Publizierbarer Endbericht

Gilt für Studien aus der Programmlinie Forschung

A) Projektdaten

Allgemeines zum Projekt	
Kurztitel:	Reclip:convex
Langtitel:	Research for Climate Protection: Value-adding Convection-Permitting Climate Simulations Austria
Zitiervorschlag:	siehe Kurztitel
Programm inkl. Jahr:	ACRP 10th call (2017)
Dauer:	01.06.2018 bis 28.02.2021
KoordinatorIn/ ProjekteinreicherIn:	Zentralanstalt für Meteorologie und Geodynamik (ZAMG)
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Projekt- und KooperationspartnerIn (inkl. Bundesland):	- University of Graz, Wegener Center for Climate and Global Change (WEGC), Regional Climate Research Group RCRG - University of Natural Resources and Life Sciences (BOKU), Vienna; Institute of Meteorology (BOKU-MET) - Austrian Institute Of Technology (AIT)
Schlagwörter:	Convection permitting climate simulations, soil moisture atmosphere feedback mechanism, Urban heat island effect, Thunderstorms, convective extremes, land surface models
Projektgesamtkosten:	248.314 €
Fördersumme:	248.314 €
Klimafonds-Nr:	KR17AC0K13666
Erstellt am:	29.09.2021

B) Projektübersicht

1 Kurzfassung

(max. 2 Seiten, Sprache Deutsch)
Kurze Darstellung des Projekts, Zusammenfassung der wesentlichen Projektergebnisse qualitativ und quantitativ (bei Szenarien, Kostenanalysen, volkswirtschaftlichen Studien, Potenzialstudien sind ausgewählte nummerischen Werte festzuhalten – in % sowie die Werte selbst).

Das Projekt „reclip:convex" verfolgt zwei Hauptziele:

1. Wie wirken sich Bodenfeuchteanomalien während Trocken- und Regenperioden auf konvektive Niederschläge und Hitzewellen im Alpenraum unter Einfluss des Klimawandels aus?
2. Welche Maßnahmen können im urbanen Raum umgesetzt werden, um zukünftigen Hitzebelastungen in Städten effektiv entgegen zu wirken?

Neue, sogenannte „konvektions-erlaubende" Klimamodelle, die mit einer Auflösung von 1 km bis 3 km auch vertikale Luftbewegungen besser abbilden können, sollen auch einzelne Gewitter in den Simulationen physikalisch erfassbar machen. Auch wird in diesen Modellen die Struktur der Alpen und deren Vorländer besser erfasst, sodass regionale Rückkopplungsmechanismen auf das Wettergeschehen realistischer wiedergegeben werden. Fragen, wie sich beispielsweise Änderungen der Bodenfeuchte auf die Entwicklung von Gewittern und Hitzewellen auswirken oder wie sich Niederschlagsereignisse durch den beschleunigten Wasserkreislauf verändern, können damit detailliert untersucht werden. Die Wissenschaft erhofft sich dadurch eine Reduktion der Unsicherheiten in Aussagen über den zu erwartenden Klimawandel im Alpenraum.

In der internationalen Pilotstudie "Convective phenomena at high resolution over Europe and the Mediterranean" (CORDEX-FPS) des World Climate Research Programme (WCRP) wird derzeit ein Satz an konvektions-erlaubenden Klimasimulationen für den erweiterten Alpenraum generiert. In dem österreichischen Projekt "reclip:convex" (reclipconvex.zamg.ac.at), finanziert durch den Klima- und Energiefonds und umgesetzt von der Zentralanstalt für Meteorologie und Geodynamik (ZAMG), dem Wegener Center für Klima und Globalen Wandel der Karl-Franzens-Universität Graz (WEGC), dem Institut für Metorologie und Klimatologie der Universität für Bodenkultur Wien (BOKU-Met) und dem Austrian Institute of Technology (AIT), werden Rückkopplungsmechanismen im Ostalpenraum untersucht. Dabei wird auch der neue Satz an konvektions-erlaubenden Klimasimulationen speziell für das österreichische Staatsgebiet aufbereitet und der Klimafolgenforschung sowie der Öffentlichkeit über das Datenportal des Climate Change Centre Austria (CCCA) kostenlos zur Verfügung gestellt.

In Rahmen des Projekt Urban Klimawandel und Klimawandel Anpassung in Vienna ist auch untersucht. Speziell für Stadtgebiete bieten urbane Klimamodelle den derzeit neuesten Stand der Technik. Mit dem deutschen regionalen Klimamodell Cosmo-CLM und speziellen urbanen Erweiterungen (TERRA-URB), welche anthropogene Wärmeemissionen und hochaufgelöste Versiegelungslayer integrieren, wurden von AIT urbane Klimasimulationen mit einer Auflösung von 1x1 km für den Großraum Wien (100x100 km) durchgeführt. Vier Begrünungsszenarien („Status Quo", „Moderate Begrünung", „Maximale Begrünung" und „Worst Case") die entsprechenden Daten für Versiegelung, Pflanzenbedeckung und Baumbestand aus den Karten der USTs (Urban Standard Topology) extrahiert und die Inputdaten des Klimamodells entsprechend modifiziert.

Die Ergebnisse von dieser Studie zeigen, dass vor allem die Nachttemperaturen mit zunehmender Begrünung entsprechend abgesenkt werden können und in weiten Bereichen der Stadt im Mittel Reduktionspotentiale von mehr als 2 °C erreichbar sind. Dies macht sich vor allem in einer deutlichen Abnahme der Anzahl der Tropennächte (Tmin > 20 °C) bemerkbar.

Auch in den Tagesgängen eines Bestandsgebietes des 10.Bezirks für 2 speziell ausgewählte „Normtage" ist der Temperaturrückgang während der Nachtstunden deutlich zu sehen.

2 Executive Summary

(max. 2 Seiten, Sprache Englisch)
Siehe oben.

The two main goals set out for this research project were:

i) to further our understanding of the uncertainties associated with changes in soil moisture and role of positive and negative soil moisture feedbacks in triggering and sustaining summertime convection under climate change conditions.

ii) investigate heat stress in Austrian cities and suggest possible adaptation strategies.

Key findings

1. Soil moisture feedbacks are (positive / negative) are important for individual precipitations events but do not play a dominant role on climatological scale (neither in current climate nor in future climate conditions).
2. Soil moisture feedbacks can influence the location of the precipitation however, extent and intensity of precipitation remain unchanged (besides displacement of precipitation no significant effect on mean value statistics is seen).
3. Due to soil moisture's dependency from previous precipitations events, local seasonal precipitation perturbations upto +/- 50 % are induced while root soil moisture stays in the range of +/- 5 %.
4. Positive temporal soil moisture feedbacks correspond to intensive precipitation events while negative feedbacks are in favour of weak precipitation events.
5. These relationships remain even under different climate change scenarios (with increasing/decreasing seasonal mean precipitation and weakly/strongly decreasing soil moistures).
6. Climate change effects are majorly caused by climate change from outside the model domain
7. Convection-permitting urban climate simulations can reproduce the urban heat island effect for the city of Vienna with good accuracy. Three runs with a "Status Quo" (STQ), "Moderate Greening" (MOD) and "Maximum Greening" (MAX) were conducted.
8. Our results show a reduction up to 2 degrees Celsius in minimum nighttime summer temperatures is possible for MOD scenario.
9. Summertime precipitation in urban simulations exhibited unrealistic high values.

10. Our results also confirm previous studies that suggest that Extreme precipitation events are not well captured in big-domain setups where model has higher degree of freedom.
11. The WRF model is unable to produce realistic wind fields during thunderstorms (unable to simulate downdrafts)
12. Soil moisture initialization effect lessens with the progression of simulation due to saturation of soil.
13. Clausius Clapeyron Scaling works very well in convective permitting climate model simulations.

Scientific challenges and outlook

1. Results pertaining to soil moisture feedback mechanism in the Alpine region cannot be generalized as these results are based on one regional climate model results.
2. Unrealistic precipitation values in urban climate simulations for summer season need further investigations.
3. An appropriate combination of physical schemes is required to reproduce the extreme precipitation events.
4. There is a need for Soil moisture observational dataset that can be used to verify and validate land surface models.

Policy messages

1. Results from urban simulation experiments show that greening scenarios can significantly help reduce the nighttime temperatures in Vienna.
2. Green infrastructure is more efficient at higher daily temperature and during night time, which makes it a promising candidate for improving adaptive capacity of urban areas in the future.
3. Soil moisture feedbacks mechanism and soil moisture initializations have not shown significant effect on extreme precipitation events and further scientific investigation is required.

3 Hintergrund und Zielsetzung

(max. 2 Seiten) Beschreibung von Ausgangslage, Aufgabenstellung und Zielsetzung.

The anthropogenic climate change is a global phenomenon, however, on regional scale global and regional climate model projections depict a high variability in temperature and precipitation results. Simulations carried by these models agree that global mean temperature will continue to rise in the first and second half of this century.

Scientific studies suggest that in Europe with increase in temperature, precipitation will significantly increase / decrease in the North / South Europe in the first as well in the second half of this century. However, this climate change signal is different in European Alpine region (hereafter referred to as Alps) which lies in the transitory region of this gradient. Although most simulations agree that Alps are more sensitive to climate change than other regions with a temperature rise of more than twice of the global mean, results are uncertain regarding the precipitation distribution especially in summer months when fine scale processes like convection play significant role. This discrepancy in parts comes from the coarse spatial resolution of these models as well as from knowledge gaps in our understanding of the underlying physical processes and their significance in the climate system.

Rising temperatures over the Mediterranean together with a rise in specific humidity (according to the Clausius-Clapeyron relationship) and an increase in atmospheric blocking events during summertime are ingredients of a potential intensification of both, convective events and heat stress. Alongside also the processes in the development and intensity of related extreme events including soil-moisture feedbacks and the urban heat island effect might change in the future.

Existing global and regional climate model simulations and the national climate change scenarios ÖKS15 do not properly represent the effects of complex terrain, convection, soil-atmosphere feedbacks, and planetary boundary layer processes in urban areas due to their coarse resolution.

Recent breakthrough in regional climate modelling has led to development of new generation of regional climate models which are often referred to as "convection permitting" climate models. In recent years many research projects have focused on exploring the added-value of these convection permitting climate models especially in filling knowledge gaps and improving our understanding of climate system. These highly sophisticated "convection-permitting" climate models, with a resolution of 1km to 3km can not only better represent vertical air movements but are also able to simulate individual thunderstorms that are physically detectable in these simulations.

These convection permitting regional climate models are now bridging the gap to impact models, like urban models, in a physically based manner. The Alpine mountains and forelands are better represented in these simulations, hence, making it possible to better depict regional feedback mechanisms. The reported project "reclip:convex" is also one such project where researchers from AIT, BOKU, WEGC and ZAMG have used "convection permitting" and "Urban modelling" approach to pursue research questions such as, how changes in soil moisture affect the development and sustenance of thunderstorms and heat waves or how precipitation events change because of the accelerated water cycle on climatic scale.

The "reclip:convex" project had the following main research questions (RQ) and objectives insight:

RQ1: How are summertime precipitation and heat events in the Eastern Alpine region affected by dry/moist soil and atmospheric pre-conditions?

RQ2: How does summertime deep convection change in a changing climate? Can we expect an overemphasised increase in summertime precipitation extremes?

RQ3: Do soil-atmosphere feedbacks in a changing climate control climate change effects on summertime precipitation and heat events?

RQ4: When simulated with convection-permitting models, what measures in urban areas do effectively reduce heat events in Austrian cities?

RQ5: Is there an added value in modelling techniques due to resolutions beyond 3 km?

A further objective of the project was to extend the set of Austrian climate change projections, ÖKS15, which is part of the Austrian adaptation strategy, by means of the CORDEX-FPS ensemble.

4 Projektinhalt und Ergebnis(se)

(max. 20 Seiten)
Darstellung des Projektes, der Ziele und der im Rahmen des Projektes durchgeführten Aktivitäten. Darstellung der wesentlichen Arbeitspakete und Aktivitäten. Präsentation der Projektergebnisse.

Soil moisture precipitation feedback strength

WEGC team implemented a method to measure the strengths of the soil moisture precipitation feedback based on the approach of Guillod et al. (2015) and Moon et al. (2019) on temporal and spatial scales. This method is based on soil moisture anomalies (deviations from its climatological mean; referred to as "strength") that exist before a precipitation event is taking place. Deriving such anomalies for numerous individual precipitation events allowed us to investigate soil moisture feedback strengths in a statistical manner. In order to investigate how precipitation events are related to soil moisture feedbacks in Austria (see RQ1) and to overcome the lack of highly resolved (spatial and temporal) soil moisture observations in Austria, the High Resolution Land Data Assimilation System (HRLDAS; Chen et al.,

2007) was operated on a 1 km x 1 km grid covering the Eastern Alps for the period 2005 to 2014. Required meteorological conditions (precipitation, air temperature, surface radiation, near surface wind, relative humidity, and surface pressure) have been derived from the analyses fields of the nowcasting system INCA (Haiden et al., 2011) and the analyses fields of the ECMWF re-analyses ERA5 (Hersbach et al., 2020). Long-wave radiation was parameterized via short-wave radiation, air temperature, and relative humidity following Gabathuler et al. (2001). The outcome of these investigations reveal that the entire Austrian domain lies within an energy-limited regime on average (see Figure 1), indicating that there is no systematic pre-condition for neither positive nor negative soil moisture precipitation feedbacks. Also, an inspection of individual afternoon precipitation events does not indicate any favor for any type of the feedbacks (see Figure 2), but it clearly demonstrates that single events are definitely subject of positive or negative feedbacks.

