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Future Impacts of the Reforestation Policy on the amospheric parameters: a sensitivity study over Ireland

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Abstract

The increase of temperature attributed to anthropogenic emissions is projected to continue in future climate scenarios. Several protocols and policies are being put in place in several European countries to reduce both emissions and impact of human activities. The Irish Reforestation policy is a good example of such protocols. Nevertheless often contemplated policies do not take into account their potential effects on the atmospheric variables. This study aims to assess the influence of the increase of vegetation cover over Ireland, with respect to the surface temperature and the livestock heat comfort, using the Weather Research Forecast (WRF) model. Two main multi-scale numerical simulations are performed: (i) a control scenario with no change in vegetation cover and (ii) a scenario with increased tree cover based on the suggested Irish Reforestation policy. The vegetation change increases the temperature over the simulated domain and moreover, it enhances the livestock heat discomfort during the day-time, with different magnitude all over the domain. It is concluded that the reforestation policy, which is introduced to mitigate the greenhouse emissions, causes a further increase in the temperature and livestock heat discomfort.

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Keywords: Climate change, reforestation policy, livestock, sensitivity study

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1. Introduction

The continued emissions of greenhouse gases cause a continuous increase in the temperature, even considering the intrinsic interannual variability, as it leads further warming and changes in all components of the climate system[1]. To limit climate change, many policies for greenhouse emission reduction have been applied to different levels, i.e. from the European scale, as the 2020 package and the EU climate action, to country one, as the Forestry programme[2] in Ireland. This is an afforestation policy which aims to increase the forest cover from 10.7% to 18% in 2020[2]. The introduced policy is planned to positively affects different aspect of the environment as carbon sequestration, increase in biodiversity, and it should have no impacts on the water quality, as well as social aspects[3].

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Vegetation cover and vegetative canopies strongly influence both energy and moisture surface-atmosphere fluxes[4]. Interaction with the atmosphere is fundamentally caused by: vegetations response to the incoming radiation and its emission in the longwave portion of the spectrum; the modification of the aerodynamics roughness length; plant transpiration and photosyntesis processes[4].

The impact of climate change on the landuse has been well studied[5 6 7 8], an example being the forced migration of crop species in Europe due to variation in both temperature and precipitation patterns[7]. However, the opposite feedback effect, less considered in the past, has seen an increase in the recent studies[9 10 5]. Previous literature has provided evidence that conversion of all land types to agriculture resulted in cooling impacts[5 9]. Furthermore, local changes in the landuse impact beyond their scale and affect the weather and climate of a wider area[5].

Climate change impacts also on livestock through direct and indirect effects[11]. In fact, a high confidence of accruing a reduction in animal feeding and growing rate is reported in the literature[11]. In a study for the impact of the UK changing climate on dairy cow production, it is found that milk yields will be reduced and the mortality rates will increase due to the heat stress throughout the current century[12 11]. This will lead to an annual total losses amounting to around £40 million by the 2080s under a medium-high greenhouse gasses emission scenario[12]. Most of the recent studies related to climate change and livestock are focused on the impact in the developing countries, as is possible to see from Thorton et al.[13]. Developed areas have less studies, such as Central and Northern Europe[12], which are still affected by climate change in the next decades[1 7] and have almost half of the total European beef production[14].

This work aims to assess, through a sensitivity approach, the effect of the reforestation policy in Ireland on the meteorological parameters, since the vegetation highly affects the climate system through atmospheric dynamics[4] and not only as a sink for greenhouses gasses, as suggested by the policy[2 15]. Therefore, this study considers the effect of the policy on their wellbeing, which is assessed through a developed index to quantify the thermal comfort of the livestock.

2. Method

2.1. Study area and period

The study focuses on most of the land that the reforestation policy targets, as can be seen in figure 1 from the centering of the domains. In fact, the domains are designed to have the smaller domain (D04) over the Republic of Ireland, even if excluding Northern Ireland and County Donegal, due to computational costs. Ireland has a population of 4.6 milion, 62% of it lives in urban areas that cover 2.4% of the total land area[16]. In the rural areas, there is a national average of 26 persons per km^2.

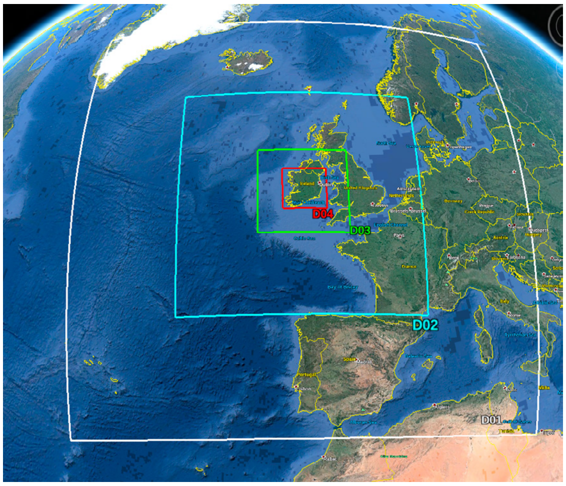

Fig. 1. Two-way nested simulation's domain centered over Ireland.

