general, SOILM compared to the control experiment, simulates higher temperatures over almost entire domain for both JFM and JAS seasons (Figs. 5a and 5b). But, these differences are statistically significant over the whole domain for JAS season (Fig. 5b), while for JFM season they are significant only sporadically and mostly in the southern part of Europe (Fig. 5a). On the other hand, the results of the SOILM_VEG experiment indicates opposite impact of dynamic vegetation on winter and summer seasonal temperatures when compared with CTRL experiment: relative cooling is simulated for winter season (Fig. 5c), while relative warming is obtained for the summer season (Fig. 5d). Although the differences for the JFM season are mostly not significant, they still they suggest opposite vegetation impact on wintertime and summertime average temperatures. Generally, the vegetation cover tends to decrease winter temperatures in continental Europe, but with only few areas for which is that change statistically significant (Fig. 5c). An exception is Iberian Peninsula with statistically significant increase of JFM temperature (1–2 °C), where both SOILM and SOILM_VEG simulate increased JFM temperature. The changes in JAS temperatures are more pronounced than those for JFM season. Both SOILM and SOILM_VEG experiments have similar patterns of positive temperature anomalies. The warming is the strongest over the southern and eastern Europe. Comparison of Figs. 5b and 5d reveals that although temperature increase relative to the CTRL temperature is simulated in both experiments, it is more pronounced in the SOILM_VEG (except over the northern part of the domain). Therefore, relatively stronger contribution to the temperature increase in JAS season may be attributed to the processes represented in SOILM experiment, while vegetation model in SOILM_VEG additionally enhances temperature increase, but with no influence on its spatial distribution resulting in an overall temperature change about 8 °C over the central part of the Europe.

Figure 6 indicate that interannual temperature variability is generally more pronounced during the cold season than during the warm part of the year. This is most probably associated with wintertime interannual variability of snow cover. Maximum of temperature variability for both seasons are placed over the eastern part of the domain. For JFM season, the fields of standard deviation of temperature are spatially similar for all three experiments (Figs. 6a, 6c and 6e) with no substantial differences in their amplitudes. The temperature variability in the SOILM is slightly weaker (Fig. 6c) than in CTRL and SOILM_VEG. Interannual variability of JFM temperature in SOILM_VEG (Fig. 6e) is again more comparable with CTRL (Fig. 6a). Generally, results indicate that processes simulated in SOILM and SOILM_VEG experiments do not affect substantially interannual temperature variability over the considered domain. Still, SOILM simulates temperature with somewhat lesser variability than CTRL and SOILM_VEG experiments. During the summer months (i.e. JAS season) the variability is much smaller than for JFM season (cf. Figs. 6a and 6b). The variability is slightly increased in SOILM experiment (Fig. 6d), while SOILM_VEG do not contribute much to the variability (cf. Figs. 6d and 6f) suggesting that changes in temperature variability is associated primarily with the processes simulated in SOILM experiment. Obviously, vegetation model in the SOILM_VEG experiment slightly increases summertime temperature (as depicted in Fig. 5f), but with no detectable impact on its interannual variability.