Impact of soil moisture perturbations on precipitation

In order to further investigate the role of soil moisture on precipitation in Austria (see RQ1), convection-permitting (3 km x 3 km horizontal grid spacing) one-year simulations (year 2009 plus 3 months for spin up) covering the Eastern Alpine region with CCLM driven by analysis fields of the ECMWF Integrated Forecast System (IFS) (Bechtold et al., 2008) have been conducted with and without perturbations of the soil moisture.

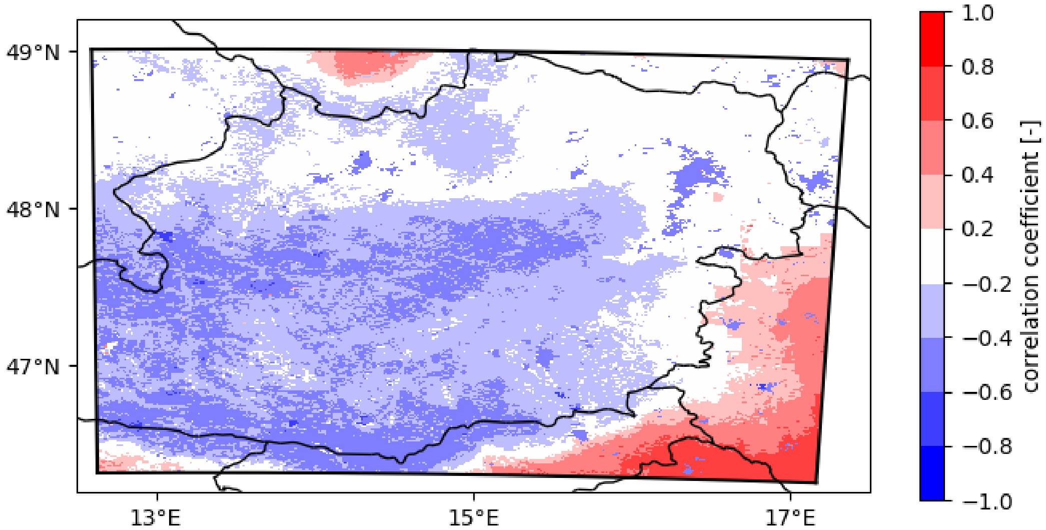


Figure 1: Temporal correlation coefficient between daily mean average morning (6:00 to 12:00 UTC) soil moisture and daily mean accumulated evapotranspiration from May to September, for the period of 2005 to 2014 from HRLDAS. All of Austria shows negligible or negative correlation, indicating a wet, energy-limited evapotranspiration regime. To the southeast the conditions are reversed, indicating a transition zone. From Schaffer (2021).

Thereby, perturbations of the soil moisture were induced by forcing deep (well below the hydrological active layer) soil moisture during model integration to be lower (-10 %, -5 %) or higher (+5 %, +10 %) than in the unperturbed case. This has the advantage that upper soil layers are in balance with atmospheric processes due to well-developed feedbacks, while moisture changes are introduced from below. On a seasonal basis, this leads to minor (< 1 %) changes in domain-wide total amount of precipitation and soil moisture, while local deviations on the order of +/- 50 % for precipitation and about +/- 5 % for soil moisture for summer months (JJA) occur (Figure 3). Moreover, the perturbations are not additive: changes in precipitation are not a trivial function of changes in soil moisture.

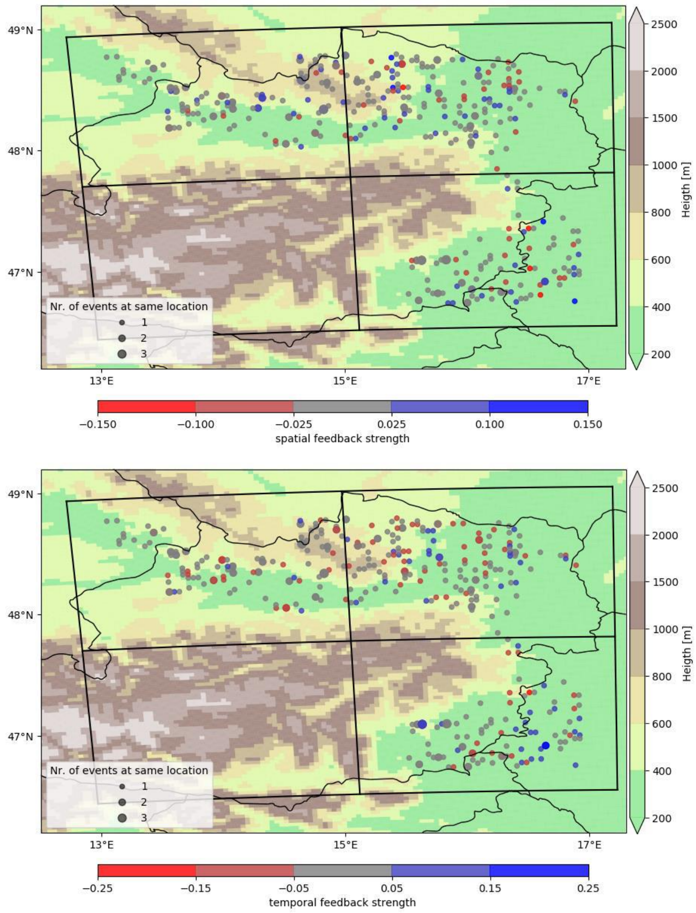


Figure 2: Spatial (left) and temporal (right) feedback strength of individual afternoon precipitation events from 2005 to 2014 (may to September) from HRLDAS. Red indicates negative, blue positive and grey insignificant soil moisture feedback conditions. The size of the dots represents the number of events at the same location. From Schaffer (2021).

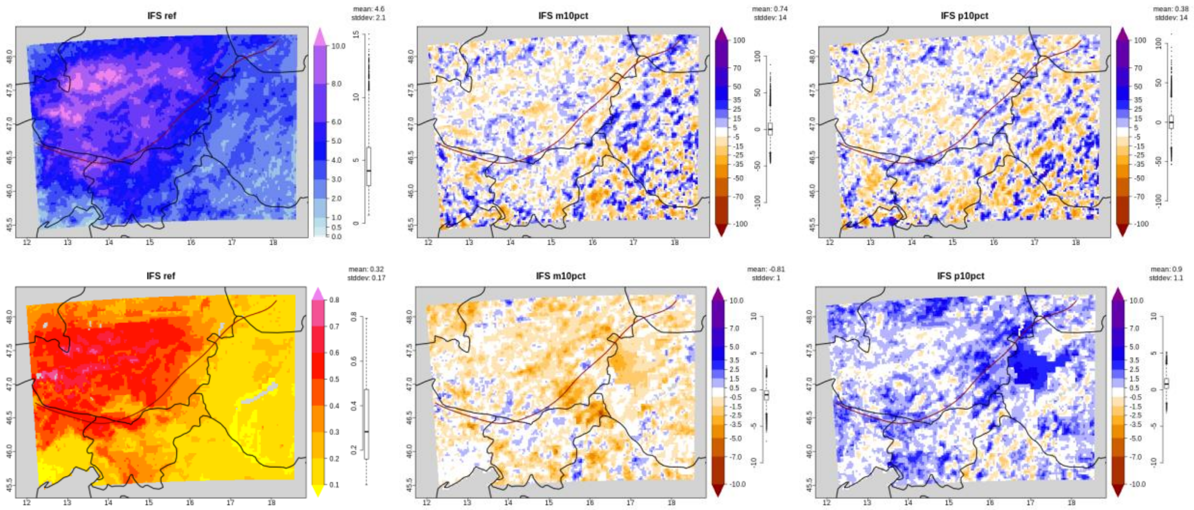


Figure 3: Seasonal (JJA) precipitation [mm/d] (top row) and upper layer (0 cm to 94 cm below surface) soil moisture fraction [-] (bottom row) and their changes due to a reduction (-10 %; middle column) and an increase (+10 %; right column) of deep soil moisture (94 cm to 1534 cm). The red line indicates a transition from more energy-limited (correlation between daily upper layer soil moisture and daily evapotranspiration > 0.35) to more moisture-limited regime (correlation of such < 0.35). (Results from +/- 5 % changes of deep soil moisture give similar result.)

An event based analysis via the Structure-Amplitude-Location index (SAL) (Wernli et al., 2008), reveals that the internal structure of precipitation objects does not systematically change (S, A, L are approx. 0.0), but their position is affected: on average single precipitation objects deviate from their initial position in the unperturbed simulation between 2 and 5 x grid spacing (i.e. 6 km to 15 km), depending on the season (Figure 4).

Further analyses of stationary precipitation events based on the approach of Guillod et al. (2015) and Moon et al. (2019) allow to investigate the influence of different types of soil moisture precipitation feedbacks on precipitation. In agreement with the analyses based on HRDLAS, the idealised CCLM simulations with the perturbed soil moisture fields indicate that the spatial and temporal feedback strengths are densely distributed across the precipitation events (standard deviation is smaller than 5 %), with a small (1.8 %) systematic favour for a positive feedback, which is related to the fact that the 2009 has a higher correlation between evapotranspiration and soil moisture (not shown) than the HRLDAS period (2005 to 2014).

Interestingly, especially in summertime (JJA), events with higher precipitation intensities are more likely under the influence of a positive temporal feedback and vice versa.

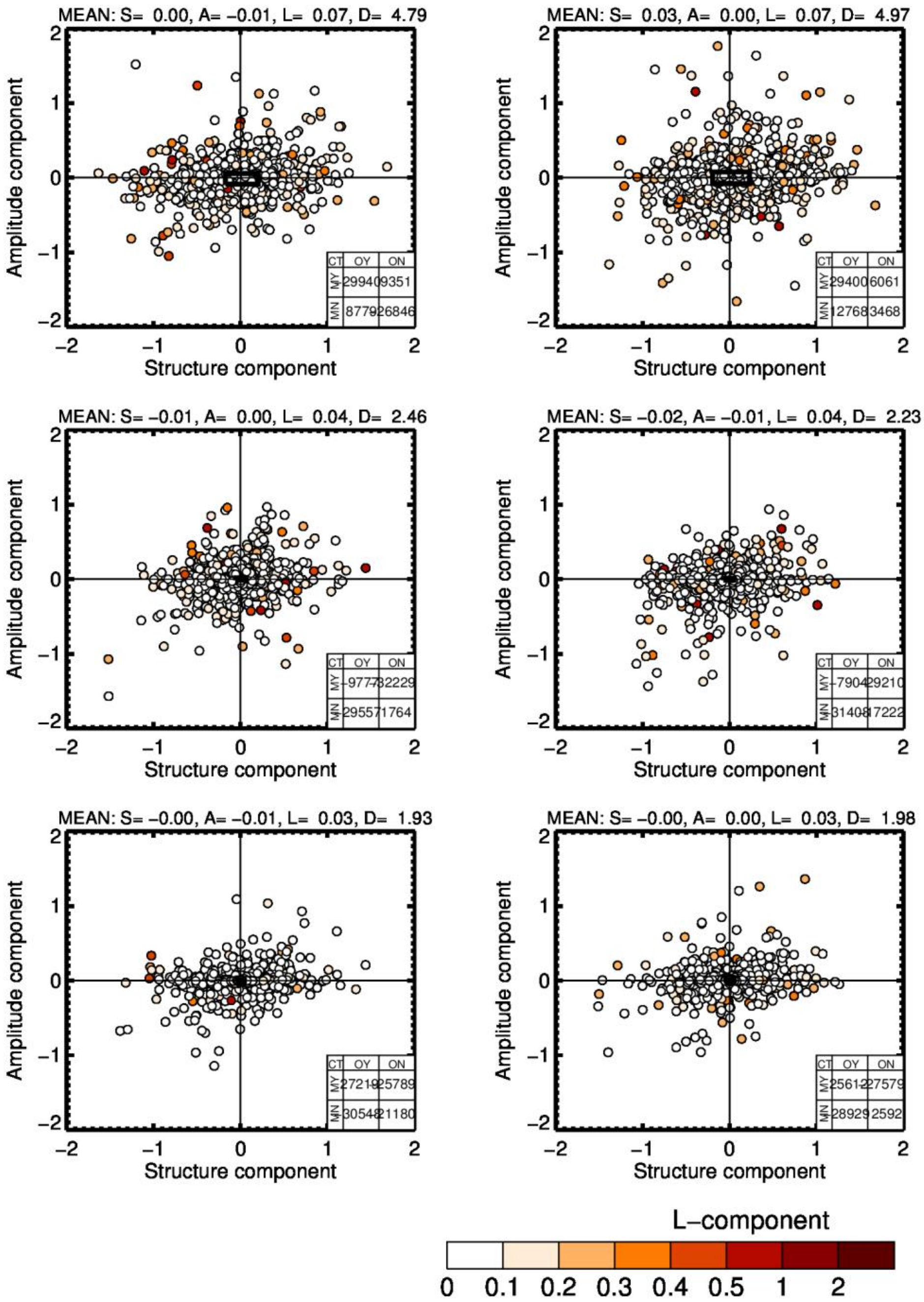


Figure 4: Seasonal (MAM, top row; JJA, middle row; SON, bottom row) SAL statistics of precipitation objects with intensities > 0.2 mm/h for -10 % (left column) and + 10 % (right column) changes of deep soil moisture. ("D" refers to the average deviation of the position of precipitation objects in terms of the grid spacing. Results from +/- 5 % changes give similar result.)

This behaviour is unaffected by soil moisture perturbations (Figure 5): the estimated average maximum precipitation intensity is more than 50 % higher for positive temporal feedback strengths than for negative ones. (There is no such clear relationship for the spatial feedback.)