On the other hand, there is a high population of livestock: 6.3 milions of cattle[17], 3.3 milions of sheeps[3] and 1.5

milions of pigs[18]. The livestock has a very high density in some regions of the inland, i.e. in the south part, for the bovine, it varies from around 110 houndreds to 220 houndreds per km^2[17]; more than 370 houndreds[3] sheeps are in the mid west of the country (counties Mayo and Galway).

Climate projection for the near future over Ireland shows that an increase of the mean temperature will be observed, and that is more pronounced in winter than in summer[19]. As for precipitation, wetter winters (+14%) with more heavy precipitation events are expected, as well as drier summers (-20%)[19]. As the policy has as a target year 2030[2], it is important to choose a suitable period for the simulations. This paper focuses on a part of the summer season, with anomalies similar to the aforementioned ones, and it is chosen from the Eobs dataset[20] of the past years.

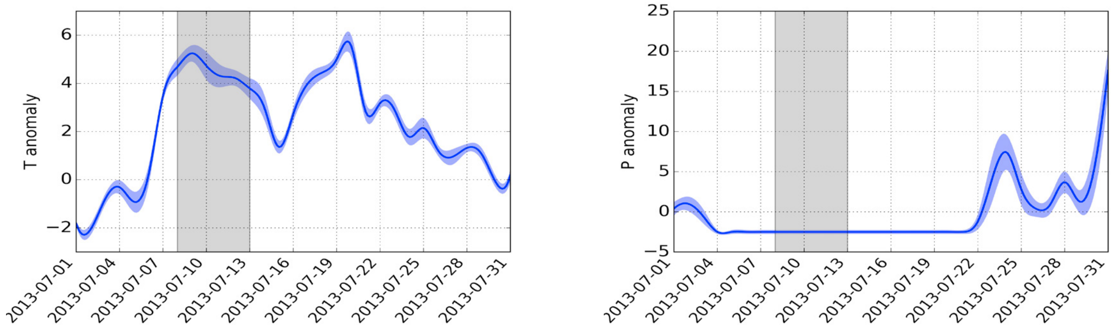

Fig. 2. Temperature and precipitation anomalies over the D04 area with respect to the period 1981 – 2010.

During July 2013, a lack of precipitation is observed over Ireland from the 5th till the 21st (fig. 2, right). During the same period there are also two peaks of $+4\,K$ with respect the reference period (1981-2010). Given the two temperature maxima, the first one is chosen due to its longer amplitude and smoother feature, which reduce possible non-linear interactions with perturbations. Figure 2 shows the chosen period as the grey-shaded area.

2.2. *Numerical simulation*

This presented sensitivity study is performed using the non-hydrostatic version of the Weather Research Forecast (WRF) model (version 3.7), a widely used model for both meteorological and climatological purposes[21]. The simulations span over a five-day period, starting the 8th at 00 UTC (Time zone: UTC+1), using four two-way nested domains. The smallest domain (Fig. 1) covers most of the Republic of Ireland and has a spatial resolution of 1.5 km. The resolution choice for the smallest domain is due to compromise computational costs, spatial landuse data and convection resolving in the model.

As initial and boundary conditions the GFS product is used, with a spatial resolution of 1 degree (about 100 km), the boundary is called by the model every 6 hours. The simulations are run with the YSU scheme for the PBL parameterization[22] and using the Noah land surface model[23] for the land surface processes.

The landuse characteristics are obtained from the MODIS data with the resolution of 30 seconds (about 927 m) for the 4 domains. From the 24 categories of landuse, only 20 of them are used (Fig. 3 left). The three urban classes in the dataset are omitted in order to use only the general category urban and build up for both cities and human-made areas. This choice is based on two main reasons: (i) this is a sensitivity and economic oriented study, (ii) there is a lack of wide-spread urban areas (0.2% of the pixel are category 13, and most likely overestimated[24]). Moreover, the option of ”surface_mosaic” is used, which means that each grid point has the three most common categories, which means that each grid point has the three most common categories, which improves the spatial representation of the forecasted variables[25].

The forest coverage over Ireland shows a high variation within the available databases[26]. The MODIS forest cover (categories 1 to 5 in figure 3 on the left) is approximately 19.7% of the analysed domain, which is double of what is observed in the Forestry2010[27].