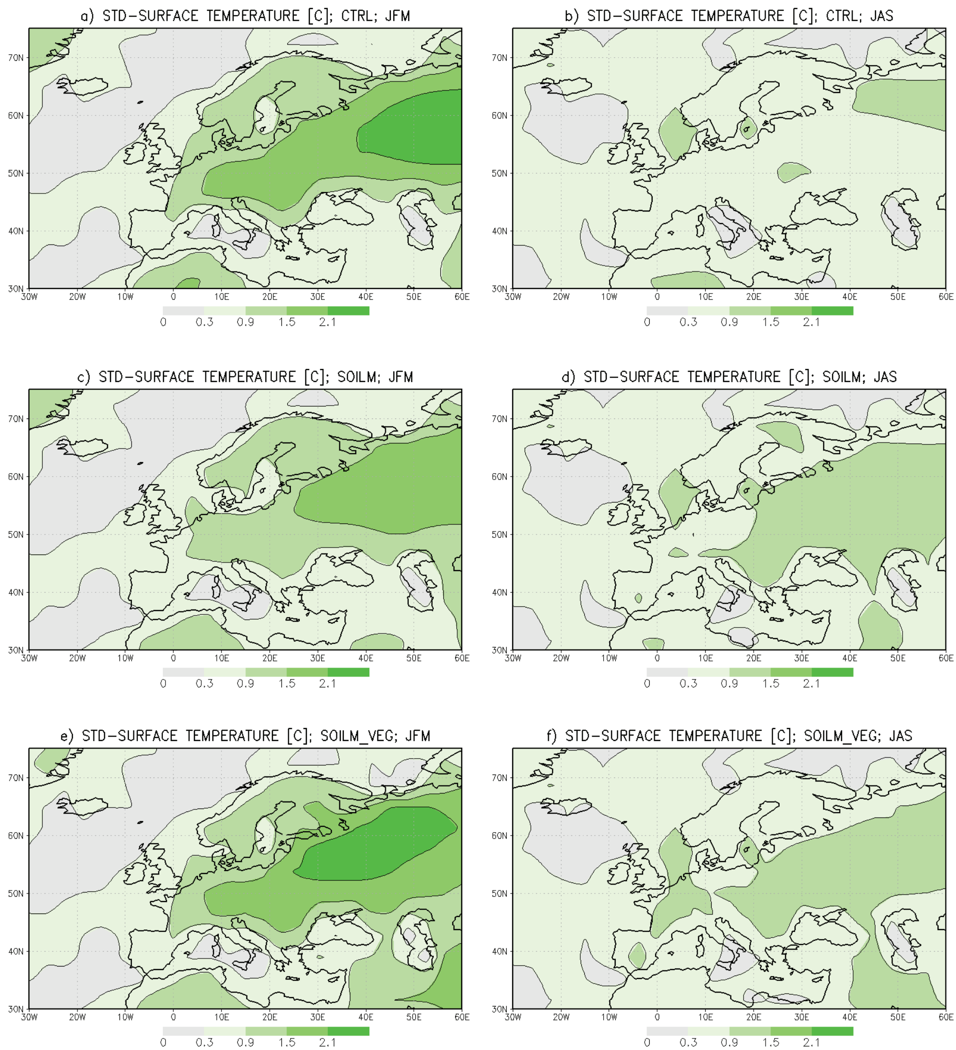

Figure 6. Surface air temperature interannual variability for (*a*) CTRL experiment, JFM season, (*b*) CTRL experiment, JAS season; (*c*) SOILM experiment, JFM season; (*d*) SOILM experiment, JAS season; (*e*) SOILM_VEG experiment, JFM season and (*f*) SOILM_VEG experiment JAS season.

3.3. Precipitation

Modelled as well as ERA_Interim precipitation shows clear impact of land-sea distribution on the precipitation during the both seasons (Fig. 7). Thus, the most abundant winter precipitation is found over the relatively warmer sea (Figs. 7a, c), while during the summer the maximal values are confined over the warm land (Figs. 7b, d) as a result of increased convective precipitation (not shown). Although ICTP AGCM overestimates ERA_Interim precipitation, their spatial distributions are quite similar (with spatial correlation coefficients of 0.76 for JFM and 0.65 for JAS season).

Based on differences between experiments presented in Fig. 8, it can be noticed that the processes modelled in the SOILM and SOILM_VEG experiments modify precipitation in both seasons. In the winter season, the precipitation changes relative to the CTRL experiment are less pronounced and mainly statistically not significant, but mostly indicate reduced precipitation (Figs. 8a and 8c), although vegetation in SOILM_VEG experiment somewhat decreases precipitation (Fig. 8e). Contrary, during the summer, soil moisture and vegetation cover have a strong and statistically significant impact on precipitation in continental Europe (Figs. 8b and d). According to the Fig. 8e, vegetation in the

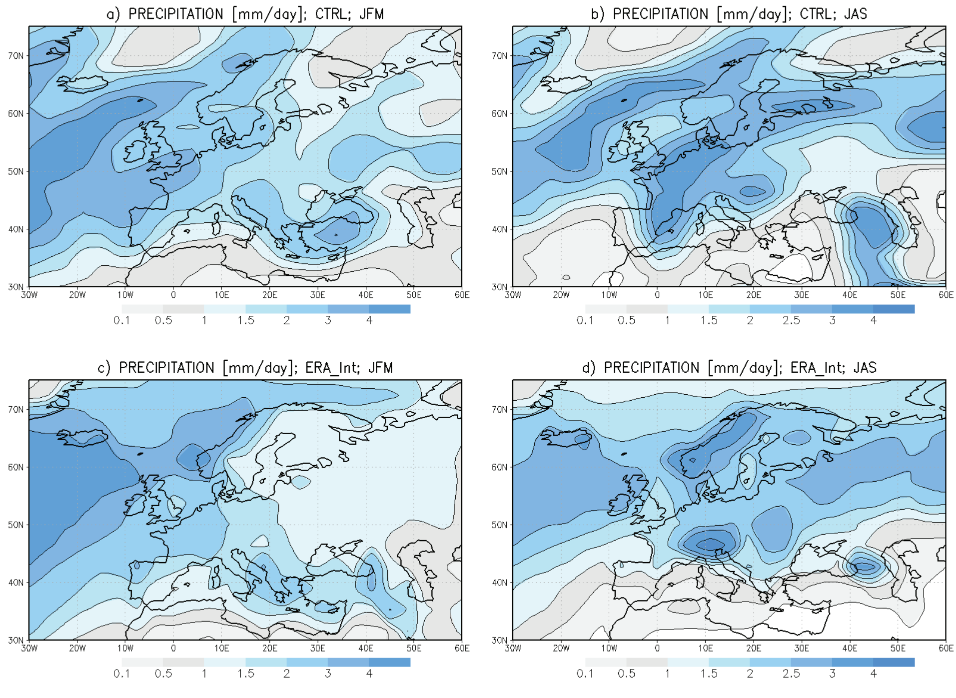

Figure 7. The same as for Fig. 4, but for precipitation.