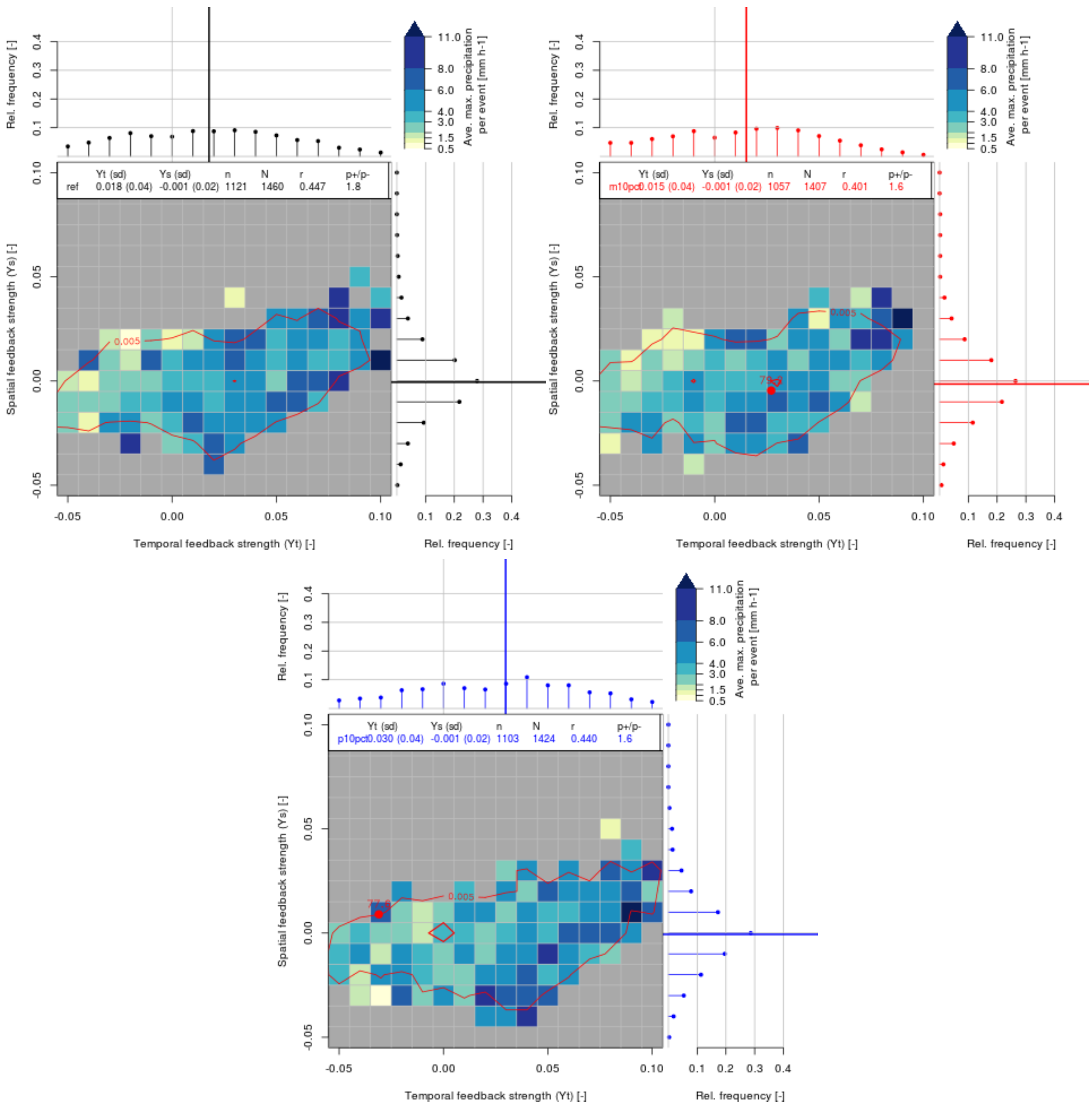


Figure 5: Seasonal (JJA) relative frequency distributions (marginal and 2D; red contour lines) for spatial and temporal feedback strengths and their estimated event-averaged maximum precipitation intensity (shaded colours) of unperturbed (top panel, left) and perturbed soil moisture by -10 % (top panel right) and +10 % (bottom panel, middle) one-year CCLM simulations in the moisture-limited area (see Figure 3).

In addition to the feedback related investigations, WEGC has successfully contributed to CORDEX-FPS and conducted a convection-permitting (3 km x 3 km grid spacing: Alpine region) hindcast (period 2000 to 2014) with WRF, following the CORDEX-FPS protocol.

The uncertainty ranges, i.e. the variability between the models for wet hour frequency is reduced by half with the use of kilometer-scale models. In order to evaluate the performance of soil moisture derived from CORDEX-FPS hindcasts from WRF and CCLM as well as from the observation-driven HRLDAS (see WP2), these modelled results are compared with 12 in-situ soil moisture observation stations from the WegenerNet (Fuchsberger et al., 2021) of an overlapping period from 2014 and 2015. It is found that all models severely underestimate the observations by at least -50 % (Figure 6, left). Furthermore, the soil moisture in CCLM frequently drops to the wilting point in late summer months. But also HRLDAS, which has the best performance, shows distinctive weaknesses. The applicability of the soil moisture feedback method (see WP2) is still not sacrificed, because it is based on soil moisture anomalies, which are much better in agreement with the observations (Figure 6, right), and hence the soil moisture feedback method becomes largely independent from such biases.

Evaluation of two land surface models

ZAMG evaluated two of the most widely used land surface models (LSM) namely, SURFEX (SURFace EXternalized; LeMoigne, 2009) and NOAH LSM (Chen et. al. 1996). SURFEX is implemented in AROME (Application of Research to Operations at MEsoscale; Seity et al., 2010) and NOAH is implemented in WRF (Weather Research and Forecasting; Skamarock et al., 2008) models respectively. The analysis is based on results from a total of four simulations. This small ensemble of four simulations done with two LSM's provides an overview on model performance and can be used to estimate model uncertainty and address the question of robustness in LSM results. This evaluation can be taken as guideline; however, these results cannot be generalized, and much caution is required when interpreting these results for other regions or time slices.

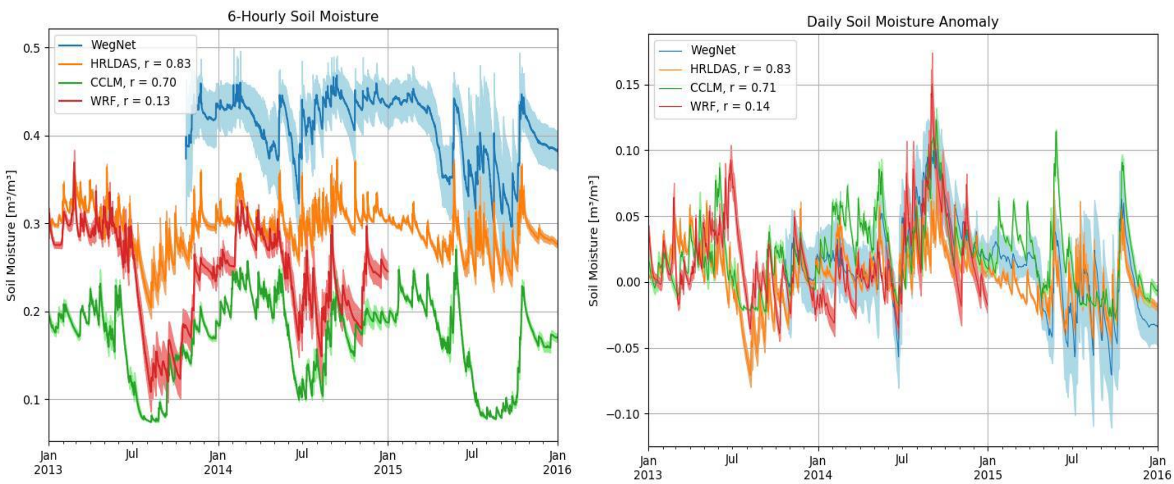


Figure 6: (Left) Mean soil moisture across 12 observation sites in the WegenerNet network (WegNet, blue), and the models at the same locations (HRLDAS, orange; CCLM, green; WRF, red) from 2013 to the end of 2015. Shaded areas refer to the variability across the 12 observation sites. (Right) same as in the left panel, but for soil moisture anomalies. From Schaffer (2021).

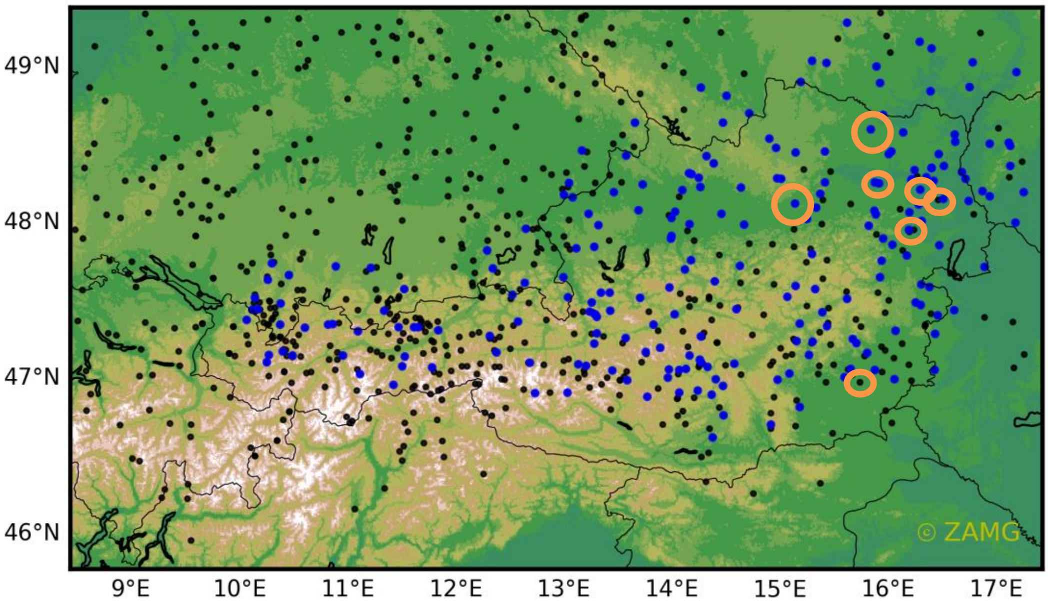


Figure 7 The study domain used in reclip:convex along with 980 stations used for seasonal / yearly analysis. The orange circles represent seven locations chosen for the monthly analysis.

Table 1 lists the simulation matrix used in this analysis. The first two columns depict the two RCMs i.e. AROME and WRF along with the two LSM and their respective horizontal gird spacing at which we have employed the two models. As one can notice three simulations were done with SURFEX model and one simulation was done with NOAH LSM. Third column describes the input data source used to drive the LSM. One simulation each with SURFEX and NOAH was driven with high resolution (1 km x 1 km) re-analysis dataset known as Integrated Nowcasting through Comprehensive Analysis (INCA), (Haiden et al., 2011). Precipitation and wind were taken from INCA and the rest of the variables required to run the LSM were taken from their respective RCMs. These two LSM simulations can be used as an alternative for evaluation of RCM results and help to address the deficiency of in-situ observations for SM in WP3.

One simulation done with AORME was driven with operational AROME model and for one simulation we have assimilated artificial high values for soil moisture and the rest of the variables in this case were also provided by AROME. This experiment was done to test model response in case of an extreme positive phase. Acronym for four simulations can be seen in fourth column of Table 1, i.e. SURFEX-INCA (i.e. SURFEX LSM, driven with INCA), SURFEX-AROME (i.e. SURFEX LSM driven with AROME), SURFEX-SODA (SURFEX LSM with assimilation of artificially high soil moisture values) and NOAH-INCA (i.e. NOAH LSM driven with INCA). The simulation time period for all four simulations was from 2016 – 2018.

Table 1 Four-member ensemble used for the analysis with RCM, LSM and acronym used for the simulation

RCM	LSM	Driving dataset	Acronym	Duration
WRF	NOAH / 1 km	INCA	NOAH-INCA	2016-2018
AROME	SURFEX / 500 m	INCA	SURFEX-INCA	2016-2018
AROME	SURFEX / 500 m	AROME	SURFEX-AROME	2016-2018
AROME	SURFEX / 500 m	SM Assimilation	SURFEX-SODA	2016-2018

The presented analysis is based on comparison of simulated ground temperature with ZAMG operated network of in-situ observations for ground temperature and due to lack of in-situ observations for soil moisture (SM) we have compared all four simulations with each other and with **WINFORE** dataset. WINFORE dataset is not based on direct observations of SM but it is currently being used as the "**operational meteorological drought monitoring system"** at ZAMG. The indicator in WINFORE is based on the **Climatic Water Balance (CWB)** which is the difference between precipitation and potential evapotranspiration. This index is calculated from a high-resolution gridded station observations dataset known as "SPARTACUS" (Hiebl and Frei, 2016). This index can be used as a pseudo indicator to monitor changes in soil moisture and charge / positive and discharge / negative phases. Comparison with WINFORE can tell if the model is able or unable to represent positive and negative SM changes. For details about the WINFORE dataset please refer to Haslinger and Bartsch, 2016.

For this analysis in total 980 station sites were used as shown in Figure 7. For yearly / seasonal analysis all available stations were used, however, for monthly analysis only seven sites which were identified by a group of hydrologists in another FFG funded project titled "A Cloud-Based System for High-Resolution Soil Moisture Monitoring over Austria" (BMON) were used (Please refer to sites marked with orange circles in Figure 7).

Figure 8 provides an overview on model performance on monthly scale for all four simulations for the three summer seasons, i.e. June, July, and August (JJA). Hourly values from each model are shown here. As one can notice that on monthly and seasonal scale both model results resemble a lot with each other. The distribution is equally distributed and mean value also do not differ much.