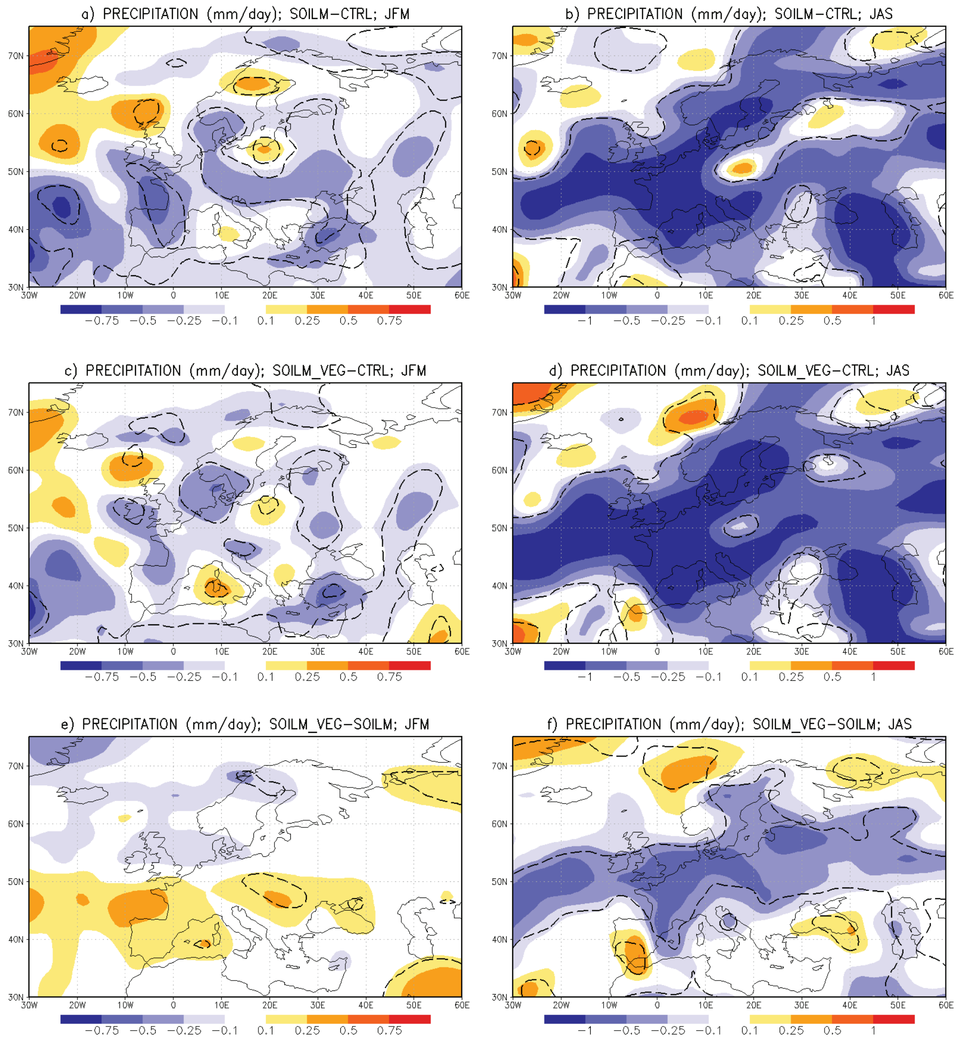

Figure 8. The same as for Fig. 5, but for precipitation.

SOILM_VEG contributes to the SOILM precipitation in such a way that it increases precipitation over the southern part of the domain, and decreases it over the northern part. Still, this impact is statistically significant only sporadically. However, during the JAS season the difference between the CTRL and other two experiments is more pronounced (Figs. 8b, d and f). Compared with CTRL, precipitation is significantly reduced in both SOILM and SOILM_VEG experiments, but with no change in its spatial distribution. Precipitation is already substantially decreased in the SOILM (Fig. 8b), and is additionally reduced by

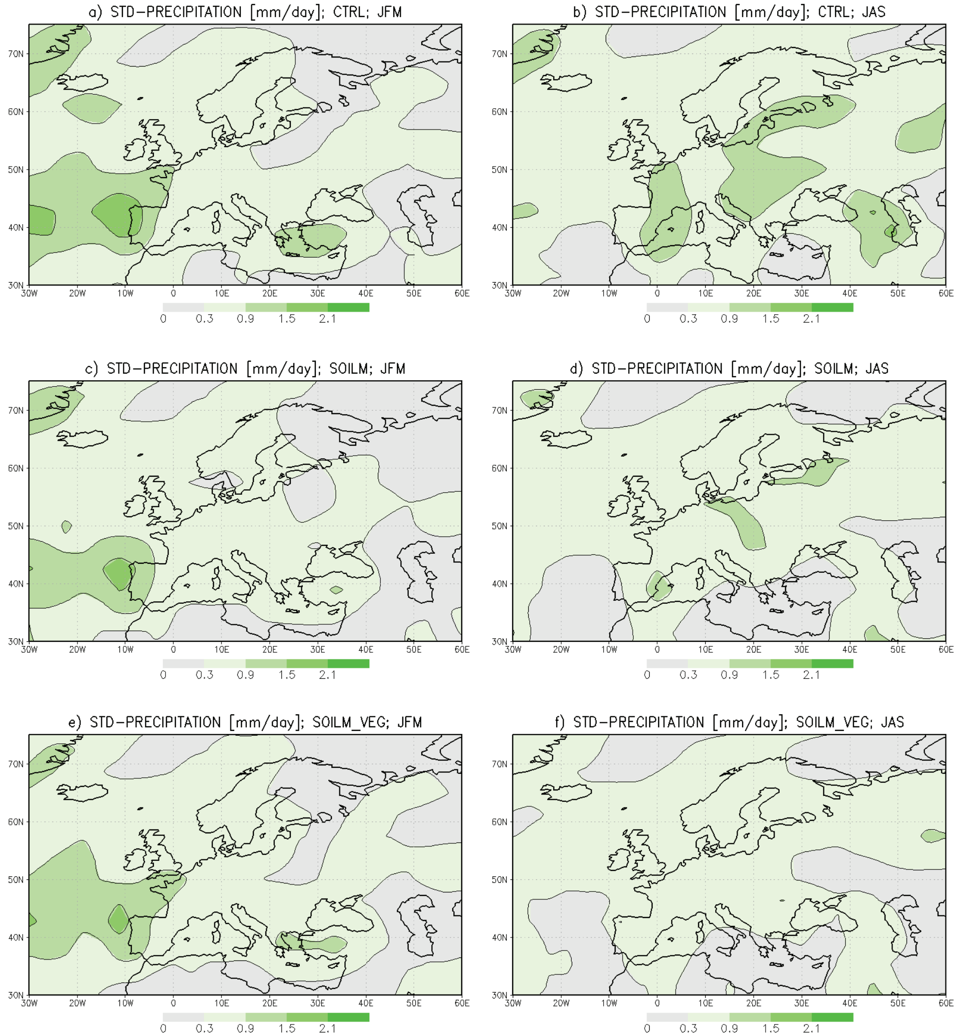

Figure 9. The same as for Fig.6, but for precipitation.

vegetation model in SOILM_VEG experiment (Figs. 8d, f). The impact of different model settings on precipitation variability changes is shown in Fig. 9. For JFM season (Figs. 9a, c and e), all of experiments indicate weak interannual precipitation variability (0.3–0.9 mm/day) over the most of the domain. Only over the Atlantic Ocean and the Iberian Peninsula the variability is somewhat larger (1.5–2.1 mm/day). It is slightly (but not significantly) weaker in SOILM and SOILM_VEG than in CTRL. During the summer, the precipitation is more varying over the land than over the sea (Figs. 9d, e and f), but with still small values

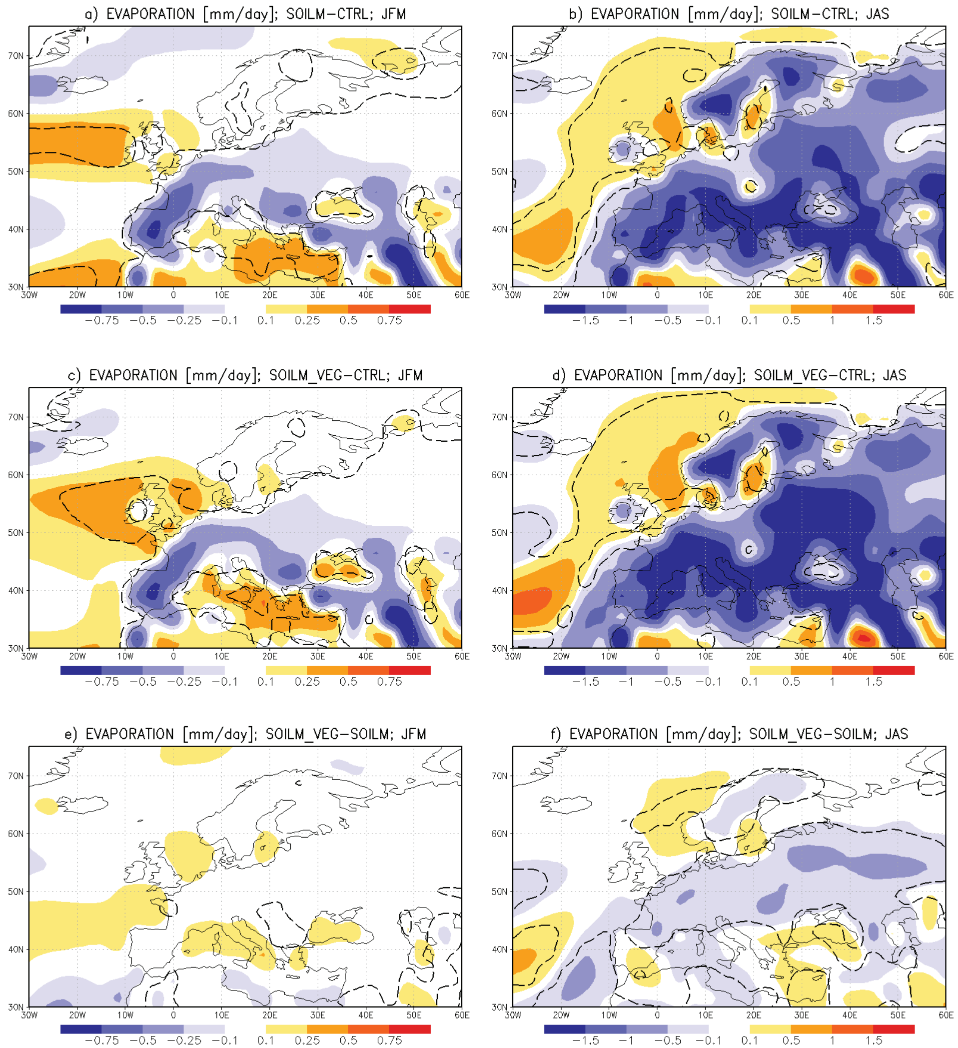

Figure 10. The same as for Fig. 5, but for evaporation.

(0.9–1.5 mm/day). Compared with the control experiment, precipitation variability is slightly reduced in the SOILM and SOILM_VEG experiments.

3.4. Evaporation

The impact of soil moisture and vegetation coupling on evaporation climatology is shown in Fig. 10. In both SOILM and SOILM_VEG experiments, JFM evaporation is enhanced over the sea and reduced over the land (Figs. 10a, c).