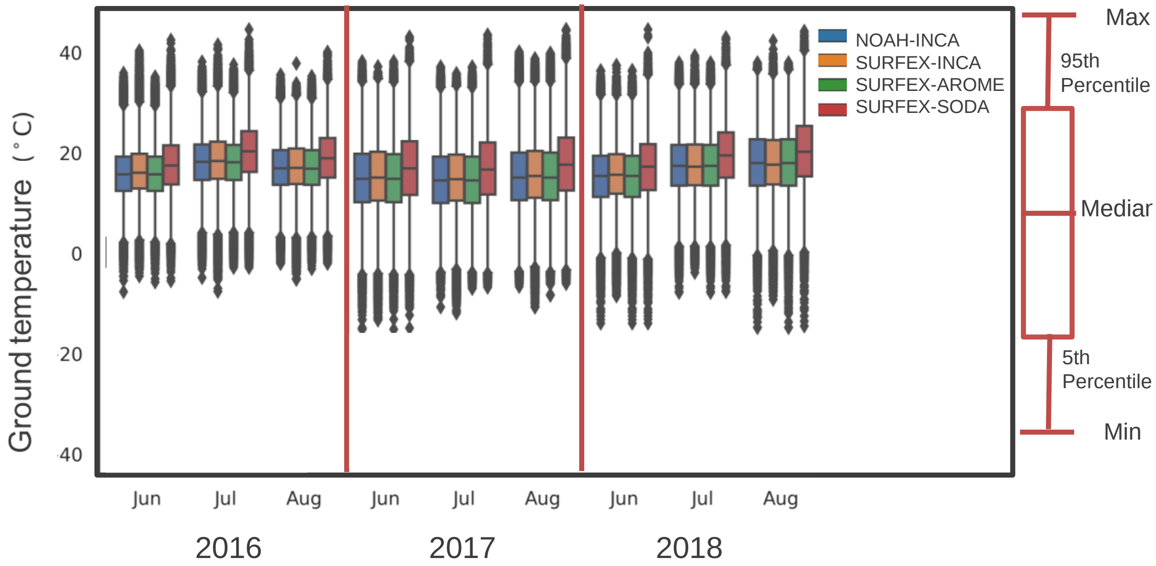


Figure 8 Box plot showing simulated ground temperature for all four simulations for the three summer seasons.

However, in the upper and lower percentile and range / number of outliers differ significantly among the four simulations. On point scale (Ground temperature variations on single station sites) we also see differences, however, these differences look like systematic errors and also remain within the known 2 Celcius range. Model performance in general remained persistent throughout the year with good results for other months and seasons as well (not shown here).

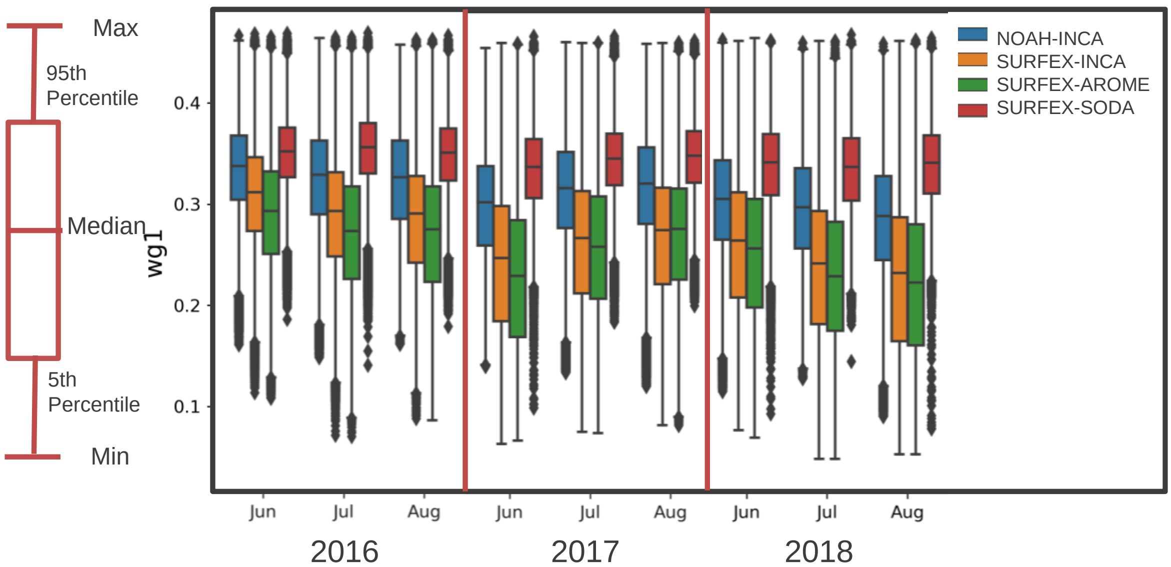


Figure 9 Box plot showing variations in 10 cm soil moisture in all four simulations for summer season (JJA) of 2016, 2017 and 2018

Figure 9 shows the variation in simulated soil moisture (wg1) at 10 cm for JJA, 2016 - 2018. In this figure one can notice similar to Figure 8 all simulations are able to represent the changes in SM successfully. The overall change in each month for all three seasons is not very large at this temporal and spatial scale. The difference in mean value is also very small and the shift looks more like a systematic shift in all these simulations and is persistent in all summer months throughout the evaluated time period. Yearly analysis also shows that diurnal cycle of SM is also captured by these simulations and overall, all models agree on changes in SM. The results for artificial moistened simulation SURFEX-SODA do not differ to a large scale from other simulations. From overview of these results one can conclude that both SURFEX and NOAH models are able to simulate SM and ground temperature with good accuracy and despite being two different LSMs both have shown similar results which to some extent show the robustness of these results. Moreover, we have found similar model behavior in more detailed monthly analysis as well (please refer to Figure 10, Figure 11).

As mentioned earlier, in order to assess model's performance in simulating the charge and discharge phase of SM variation we have compared the SM results with **WINFORE** dataset. Figure 10 show the comparison of daily SM from two INCA driven LSM simulations (i.e. SURFEX-INCA and NOAH-INCA) with WINFORE dataset for one station i.e. 11395, from the seven sites chosen for the analysis (please refer to Appendix for similar results from other sites). As one can notice both models are able to simulate the direction of SM changes successfully and agree with WINFORE dataset for all simulated summer seasons. Although there are some discrepancies in depicting the small daily variation, large crests and troughs are quite nicely captured. At daily scale one can also notice model's short comings such as systematic delays in response and over or underestimation. However, these results still highlight that both models are actually performing very well, and the results agree nicely with WINFORE indicator.

Figure 11 is similar to Figure 10 where daily simulated ground temperature is compared with in-situ observations of station number 11395. As one can see from these figures both models perform really well and almost identical to each other. The model performance remained persistent not only for JJA 2016 but in fact, for all seasons throughout the total simulation period i.e. 2016 -2018 (not shown here).

These results, hence, indicate that there are less differences in results that arise from use of a different LSM. In fact, it would not be wrong to say that these results are robust and uncertainty range in ground temperature and SM is almost negligible.

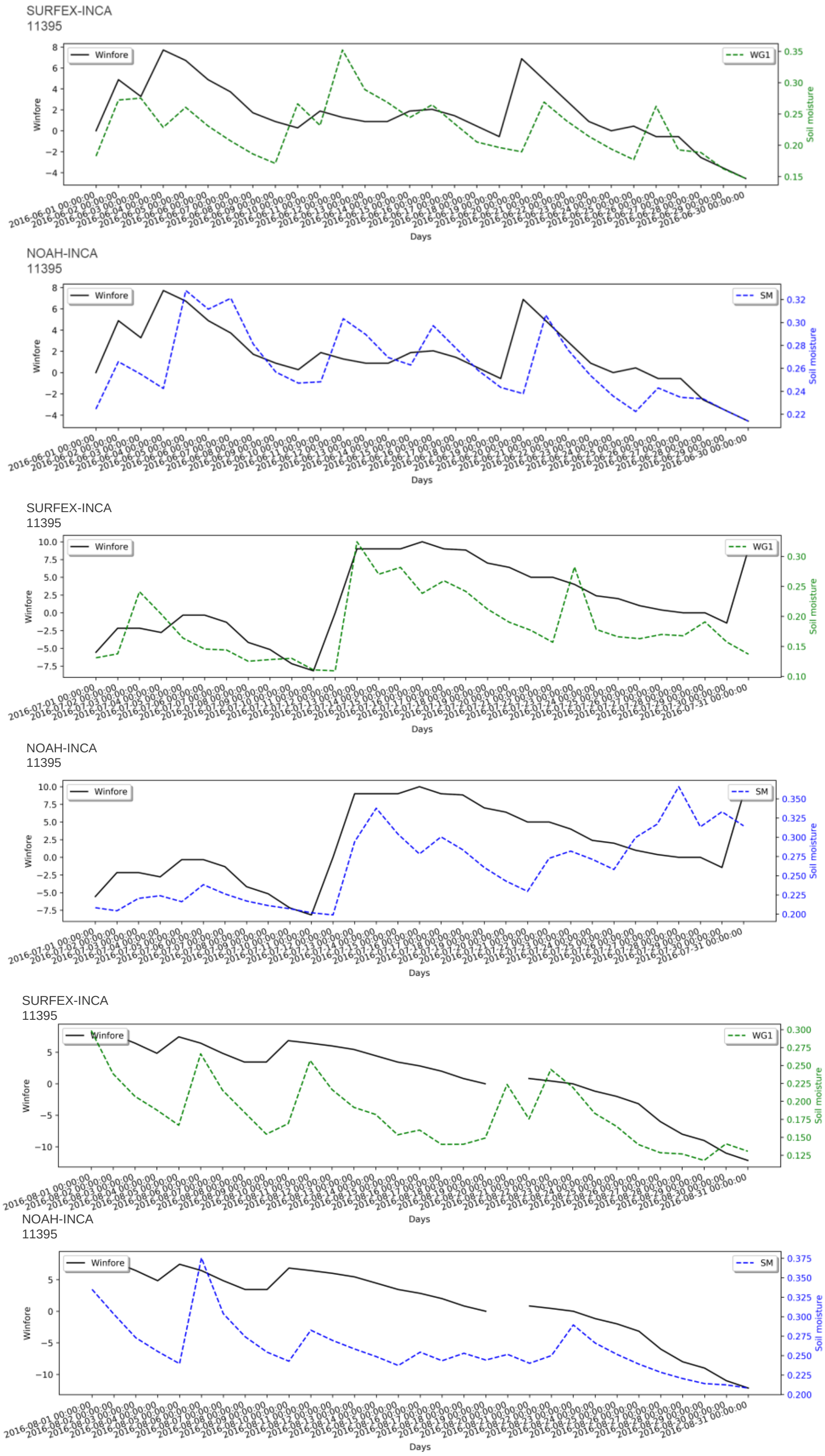


Figure 10 Comparison of monthly variation of 10 cm soil moisture with WINFORE dataset for the month of October, 2018 and station 11395 chosen as representative case.

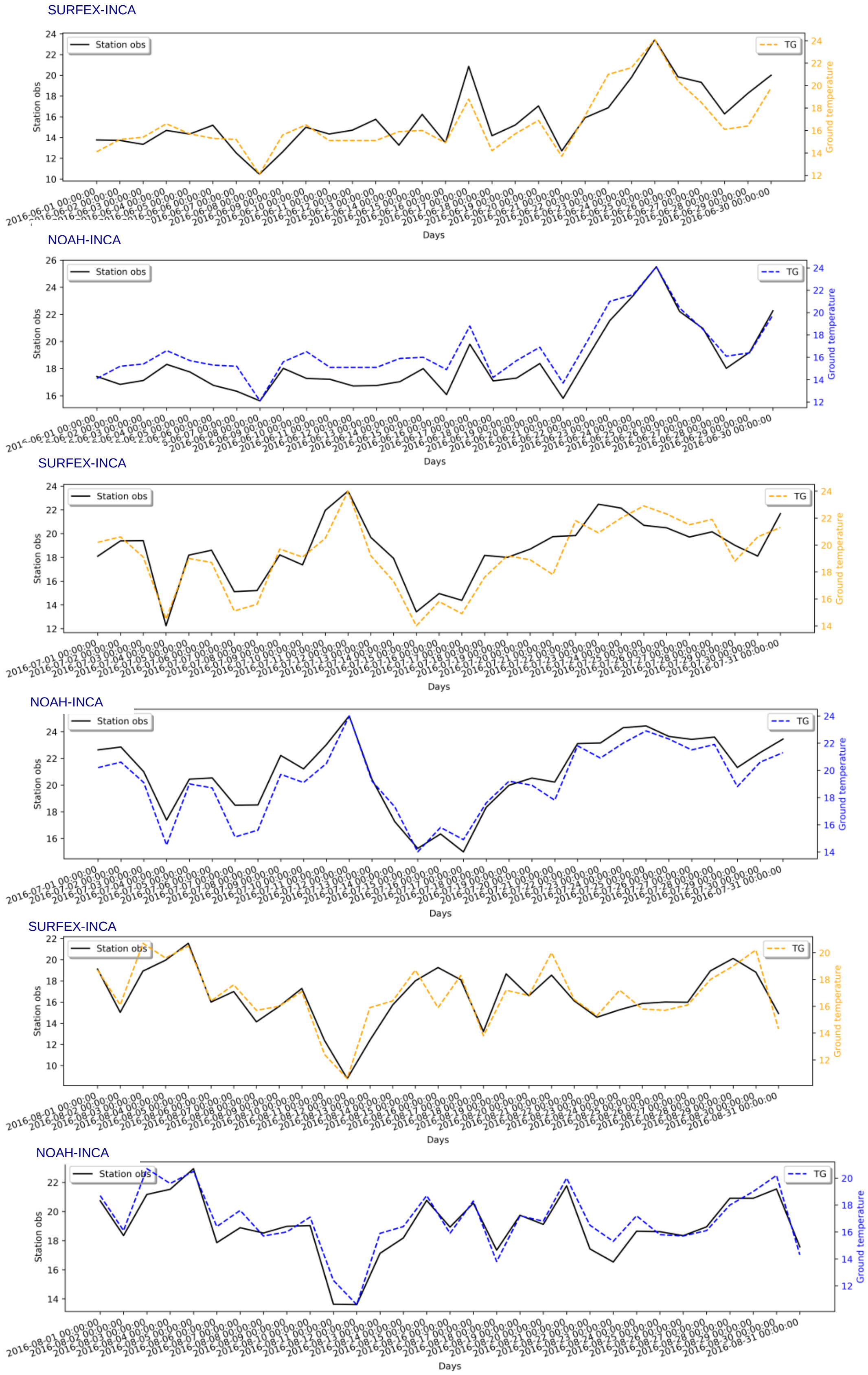


Figure 11 Comparison of simulated ground temperature with in-situ observations (station number 11395), top panel

Urban Modelling approach

Based on results from the former project reclip:century data from a 4 km run for Austria was used as forcing for a high resolution urban simulations. The area covers the Vienna Basin with 101 x 101 raster points at 1 km resolution. The applied model is the German community model Cosmo-CLM version 4.8_19 (Rocekel et al., 2008, Doms et al., 2011) with additional urban extensions in the land surface model TERRA_URB (Wouters et al., 2016).

This offers an implementation of urban physics in the Cosmo-CLM model by modifications to the input data, the soil-vegetation module TERRA ML (Schulz et al., 2016) and the land-atmospheric interactions. This implementation is online implementation where urban model is fully integrated in the atmospheric model. This is achieved by adding two additional layers to surface: a high-resolution soil sealing map and the annual mean anthropogenic heat flux (Flanner, 2009). Basic meteorological input relies on ERA-Interim data from ECMWF (Berrisford et al., 2011) and covers the period from 2001 to 2017.

In addition, four scenario runs i.e. Status Quo (STQ), a Moderate (MOD), a Maximum Greening scenario (MAX) and a Worst Case (WOC) have been conducted. The complete matrix of all model runs can be found in

Table 2 Matrix of conducted model runs

Table **2**. Including all data needed with extensions in TERRA-URB and creating a convection permitting set up for the base run it is possible to simulate and investigate the Urban Heat Island (UHI) effect.

Table 2 Matrix of conducted model runs

Model Version	Land Surface Model	Urban Extensions	Forcing Data	Greening Scenario	External Parameters	Region	Resolution	Raster Size	Time Period
CCLM cosmo_4.8_19	TERRA	no	ERA40, ERA-Interim	Base Run	WebPEP	Europe	50 km	104x104	1960-2015
CCLM cosmo_4.8_19	TERRA	no	ERA40, ERA-Interim	Base Run	WebPEP	Greater Alpine Region	10 km	125x110	1960-2015
CCLM cosmo_4.8_19	TERRA	no	ERA40, ERA-Interim	Base Run	WebPEP	Austria	4 km	190x115	1960-2015
CCLM cosmo_4.8_19	TERRA-URB	yes	ERA40, ERA-Interim	Base Run	WebPEP	Vienna Region	1 km	101x101	1960-2015
CCLM cosmo_4.8_19	TERRA-URB	yes	ERA-Interim	Status Quo	WebPEP, UST	Vienna Region	1 km	101x101	2000-2017
CCLM cosmo_4.8_19	TERRA-URB	yes	ERA-Interim	Moderate	WebPEP, UST	Vienna Region	1 km	101x101	2000-2017
CCLM cosmo_4.8_19	TERRA-URB	yes	ERA-Interim	Maximum	WebPEP, UST	Vienna Region	1 km	101x101	2000-2017
CCLM cosmo_4.8_19	TERRA-URB	yes	ERA-Interim	Worst Case	WebPEP, UST	Vienna Region	1 km	101x101	2000-2017

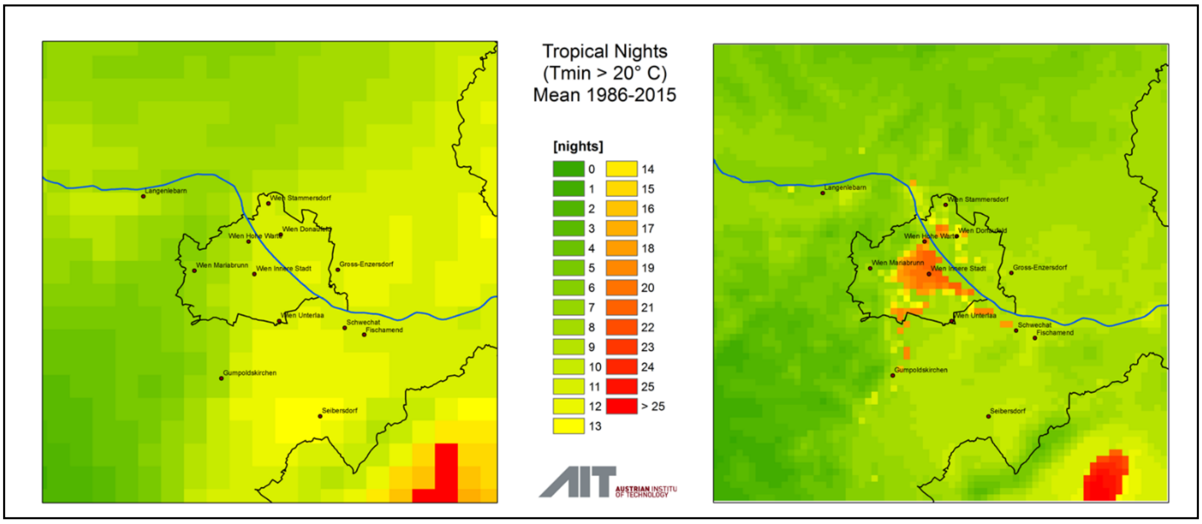


Figure 12 30-year mean of number of tropical nights – 4km simulation (left) and high-resolution urban simulation (right)

As it can be seen in Figure 12, 2m-temperature difference in Urban and suburban areas is more significant during nighttime. The urban simulations also reduce the temperature cold bias in Urban areas within city boundaries. We have observed a significant reduction in cold bias in all and simulated results show excellent agreement with measurements. While the standard version shows a distinct cold bias at 4 km this is almost eliminated in the high-resolution urban model run.

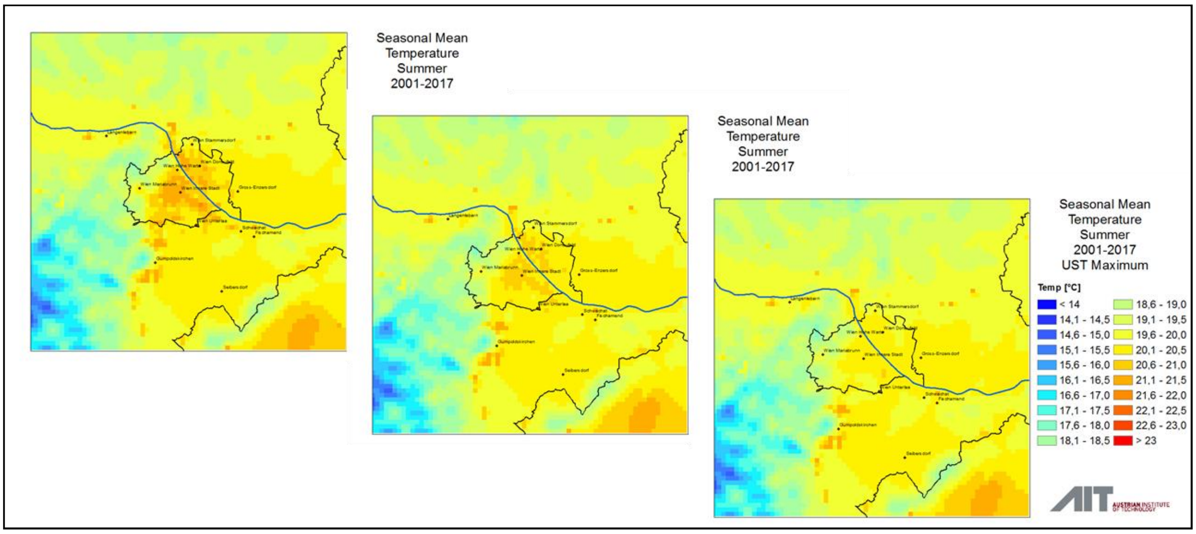


Figure 13 Seasonal mean temperature summer 2001-2017 for Status Quo (left), Moderate (center) and Maximum (right) Greening Scenario

Temperature

Based on this, input data for the regional climate model Cosmo-CLM were modified and four scenario runs have been carried out for the time period 2001 to 2017. As visible in Figure 13 results for the seasonal mean temperatures during summer show significant reductions especially in highly sealed and densely populated areas while the rural surrounding stays unaffected. As a mean a reduction of more than 2°C may be achieved.

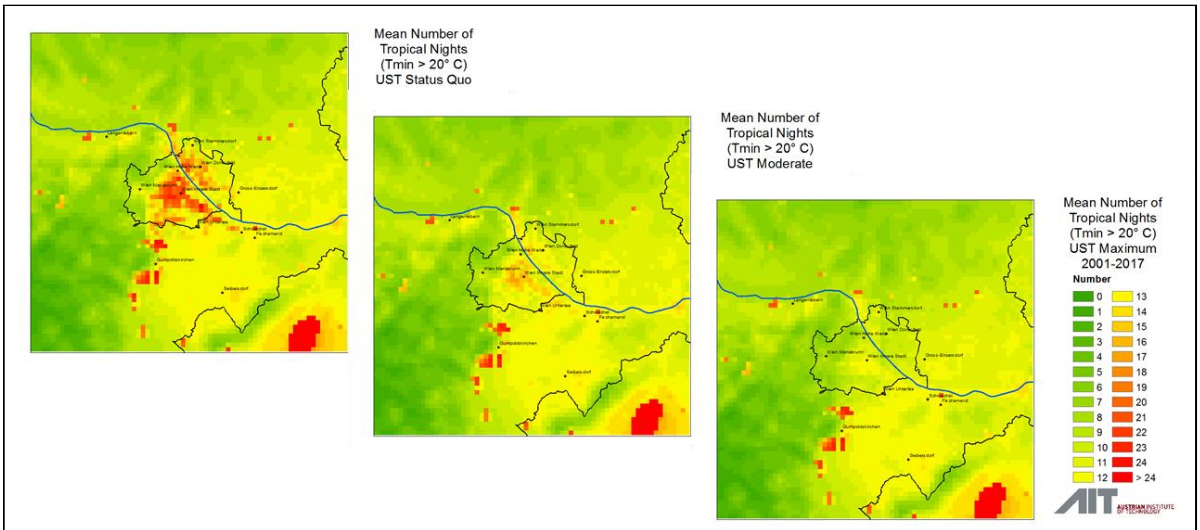


Figure 14 Mean Number of tropical nights 2001-2017 for Status Quo (left), Moderate (center) and Maximum Greening Scenario (right)

As an outcome of these simulations, it was possible to show that especially night temperatures can be lowered in wide areas of the city with increasing green infrastructure. We find a strong signal when we look at the number of tropical nights where the minimum temperatures do not drop below 20 °C. As Figure 14 indicates a reduction by a factor of three may be expected. This is because green infrastructure is obviously most effective during nighttime. We find another confirmation of this when we look at absolute values of heat days (Tmax > 30 °C), tropical nights (Tmin > 20 °C) and the number of days during heat waves for a 17-year period from 2001 to 2017 (Table 3).

For both greening scenarios temperatures during nighttime are significantly more reduced compared to daytime with higher effects in highly sealed areas. Also, negative effects for the worst case scenario are highest during nighttime with slightly stronger deterioration in suburban areas.

Table 3 Number of heat days, tropical nights, number days during heat waves and changes for different greening scenarios as a 10-year mean from 2001 to 2017

	Status Quo	Moderate Greening	Maximum Greening	Worst Case
	Heat Days	Change Heat Days	Change Heat Days	Change Heat Days
Wien Innere Stadt	17.1	-0.6	-1.6	5.2
Wien Hohe Warte	16.2	-0.7	-0.9	5.9
Wien Donaufeld	16.8	-0.6	-1.0	5.8
	Tropical Nights	Change Tropical Nights	Change Tropical Nights	Change Tropical Nights
Wien Innere Stadt	21.0	-5.9	-9.9	15.7
Wien Hohe Warte	12.1	-2.3	-3.0	23.3
Wien Donaufeld	16.5	-3.8	-7.2	20.0
	Heat Wave Days	Change Heat Wave Days	Change Heat Wave Days	Change Heat Wave Days
Wien Innere Stadt	9.4	-0.4	-1.1	3.0
Wien Hohe Warte	8.5	-0.4	-0.9	3.9
Wien Donaufeld	8.8	-0.2	-0.7	3.2

Precipitation & Soil Moisture

For summer season the model results indicate a mean precipitation amount of approx. 300 mm for the city area. Precipitation patterns for the two scenarios show a slight decrease compared to the status quo (STQ). The reduction is strictly linked to areas where soil data were changed. For the moderate greening scenario (MOD) there is a reduction up to 12 mm precipitation in mean value, for the maximum greening scenario (MAX) this may reach nearly 20 mm (please refer to Figure 15). The suburban areas around Vienna show no clear picture with very little randomly distributed gains and reductions over the whole domain.

Although mean value statistics on climatological scale show a reduction in urban precipitation we also carried out a more detailed analysis to assess model performance on monthly scale. For the monthly analysis we chose July 2013. The total precipitation sums for this month ranges from 40 to nearly 70 mm within the city boundaries. The changes induced by the greening scenarios led to both, increase and decrease of precipitation. For the moderate scenario the range goes from -13 mm to +13 mm, for the maximum scenario from -17 mm to +19 mm (Figure 16).