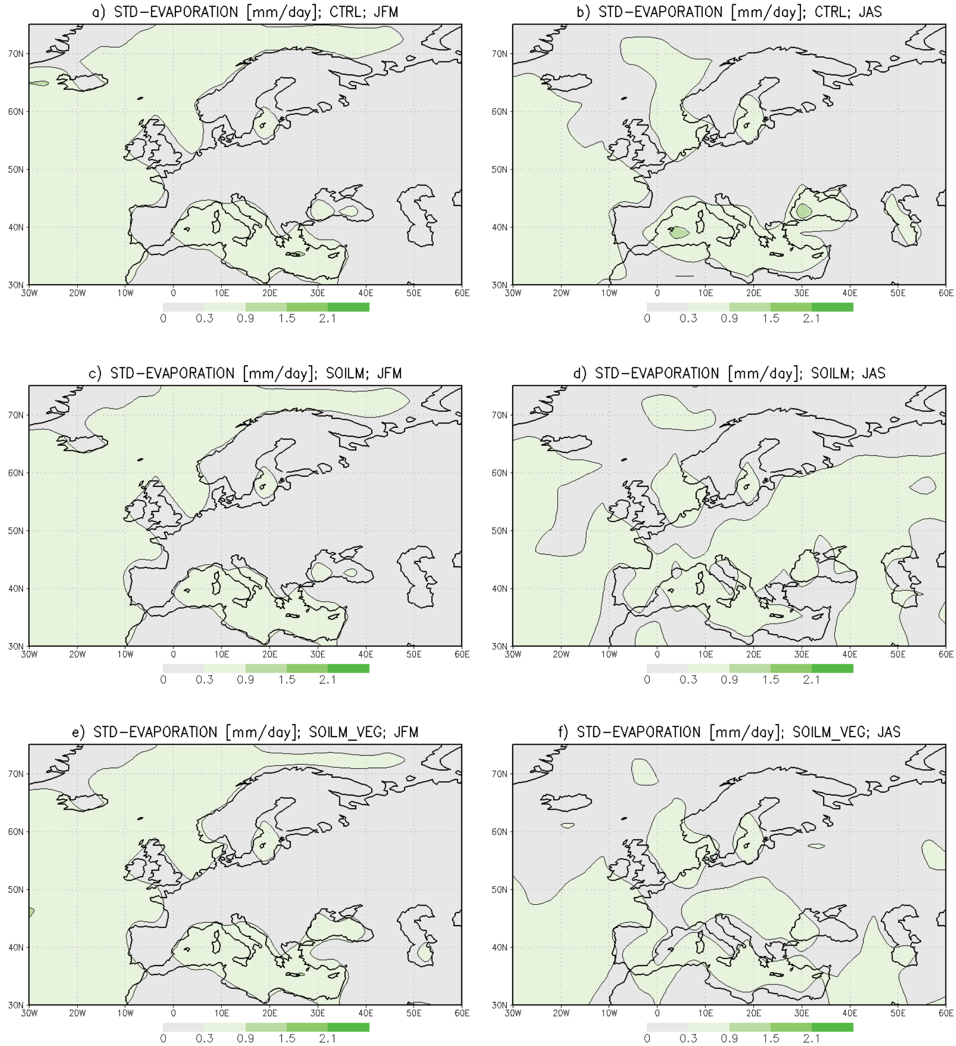

Figure 11. The same as for Fig. 6, but for evaporation.

Neither the spatial distribution nor the amplitudes differ in those two experiments (Fig. 10e) indicating that the differences seen in Fig. 10c may be primarily attributed to the soil moisture coupling, while the impact of vegetation is negligible.

In contrast to the JFM season, more pronounced impact of soil moisture and vegetation coupling on evaporation climatology is found for JAS season. Thus, significant decrease is simulated over the entire continental part of the domain (Figs. 10b, d). The main contribution to the evaporation changes is again associated with the soil moisture coupling, while the vegetation intensifies the evaporation decrease (Fig. 10f).

Evaporation variability is generally weak with slightly greater values over the sea during the JFM season (Fig. 11a). There is almost no difference between Figs. 11a, c and e indicating that neither the soil moisture nor the vegetation coupling affects JFM interannual evaporation variability in considered experiments.

JAS evaporation variability in CTRL experiment depicts almost the same spatial pattern and amplitudes as for the JFM season (cf. Figs. 11a and 11b). Soil moisture coupling increases summertime evaporation variability over the land to the some extent (Fig. 11d). However, when vegetation model is added, the variability is again decreased (cf. Figs. 11d and f) resulting in SOILM_VEG evaporation variability more similar to that for CTRL experiment.

3.5. Net surface radiation and sensible heat fluxes

Here we present the net surface radiation and sensible heat fluxes changes between performed simulations. The total rate of exchange of energy between

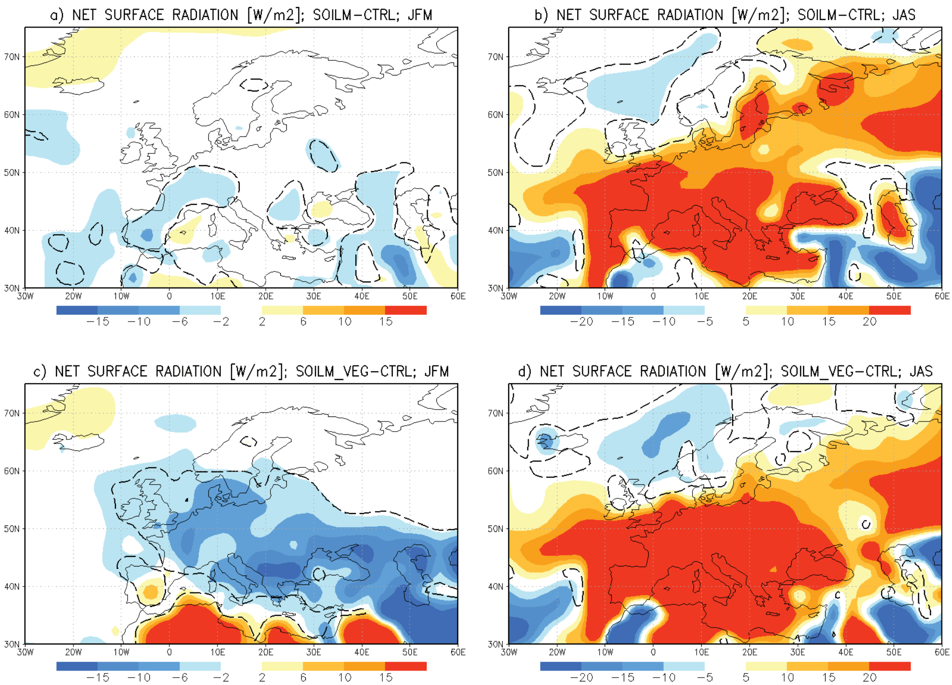

Figure 12. Differences between experiments for climatological net surface radiation (*a*) SOILM-CTRL, JFM season; (*b*) SOILM-CTRL, JAS season; (*c*) SOILM_VEG-CTRL, JFM season and (*d*) SOILM_VEG-CTRL, JAS season. The areas with statistically significant differences at 95% confidence level are encircled by dashed line.