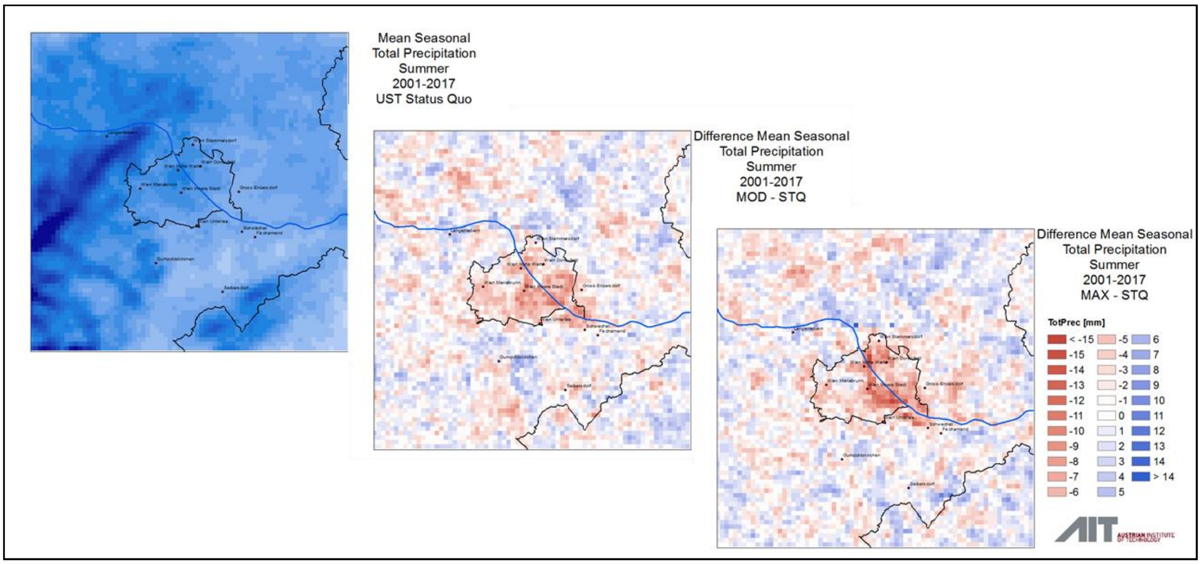


Figure 15 Mean (2001-2017) seasonal precipitation in summer for Status Quo (left) and difference for Moderate (center) and Maximum Greening (right).

Although precipitation is decreasing in some areas in the greening scenarios an increase of soil moisture can be observed. This is manly due to the reduction of soil sealing which allows more infiltration of rainwater into the ground. This may lead to additional 20% of soil moisture within the moderate and up to 30% in the maximum greening scenario (Figure 17).

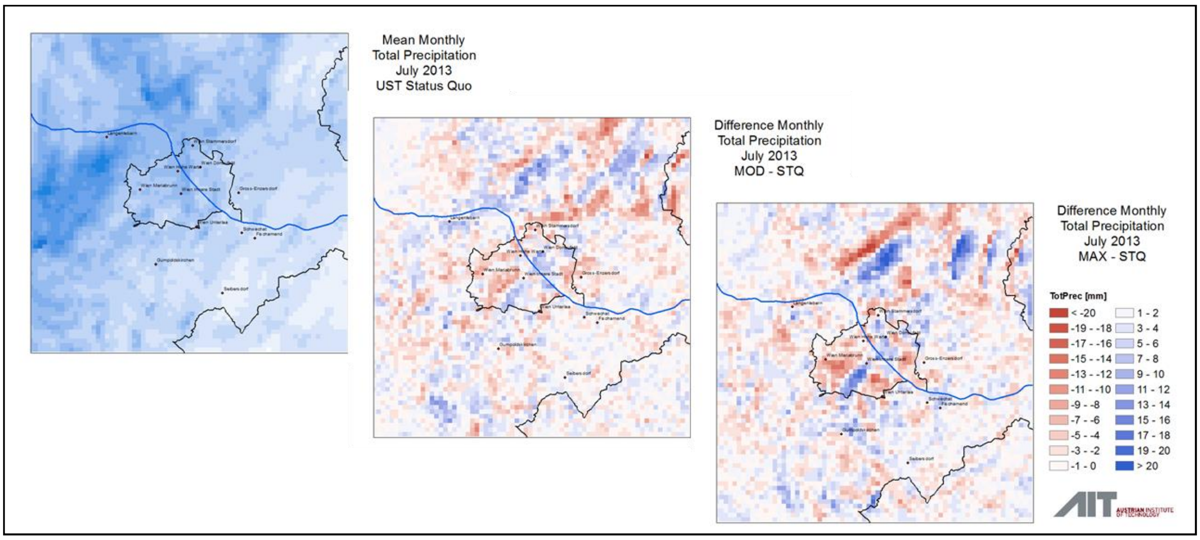


Figure 16 Total precipitation July 2013 for Status Quo (left) and difference for Moderate (center) and Maximum Greening (right).

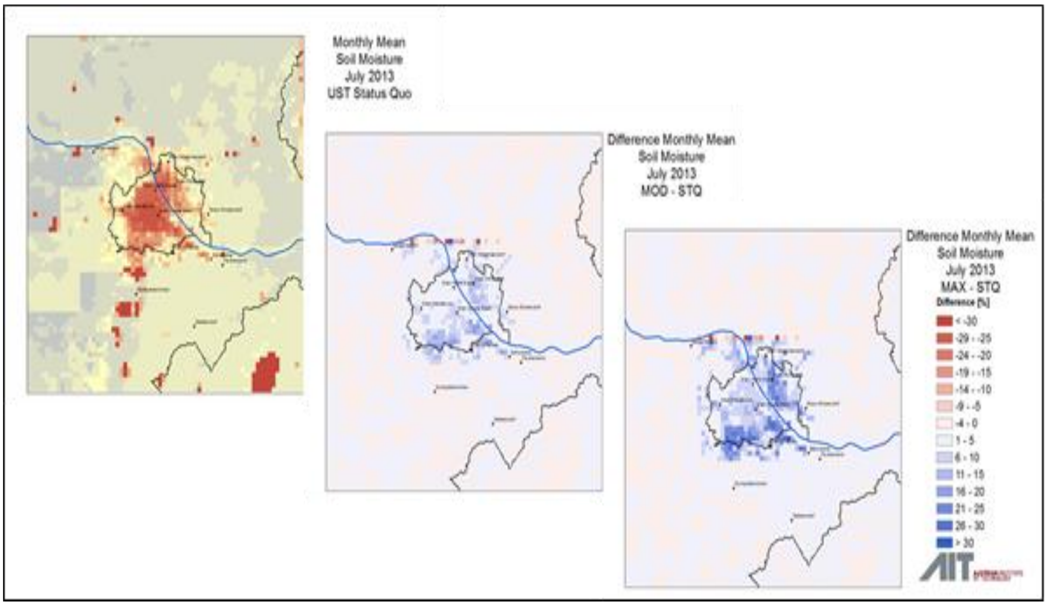


Figure 17 Soil moisture July 2013 for Status Quo (left) and difference for Moderate (center) and Maximum Greening (right).

<u>Future climate change in Urban areas for RCP8.5 scenario</u>

To get an idea how the heat island effect will develop in the future. Two model runs for time slices from 1995-2005 and 2089-2099 have been conducted. The Wegener Center for Climate and Global Change (WEGC) provided forcing data from a CORDEX FPS-CPS historical CORDEX FPS-CPS RCP8.5 run for Austria at app. 2.8 km resolution. The model used for these simulations is the Cosmo-CLM version 5.00_clm9. On the other hand, the CLM version with urban extensions used at AIT is the older version 4.8.19. This caused some severe problems which could be solved only partly.

The first problem occurred because along with other changes the representation of the vertical coordinates in version 5 is not compatible with the version used at AIT. Therefor we had to switch to the new CLM version 5.00_clm16 for which no urban extensions were available. Nevertheless, the simulation for the 2 time slices for the Greater Vienna Basin with 1 km horizontal resolution were set up and started. While the simulation for the period 2089-2099 finished without problems, the historical run crashed on 25th of April 2003. The reasons for this are still unclear and there was no way to continue the simulation after this date. So all analyses for possible future climate developments had to be done with only 7 years of data in the historical run.

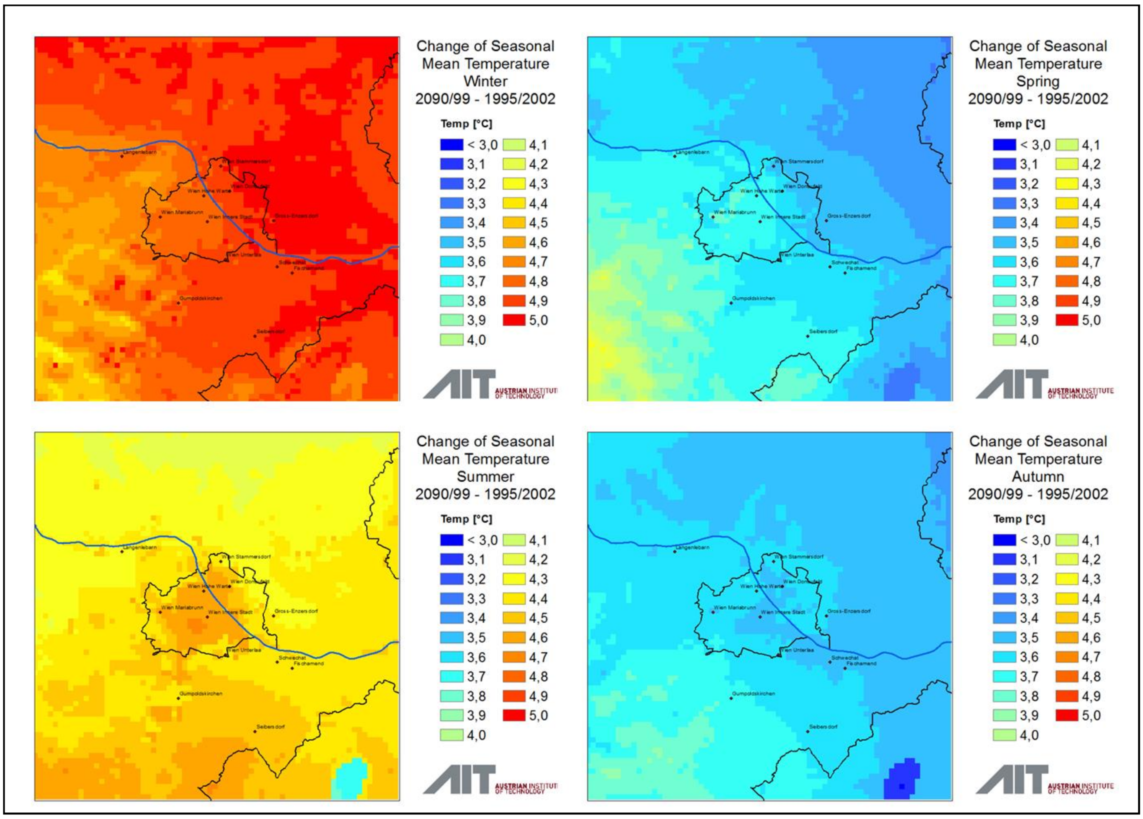


Figure 18 Mean seasonal temperature change RCP8.5, 2090-2099 compared to 1995-2002

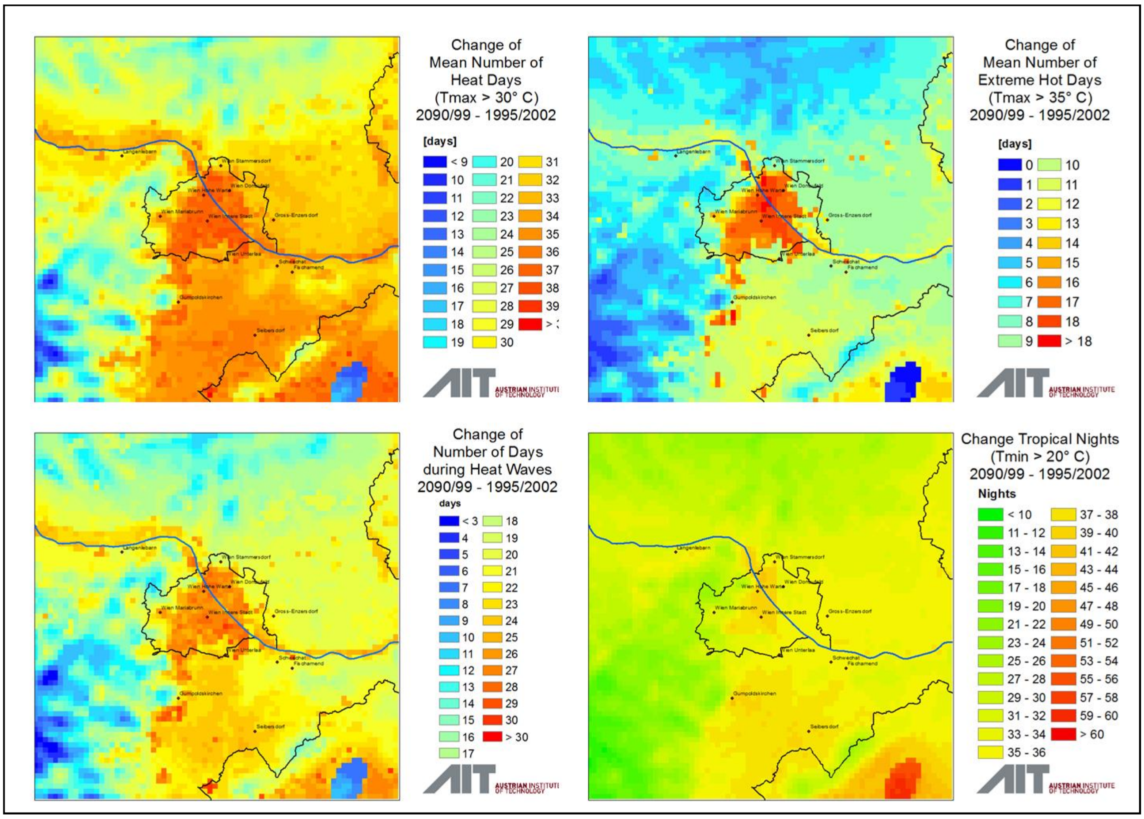


Figure 19 Change of mean number of heat days, extreme hot days, heat wave days and tropical nights, RCP8.5, 2090-2099 compared to 1995-2002

Based on the RCP8.5 scenario and available data the temperature in the city will rise by 3.5 to 3.6 °C in autumn, 3.5 to 3.8 °C in spring, 4.3 to 4.7 °C in summer and 4.7 to 5 °C in winter (Figure 18). There will be from 20 additional days per year in the outer districts to 40 at the city center where the temperature maximum exceeds 30 °C (Figure 19, top left). The number of extreme hot days with T_{max} higher than 35 °C will rise by 5 at the city boundary and up to 18 at the inner areas (Figure 19, top right). Heat waves as defined by Jan Kyselý (Kyselý et al.,2000) are episodes of at least 3 consecutive days with a maximum temperature of more then 30 °C and each additional day with T_{max} grater 25 °C as long as the mean T_{max} does not drop below 30 °C.

The number of days fulfilling this specification may rise by 10 at the cooler outer districts and by 29 at the densely populated areas (Figure 19, bottom left). Only the number of tropical nights show no significant higher increase in the city compared to surrounding areas. Nevertheless, there will be 22 to 39 additional nights where the minimum temperature stays above 20 °C (figure 15, bottom right).

Precipitation

As simulated in this realization of the RCP8.5 scenario no city specific features could be found for precipitation. The changes are quite similar to the rest of the domain and would indicate a reduction of -50 mm to -120 mm in summer season and an increase of precipitation of 65 mm to 90 mm in winter (Figure 20). Please add some text here if possible.

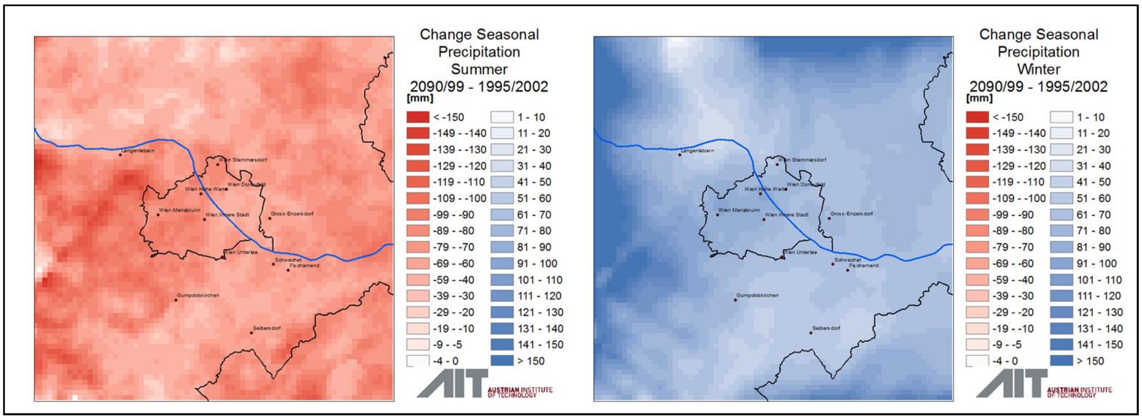


Figure 20 Change seasonal precipitation in summer (left) and winter (right)

5 Schlussfolgerungen und Empfehlungen

(max. 5 Seiten)
Beschreibung der wesentlichen Projektergebnisse. Welche Schlussfolgerungen können daraus abgeleitet werden, welche Empfehlungen können gegeben werden?

Convection-permitting climate simulations add value to coarser resolved standard RCMs (like EURO-CORDEX, especially in convective weather conditions or for extreme precipitation events. There is evidence that climate projections from standard RCMs (like EURO-CORDEX) are affected by deep uncertainty under convective conditions or for extreme precipitation events.

CORDEX-FPS simulations analysed so far, indicate an increase of hourly summertime precipitation intensity up to 35 % mainly correlated with orography, but also increases up to 20 % have been found in Salzburg, Upper and Lower Austria. In these regions, also summertime extreme precipitation events (99.9th percentile) are expected to increase on the order of 20 % until the end of the 21st century under the RCP8.5 scenario.

In the Austrian domain, precipitation is mainly affected by meso- and large-scale processes. Soil moisture feedbacks play a minor role on the intensities of single precipitation events. Positive and negative spatial and temporal feedbacks coexist. Idealized simulations with perturbed soil moisture fields reveal that soil moisture feedbacks are responsible for the actual location of precipitation events, but not for their internal structure. However, due to the soil moisture’s dependency from previous precipitation events, local precipitation changes on a seasonal basis on the order of +/- 50 % may be induced while soil moisture changes stay in a range of +/- 5 %. Furthermore, in summertime the existence of positive temporal soil moisture feedbacks corresponds to intensive precipitation events while negative temporal soil moisture feedbacks are in favour of weak precipitation events. These relationships remain even under different climate change scenarios (with increasing/decreasing seasonal mean precipitation and weakly/strongly decreasing soil moistures).

Soil textures in current RCMs are showing an oversimplified picture of the real geological situation. Since uncertainties in soil types in RCMs are a major source for uncertainty in the representation of soil moisture, external geophysical parameters need to be thoroughly revised by taking into account of latest soil mappings.

Our results also strengthen the finding that in Climate change results the major or dominant effect comes from the driving GCM.

Evaluation of two Land Surface Models used in this project reveal that both models are able to simulate the changes in the soil moisture and ground temperature successfully and both models show similar results and performance.

According to our results thunderstorm activity in large model domains is not captured well by WRF model with good accuracy. Reducing the size of the domain has a positive effect on results. In these high-resolution simulations, we have also found that WRF was unable to simulate the downdrafts. Experiments with soil moisture initialization like perturbation experiments have shown no significant effect on precipitation. Clausius Clapeyron Scaling works very well in convective permitting climate model simulations and there is a need to further conduct experiments to study in more detail to assess the impact of CC-scaling on future climate change.

Convection-permitting urban climate simulations can reproduce the urban heat island effect for the city of Vienna with good accuracy. Three runs with a "Status Quo" (STQ), "Moderate Greening" (MOD) and "Maximum Greening" (MAX) reveal that greening scenarios could be an effective adaptation measure and reduce heat stress in Urban areas. Our results show a reduction up to two degrees Celsius in minimum nighttime summer temperatures (MOD) is possible and greening infrastructure performs even better at higher daily temperature values. The only deficiency that we have seen is that in few precipitation events in summer model had produced un-realistic high values. This error was reported and discussed in the CCLM community meeting and would be corrected in the newer version of the model.

C) Projektdetails

6 Methodik

(max. 10 Seiten)

Begründung und Darstellung des gewählten Forschungsansatzes.

WEGC team implemented a method to measure the strengths of the soil moisture precipitation feedback based on the approach of Guillod et al. (2015) and Moon et al. (2019) on temporal and spatial scales. This method is based on soil moisture anomalies (deviations from its climatological mean; referred to as "strength") that exist before a precipitation event is taking place. Deriving such anomalies for numerous individual precipitation events allowed us to investigate soil moisture feedback strengths in a statistical manner. In order to investigate how precipitation events are related to soil moisture feedbacks in Austria (see RQ1) and to overcome the lack of highly resolved (spatial and temporal) soil moisture observations in Austria, the High Resolution Land Data Assimilation System (HRLDAS; Chen et al., 2007) was operated on a 1 km x 1 km grid covering the Eastern Alps for the period 2005 to 2014. Required meteorological conditions (precipitation, air temperature, surface radiation, near surface wind, relative humidity, and surface pressure) have been derived from the analyses fields of the now-casting system INCA (Haiden et al., 2011) and the analyses fields of the ECMWF re-analyses ERA5 (Hersbach et al., 2020). Long-wave radiation was parameterized via short-wave radiation, air temperature, and relative humidity following Gabathuler et al. (2001). The outcome of these investigations reveal, that the entire Austrian domain lies within an energy-limited regime on average (see Figure 1), indicating that there is no systematic pre-condition for neither positive nor negative soil moisture precipitation feedbacks. Also, an inspection of individual afternoon precipitation events does not indicate any favor for any type of the feedbacks (see Figure 2), but it clearly demonstrates that single events are definitely subject of positive or negative feedbacks.

An event based analysis via the Structure-Amplitude-Location index (SAL) (Wernli et al., 2008), reveals that the internal structure of precipitation objects does not systematically change (S, A, L are approx. 0.0), but their position is affected: on average single precipitation objects deviate from their initial position in the unperturbed simulation between 2 and 5 x grid spacing (i.e. 6 km to 15 km), depending on the season (Figure 4).

Further analyses of stationary precipitation events based on the approach of Guillod et al. (2015) and Moon et al. (2019) allow to investigate the influence of different types of soil moisture precipitation feedbacks on precipitation.

Climate change effects on soil moisture precipitation feedbacks has been investigated via one-year simulations with CCLM in a storyline (Shepherd et al., 2018) approach. For that purpose, initial and lateral boundary conditions (originally derived from IFS) have been modified (in a hydrostatically balanced way; Kröner et al., 2017) with respect to climate change signals (3D fields of temperature and specific humidity, and sea level pressure; periods 1975-2004 and 2071-2000) of the mean annual cycle derived from four GCMs (HadGEM2-CC, GFDL-ESM2, IPSL-CM5A-MR, and MIROC-ESM) employing the RCP8.5 scenario. (Note a similar approach has been used in the ARCP project EASICLIM, that investigated climate change effects on a specific extreme event in June 2009.) In addition, deep soil moisture was perturbed in the same way (by +/- 10 % and +/- 5 %) as for the one-year CCLM simulations under current climate conditions.

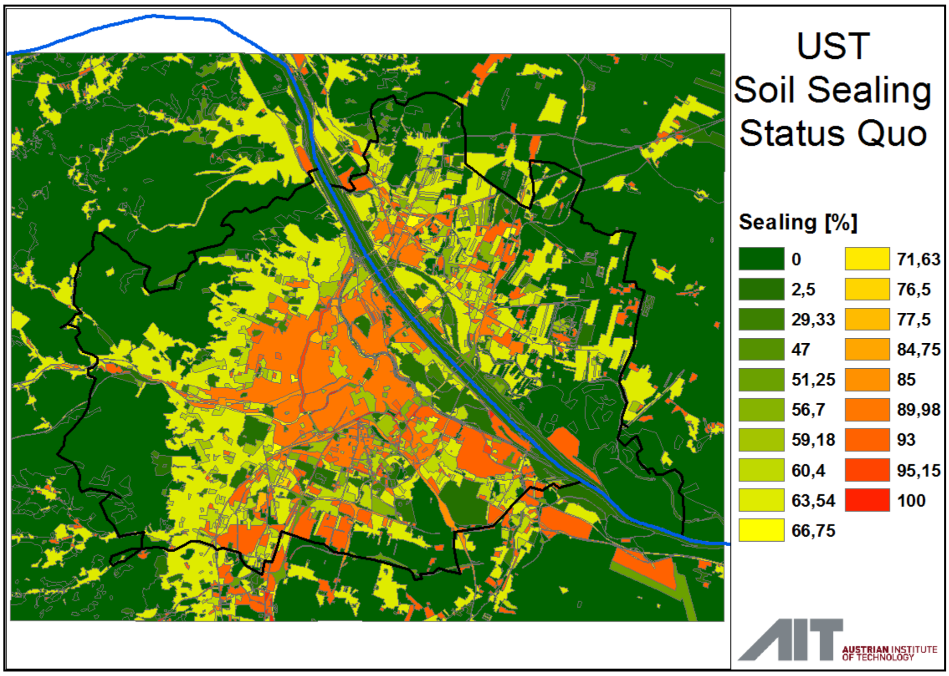


Figure 21 Map of Urban Standard Topologies (UST) – soil sealing

Clausius Clapeyron scaling (CC-scaling) was done by employing the method described in Formayer Fritz, 2017. In total we analyzed 124 Austrian weather station from the Austrian weather service ZAMG and the relative topography from ERA 5 (Albergel et al., 2018) the historical CC-scaling for precipitation events from 1 hour up to 24 hours and for return periods of two years up to 50 years. The same analyses have been performed from the model output of CCLM simulations conducted by WEGC. Since the extreme value statistics applied on individual temperature bins needs sufficient long time series, the two periods of 10-year model results for historical and future climate have been considered as a 20-year period.

To identify sealed areas and their potential for additional green infrastructure a map of Urban Standard Typologies (USTs) was used. USTs define characteristic buildup structures and combine them to different types. They are typically repeated abstract city morphologies which were developed by Green4Cities (https://www.green4cities.com) within the EASME research project "Green4Cities" for the five "Case Study Cities" Vienna, London, Hong Kong, Cairo and Santiago de Chile.

By modifying fraction of soil sealing, plant cover and deciduous forest in Urban Standard Topologies (UST), three scenarios for Vienna were defined – "Moderate Greening", "Maximum Greening" and a "Worst Case". As reference a "Base run" called "Status-Quo" scenario was also conducted.