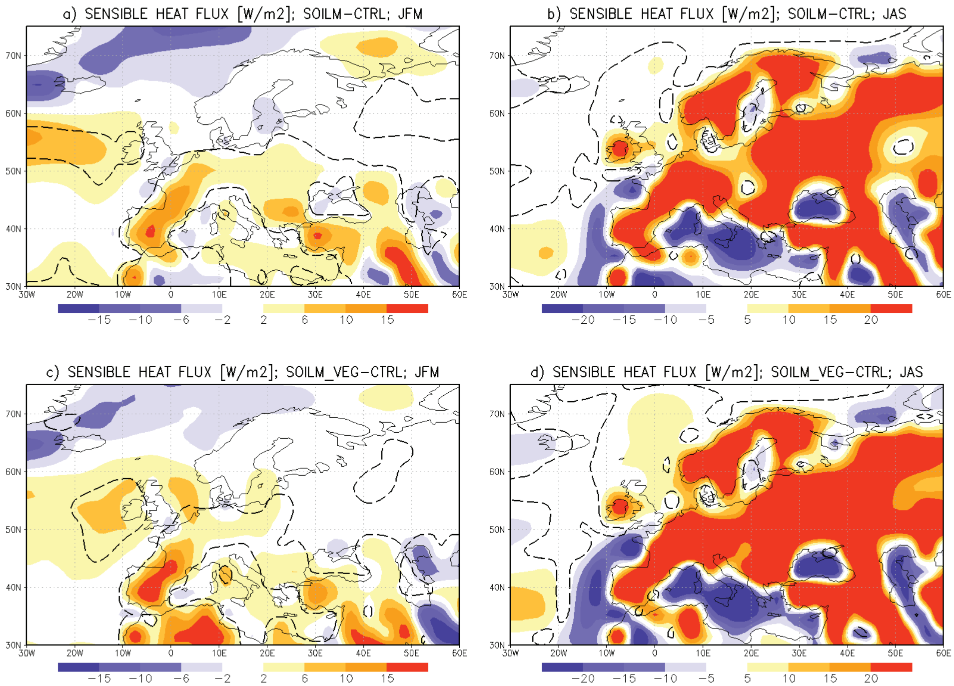

Figure 13. The same as for Fig. 12, but for sensible heat flux.

the atmosphere and the surface depends on different fluxes: incoming solar radiation absorbed by the surface, the net outgoing long wave radiation, sensible heat flux and latent heat flux (heat extracted from the surface by evaporation).

There are substantial differences in impacts of soil moisture and vegetation coupling on seasonal net surface radiation (Fig. 12). During the winter (summer), SOILM and SOILM_VEG simulations are associated with decreased (increased) net surface radiation. The impact of soil moisture model is more pronounced for JAS than for JFM season (cf. Figs, 12a and b). Vegetation substantially decreases net surface radiation in JFM season (Fig. 12c). On the other hand, sensible heat flux is increased for both seasons (Fig. 13), but changes are greater for JAS season. Comparison of relative differences between SOILM and CTRL (Fig. 13a, b) and between SOILM_VEG and CTRL (Figs. 13c, d) reveals that the main contribution to those changes is associated with processes in SOILM.

4. Summary and conclusions

The impact of soil moisture and vegetation coupling on numerical integrations made by a relatively simple atmospheric general circulation model (ICTP AGCM) is examined in this paper. For this purpose, three targeted simulations are performed: the control experiment CTRL obtained by using ICTP AGCM with simple land-atmosphere model, the SOILM experiment in which the model is coupled with a soil moisture model, and the SOILM_VEG experiment obtained by the ICTP AGCM coupled with both soil moisture and vegetation models. Analysing the period 1981–2010, changes in seasonal amplitude and interannual variability of surface air temperature, precipitation and evaporation for winter (JFM) and summer (JAS) seasons over the Europe is presented here. The impact of the soil moisture and interactive vegetation models on simulated variables is estimated by comparison of their spatial distributions obtained in the experiments, while interannual variability is evaluated by standard deviation.

Presented results indicate an opposite effect of the used soil moisture and vegetation models on the JFM temperature climatology: SOLIM is mostly associated with increased temperature and decreased their interannual variability over the land. Contrary, for the SOILM_VEG experiment there are decreased temperatures (excluding the Iberian Peninsula where relative warming is simulated in the both experiments) with somewhat increased JFM interannual variability. Still, the impact on the interannual temperature variability is quite weak. For JAS season, both of experiments are associated with a relative warming when compared with CTRL experiment. Dominant impact comes from the soil moisture model, while dynamic vegetation in SOILM_VEG additionally enhances that temperature increase. This result corresponds with that of Wang et al. (2006) who argued that vegetation may have statistically significant impact on summertime climate variability. According to Wang et al. (2006), as a result of enhanced vegetation, soil moisture may be depleted more rapidly than usually resulting in a reduced precipitation and increased temperature.