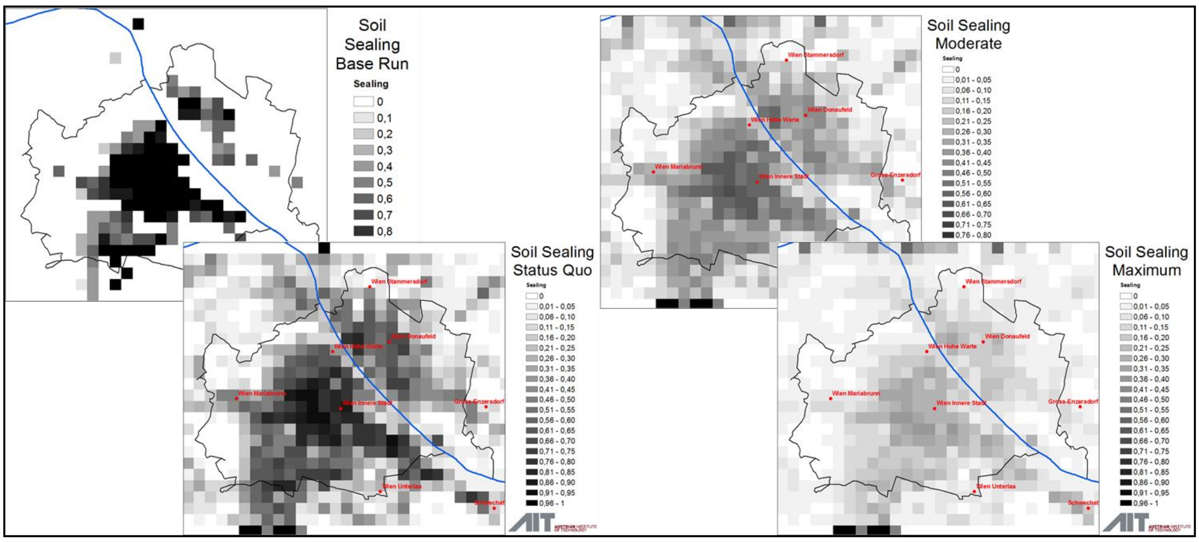


Figure 22 Map for soil sealing used in base run (top left) and modified versions for Status Quo (bottom left), Moderate (top right) and Maximum (bottom right) Greening Scenario derived from UST

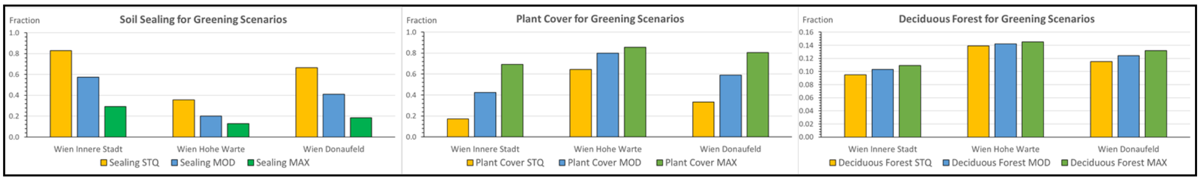


Figure 23 Fraction of soil sealing, plant cover and deciduous forest for Status Quo, Moderate and Maximum Greening Scenario for city center, an outer district and a settlement area

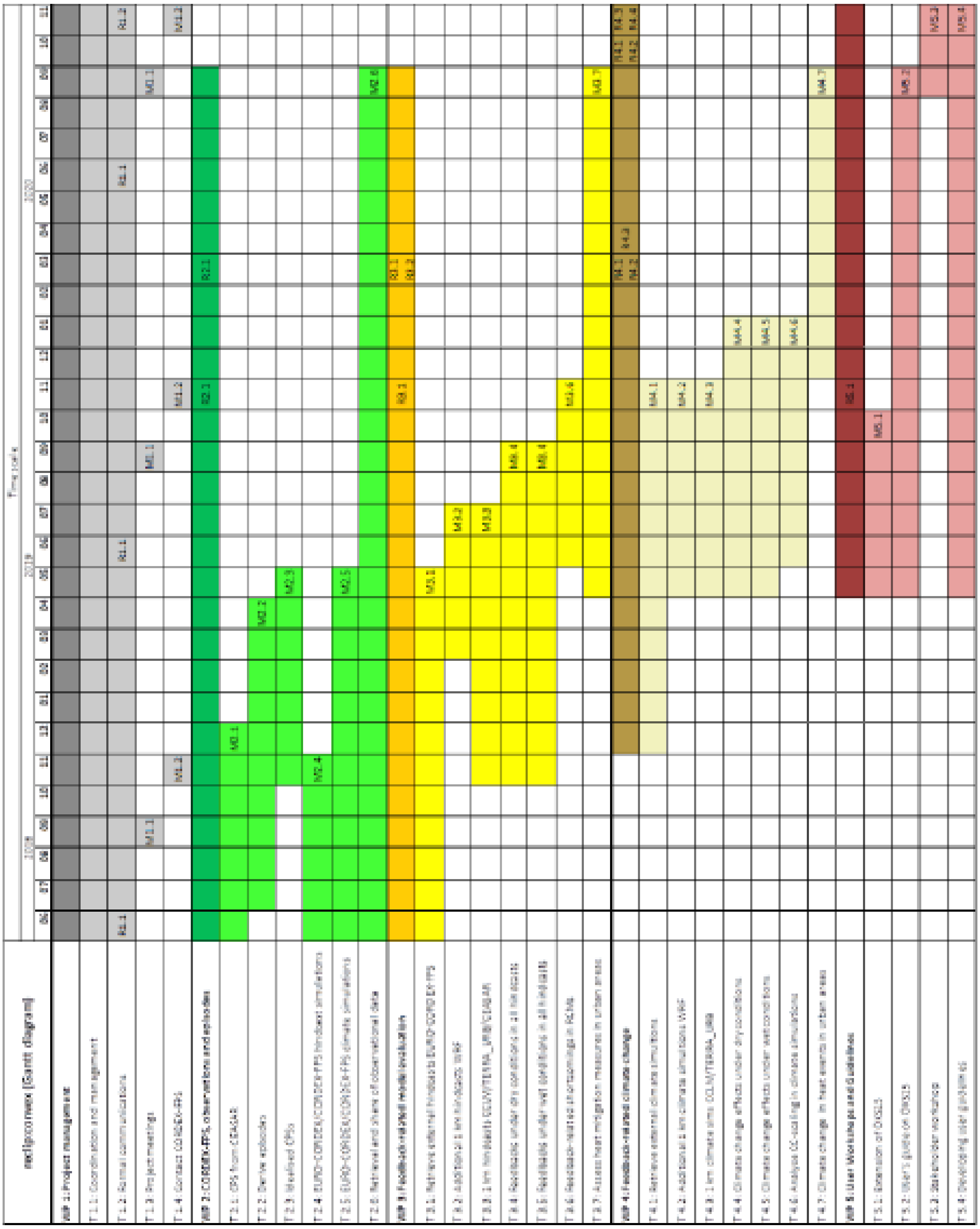
Figure 21 shows a map of the amount of soil sealing for Vienna which are used in the in the "Base run" called as "Status-Quo". Out of this UST-map values for fractions of buildings, roadways, sidewalks, parking lots as well as lawn, shrubs and trees were aggregated and used to modify the parameters soil sealing, plant cover and the fraction of deciduous forest in CLM-input.

In Figure 22 the principle of this is illustrated for soil sealing as an example. As it can be seen in this figure how the values of soil sealing were modified for the three scenarios. As you can see the soil sealing is decreased for the "Moderate" and "Maximum Greening" scenario. The "Worst Case" scenarios is where 100% soil sealing is used. Besides the soil sealing parameter as mentioned earlier two other parameters were also modified, i.e. plant cover and deciduous forest.

Figure 23 shows the amount of soil sealing, plant cover and forest fraction for the Status Quo and the two greening scenarios for the city center (Wien Innere Stadt), an outer district (Wien Hohe Warte) and a settlement area in the northeastern part of Vienna (Wien Donaufeld).

7 Arbeits- und Zeitplan

(max. 1 Seite)
Kurze Übersichtsdarstellung des Arbeits- und Zeitplans (keine Details).



8 Publikationen und Disseminierungsaktivitäten

Tabellarische Angabe von wissenschaftlichen Publikationen, die aus dem Projekt entstanden sind, sowie sonstiger relevanter Disseminierungsaktivitäten.

<u>Scientific Publications</u>

Ban N., C. Caillaud, E. Coppola, … H. Truhetz et al. (2021). The first multi-model ensemble of regional climate simulations at kilometer-scale resolution, part I: Evaluation of precipitation. Climate Dynamics. https://doi.org/10.1007/s00382-021-05708-w

Jacob D., C. Teichmann, S. Sobolowski, H. Truhetz et al. (2020). Regional climate downscaling over Europe: Perspectives from the EURO-CORDEX community. Regional Environmental Change, 20(2), 51. https://doi.org/10.1007/s10113-020-01606-9

Pichelli E., E. Coppola, S. Sobolowski, … H. Truhetz et al. (2021). The first multi-model ensemble of regional climate simulations at kilometer-scale resolution part 2: Historical and future simulations of precipitation. Climate Dynamics. https://doi.org/10.1007/s00382-021-05657-4

<u>Master thesis:</u>

Schaffer, A. (2021). Evaluation of the Soil Moisture-Precipitation Feedback in Austria. Master Thesis. Wegener Center for Climate and Global Change, University of Graz, Graz, Austria.

<u>Presentations at international conferences</u>

Awan, N.K., I. Anders, G. Pistotnik, Influence of spectral nudging on convection permitting simulations, EGU, 2019

Bevacqua, E., Piazza, M., Maraun, D., & Truhetz, H. (2018, October). An attempt to estimate the climate change effect on the June 2009 Austrian extreme event based on the storyline approach. Presented at the Annual CORDEX-FPS meeting on Convection over Europe and the Mediterranean, Lisbon, Portugal.

Goergen, K., Bastin, S., Bourgart, … and Truhetz, H.: Soil moisture-temperature coupling in a CORDEX FPS convection-permitting WRF RCM ensemble, [online] Available from: https://latsis2019.ethz.ch/, LATSIS conference at ETH Zürich, 2019.

Mishra, A. N., Maraun, D., Truhetz, H., Bevacqua, E., Knevels, R., Proske, H., Petschko, H., Brenning, A. and Philip, L.: Climate Change’s Influence on June 2009 Extreme Precipitation Event Over Southeast Austria, EGU 2020.

Mishra, A. N., Truhetz, H. and Goergen, K.: Evaluation of the precipitation diurnal cycle in WRF CORDEX-FPS hindcasts & climate change’s influence on the Austrian test case, 2019.

Pichelli, E., Coppola, E., Ban, N., Giorgi, F., Stocchi, P., Alias, A., Belusic, D., Berthou, S., Caillaude, C., Cardoso, R. M., Chan, S., Christensen, O. B., Dobler, A., de Vries, H., Georgen, K., Kendon, E. J., Keuler, K., Lenderink, G., Lorenz, T., … Vergara-Temprado, J. (2020, Mai 8). Precipitation projections of the first multi-model ensemble of regional climate simulations at convection permitting scale. EGU General Assembly 2020, Vienna.

Truhetz, H. and Goergen, K.: Effects of a shallow convection scheme in perennial convection permitting CORDEX-FPS WRF simulations, [online] Available from: https://latsis2019.ethz.ch/, LATSIS conference at ETH Zurich, 2019.

Truhetz, H., Csaki, A. and Goergen, K.: Effects of shallow convection schemes in perennial convection-permitting simulations with CCLM and WRF, CLM Assembly 2019.

Truhetz, H., Reszler, C., & Switanek, M. B. (2019, February). Floods in Southeastern Styria simulated by RCMs operated on the hydrostatic and convection permitting scale. Presented at the AHPC 2019, Grundlsee, Austria.

Züger, J., High Resolution Urban Climate Modelling, CLM-Assembly, Paestum, 2019

Planned Publications

Awan N. K., H. Truhetz, A. Schaffer, Evaluation of the representation of soil moisture in convection-permitting long-term simulations

Truhetz H., N. K. Awan, A. Schaffer, Evaluation of soil moisture precipitation feedback in current and future climate simulations

Stakeholder’s workshop

Stakeholder’s workshop was virtually organized on 15th of September, 2021. Reclip:convex results were presented to audience from several national and international universities and research institutes. The model development community and weather forecasters also found our results very interesting as soil moisture initialization, perturbations and assimilation is widely pursued topic.

Press release

Findings of reclip:convex were also dissimenated to general public via a press article “Das Sommergewitter in Klimawandel” that was published in “Der Standard” on 08th of July, 2020.

Newsletter

Prelimenary findings and final results were shared with colleagues and peers via ZAMG newsletter.

Diese Projektbeschreibung wurde von der Fördernehmerin/dem Fördernehmer erstellt. Für die Richtigkeit, Vollständigkeit und Aktualität der Inhalte sowie die barrierefreie Gestaltung der Projektbeschreibung, übernimmt der Klima- und Energiefonds keine Haftung.

Die Fördernehmerin/der Fördernehmer erklärt mit Übermittlung der Projektbeschreibung ausdrücklich über die Rechte am bereitgestellten Bildmaterial frei zu verfügen und dem Klima- und Energiefonds das unentgeltliche, nicht exklusive, zeitlich und örtlich unbeschränkte sowie unwiderrufliche Recht einräumen zu können, das Bildmaterial auf jede bekannte und zukünftig bekanntwerdende Verwertungsart zu nutzen. Für den Fall einer Inanspruchnahme des Klima- und Energiefonds durch Dritte, die die Rechtinhaberschaft am Bildmaterial behaupten, verpflichtet sich die Fördernehmerin/der Fördernehmer den Klima- und Energiefonds vollumfänglich schad- und klaglos zu halten.