For JFM season, both SOILM and SOILM_VEG are relatively drier than CTRL, but it seems that vegetation in SOILM_VEG somewhat mitigates amplitudes of that dryness. JFM precipitation variability is not significantly affected with different experimental settings, although it is slightly decreased, mainly as a result of soil moisture coupling. Differences between experiments are more pronounced for JAS season, and precipitation is strongly reduced in both experiments. Soil moisture coupling in SOILM experiment predominantly affects the precipitation, while vegetation simulated in the SOILM_VEG additionally decreases precipitation. This is consistent with some previous results, for example, Notaro et al. (2006) who reported that vegetation and precipitation are negatively correlated for warmer part of the year. Variability of modelled JAS precipitation is not modified significantly, but it is still slightly decreased (mainly as a result of soil moisture coupling).

During the both seasons, evaporation is enhanced over the sea, and suppressed over the land. For JFM season, the changes of evaporation relative to the CTRL experiments are almost the same in SOILM and SOILM_VEG experiments indicating predominant effect of soil moisture coupling. There is no significant change in evaporation variability, neither in SOILM nor in SOILM_VEG experiment. However, JAS evaporation differences relative to the CTRL experiment are much greater, and JAS evaporation is substantially reduced over the land in SOILM experiment what is even more pronounced in SOILM_VEG. JAS evaporation variability is increased over the land in SOILM experiment, while it is somewhat decreased over the eastern part of the domain in SOILM_VEG experiment. It is an indication that vegetation may reduce evaporation variability.

Generally, SOILM and SOILM_VEG experiments indicate that the coupling with soil moisture and vegetation models induce much stronger impact on the climatology of the temperature, precipitation and evaporation than on their interannual variability. Furthermore, the impact on climatology of those variables is more pronounced for JAS than for JFM season with no changes in spatial distributions. According to the presented results, the impact on the investigated variables relative to the control experiment is mainly due to processes associated with soil moisture coupling. The effect of dynamic vegetation on the analysed variables depends on the season. During the winter, its effect is opposite than that of the soil moisture coupling (there is a kind of cancellation of those two effects). While the effect of vegetation on winter temperatures is substantial, its impact on precipitation and evaporation is rather weak. However, simulated impacts of soil moisture and vegetation coupling for JAS season are associated with anomalies of the same sign resulting in much stronger and statistically significant differences relative to the control experiment. Generally, the impact of soil moisture coupling is predominant in both seasons, but dynamic vegetation has an opposite effect during JFM and JAS season. During the summer, it additionally (and statistically significantly) amplifies the effect of the soil moisture.

Generally, during the summer (when temperature and precipitation changes are substantial and statistically significant), the soil wetness availability is reduced as a consequence of decreased precipitation. Enhanced net surface radiation is associated with decreased evaporation, whilst increased sensible flux substantially warms the lower atmosphere resulting in temperature increase.

Acknowledgements – The authors would like to thank two anonymous reviewers for their constructive and helpful comments. This work was supported by University of Zagreb (grant 202312).

References

Bonan, G. B. (2002): *Ecological climatology: Concepts and applications*. Cambridge University Press, London, UK, 678 pp.

Bourke, W. (1974): A multi-level spectral model. I. Formulation and hemispheric integrations, *Mon. Weather Rev.*, **102**, 687–701, DOI: 10.1175/1520-0493(1974)102<0687:AMLSMI>2.0.CO;2.

Buermann, W. (2002): The impact and response of vegetation to climate at interannual timescales, *Ph.D. Thesis, Boston University,* 140 pp.

Chen, J. M. and Black, T. A. (1992): Defining leaf area index for non-flat leaves, *Plant Cell Environ.*, **15**, 421–429, DOI: 10.1111/j.1365-3040.1992.tb00992.x.

Dee, D. P., Uppala, S. M., Simmons, A. J., Berrisford, P., Poli, P., Kobayashi, S., Andrae, U., Balmaseda, M. A., Balsamo, G., Bauer, P., Bechtold, P., Beljaars, A. C. M., van de Berg, L., Bidlot, J., Bormann, N., Delsol, C., Dragani, R., Fuentes, M., Geer, A. J., Haimberger, L., Healy, S. B., Hersbach, H., Hólm, E. V., Isaksen, L., Kållberg, P., Köhler, M., Matricardi, M., McNally, A. P., Monge-Sanz, B. M., Morcrette, J.-J., Park, B.-K., Peubey, C., de Rosnay, P., Tavolato, C., Thépaut, J.-N. and Vitart, F. (2011): The ERA-Interim reanalysis: configuration and performance of the data assimilation system, *Quart. J. Roy. Meteor. Soc.*, **137**, 553–597, DOI: 10.1002/qj.828.

Held, I. M. and Suarez, M. J. (1994): A proposal for intercomparison of the dynamical cores of the atmospheric general circulation models, *Bull. Amer. Meteor. Soc.*, **75**, 1825–1830, DOI: 10.1175/1520-0477(1994)075<1825:APFTIO>2.0.CO;2.

Kucharski, F., Molteni, F., King, M. P., Farneti, R., Kang, I. S. and Feudale, L. (2013a): On the need of intermediate complexity general circulation models: a 'SPEEDY' example, *Bull. Amer. Meteor. Soc.*, **94**, 25–30, DOI: 10.1175/BAMS-D-11-00238.1.

Kucharski F., Zeng, N. and Kalnay, E. (2013b): A further assessment of vegetation feedback on decadal Sahel rainfall variability, *Clim. Dyn.*, **40**, 1453–1466, DOI: 10.1007/s00382-012-1397-x.

Notaro, M., Liu, Z. and Williams, J. W. (2006): Observed vegetation climate feedbacks in the United States, *J. Climate*, **19**, 763–786, DOI: 10.1175/JCLI3657.1.

Oke, T. R (1987): *Boundary layer climates*. Methuen, London, 372 pp.

Pielke, R. A., Avissar, R., Raupach, M., Dolman, A. J., Zhen, X. and Denning, A. S. (1998): Interactions between the atmosphere and terrestrial ecosystems: Influence on weather and climate, *Glob. Change Biol.*, **4**, 461–475, DOI: 10.1046/j.1365-2486.1998.t01-1-00176.x.

Pollard, D. and Thompson S. L. (1995): Use of a land-surface-transfer scheme (LSX) in a global climate model: the response to doubling stomatal resistance, *Global Planet. Change*, **10**, 129–161, DOI: 10.1016/0921-8181(94)00023-7.

Rayner, N. A., Parker, D. E., Horton, E. B., Folland, C. K., Alexander, L. V., Rowell, D. P., Kent, E. C. and Kaplan, A. (2003): Global analyses of sea surface temperature, sea ice, and night marine air temperature since the late nineteenth century, *J. Geophys. Res.*, **108**, 4407, DOI: 10.1029/2002JD002670.

Rechid, D. (2009): On biogeophysical interactions between vegetation phenology and climate simulated over Europe, in: *Reports on Earth System Science*. Max Planck Institute for Meteorology, Hamburg, Germany, No. 61/2009, 130 pp.

Rosenberg, N. J., Blad, B. L. and Verma, S. B. (1983): *Microclimate: The biological environment*. John Wiley & Sons, New York, 495 pp.

Seneviratne, S. I. and Stöckli, R. (2007): The role of land-atmosphere interactions for climate variability in Europe, in: *Climate variability and extremes during the past 100 years*. Springer, Dordrecht, **33**, 179–193, DOI: 10.1007/978-1-4020-6766-2_12.

Shukla, J. and Mintz, Y. (1982): Influence of land-surface evapotranspiration on the Earth's climate, *Science*, **215**, 1498–1501, DOI: 10.1126/science.215.4539.1498.

Sud, Y. C., Shukla, J. and Mintz, Y. (1988): Influence of land surface roughness on atmospheric circulation and precipitation: A sensitivity study with a general circulation model, *J. Appl. Meteorol.*, **27**, 1036–1054, DOI: 10.1175/1520-0450(1988)027<1036:IOLSRO>2.0.CO;2.

Wang, W., Anderson, B. T., Phillips, N., Kaufmann, R. K., Potter, C. and Myneni, R. B. (2006): Feedbacks of vegetation on summertime climate variability over the North American grasslands. Part I: Statistical analysis, *Earth Interact.*, **10**, 1–27, DOI: 10.1175/EI196.1.

Whittaker, R. H. (1975): *Communities and ecosystems*. MacMillan, New York, 385 pp.

Woodward, F. I. (1987): *Climate and plant distribution*. Cambridge University Press, London, UK, 174 pp.

Xue, Y., de Sales, F., Vasic, R., Mechoso, C. R., Arakawa, A. and Prince, S. (2010): Global and seasonal assessment of interactions between climate and vegetation biophysical processes: A GCM study with different land-vegetation representations, *J. Climate*, **23**, 1411–1433, DOI: 10.1175/2009JCLI3054.1.

Zeng, N. (2003): Glacial-interglacial atmospheric changes – The glacial burial hypothesis, *Adv. Atmos. Sci.*, **20**, 677–693, DOI: 10.1007/BF02915395.

Zeng, N., Mariotti, A. and Wetzel, P. (2005): Terrestrial mechanisms of interannual variability, *Global Biogeochem. Cy.*, **19**, GB1016, DOI: 10.1029/2004GB002273.

SAŽETAK

Utjecaj vlažnosti tla i vegetacijskog pokrova na numeričke simulacije površinske temperature, oborine i evaporacije na području Europe

Irena Ružić i Ivana Herceg-Bulić

U ovom radu ispitan je utjecaj vegetacijskog pokrova i vlažnosti tla na klimatske simulacije na području Europe. U tu je svrhu korišten model opće cirkulacije atmosfere – ICTP AGCM. Napravljene su tri ciljane simulacije za vremensko razdoblje 1981.–2010. god.: kontrolni eksperiment u kojem je simulirano međudjelovanje tla i atmosfere jednostavnim modelom interakcije tla i atmosfere (eng. *land-surface model*), zatim eksperiment u kojem je atmosferski model združen s modelom vlažnosti tla (eng. *land-surface temperature and soil moisture coupling*) te eksperiment modelom vlažnosti tla i s interaktivnom vegetacijom (eng. *interactive vegetation coupling*). Ispitan je utjecaj modela vlage u tlu i dinamičke vegetacije na amplitudu i međugodišnju promjenjivost površinske temperature zraka, oborine i evaporacije za zimsku i ljetnu sezonu. U usporedbi s kontrolnim eksperimentom, model združen s modelom vlage u tlu simulira povećanje temperature iznad kontinentalnog dijela Europe tijekom obje promatrane sezone. Međutim, modelom s interaktivnom vegetacijom se povećanje temperature simulira samo tijekom ljeta, dok je zimi dobiveno njeno smanjenje. Općenito, model dinamičke vegetacije smanjuje ukupnu oborinu, a područja s najizraženijim smanjenjem se podudaraju s područjima reducirane evaporacije. Rezultati prikazani u ovom radu ukazuju da model vlage u tlu i model interaktivne vegetacije značajno utječu na amplitude simulirane temperature zraka, oborine i evaporacije. Suprotno tome, nije dobiven značajan ujecaj na međugodišnju varijabilnost promatranih parametara.

Ključne riječi: model ICTP AGCM, model vlage u tlu, model dinamičke vegetacije, površinska temperatura zraka, oborina, evaporacija, međugodišnja varijabilnost

Corresponding author's address: ire.ruzic@gmail.com