Two simulations are performed with different landuse characterization over Ireland: the first is considered as the reference simulation and will be referred as CTR hereafter. In this simulation, the standard landuse chatacterization is used (fig. 3 left). As for the second run, the current crop and vegetation mosaic (category number 14) has been replaced

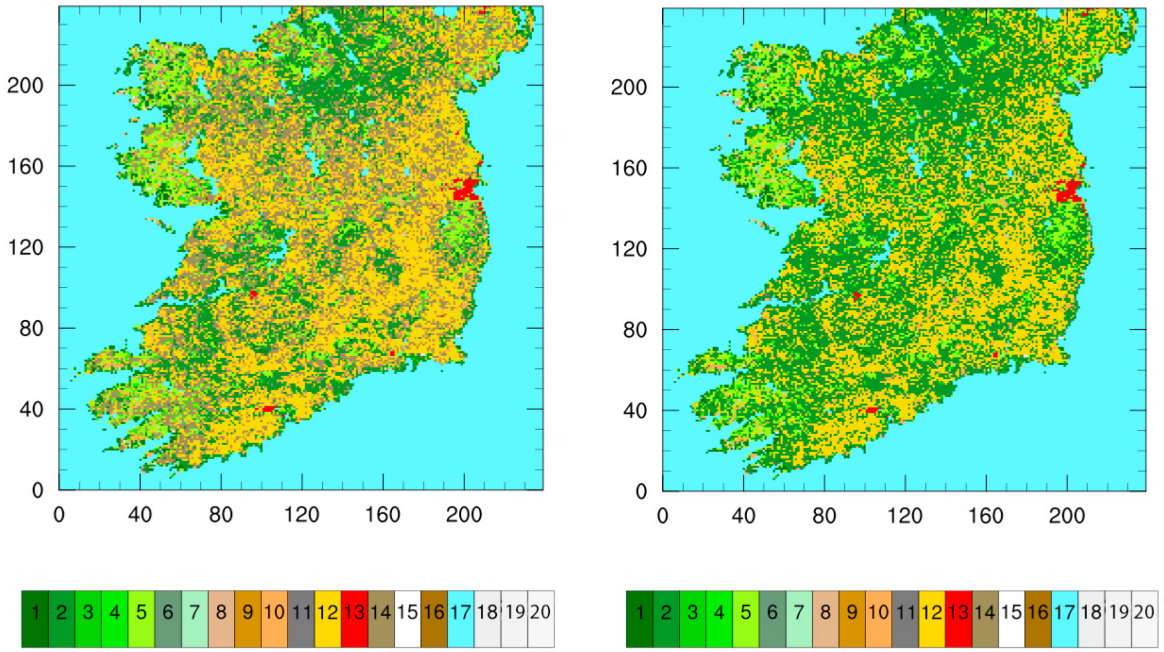

Fig. 3. Landuse cathegories as defined in MODIS [21]. The CTR landuse is on the left. The VEG run is obtained substituing to the land cathegory 14 (crop and natural vegetation mosaic) the number 2 (evergreen broadleaf).

with the most common forest category (number 2, 57% of the forest grid points). This run is called VEG, the new landuse distribution can be seen in the right side of Figure 3. With this substitution, the vegetation cover was increased to 36.2% of the land in the domain, that is less than the double of the Reforestation policy aim.

3. Results and discussion

3.1. Model validation

The model outputs for temperature was compared against the 2-meter height air temperature data for five meteorological stations within the area of study. The stations are not in urban areas, due to the previously discussed lack of the urban parametrization. All data are obtained from the Irish meteorological station network [28] and they cover the D04-region, as the left side of Figure 4 shows.

To evaluate the overall performance of the model, statistical indices are used to assess the performance of model with respect to the observed data, as well as a linear regression with the hourly CTR output obtained for the stations location [28]. The Mean Bias Error (MBE), measured in Celsius degrees, the Mean Percentage Error (MPE) and the Mean Absolute Percentage Error (MAPE), as well as the slope and the r-square from the linear regression, are used as indexes and they are calculated on the whole period. The results are shown in table 1.

Table 1. Table of the indexes obtain for the 5 sites considered to validate the model.

Station name	Slope	r^2	MBE (^oC)	MPE (%)	MAPE (%)
Gurteen	0.94	0.85	-1.97	-9.39	11.34
Moore Park	1.25	0.67	-2.20	-7.43	16.34
Oak Park	0.98	0.85	-2.82	-13.72	15.88
Dublin Airport	1.16	0.83	-2.64	-13.08	15.90
Dunsany	0.96	0.83	-2.08	-10.57	13.25

All locations, with the exeption of Moore Park's, show a linear behaviour both with a slope close to one and a good r-squared. This behaviour is well seen in figure 4, on the right, from the scattered features, especially of the Moore Park station (blue points). An underestimation of the temperature is observed in all sites, as can be seen from the negative MBE and the scatter plot. The simulations has a MPE around 10%, the negative value of this index assess the average behaviour of underestimation of the measured value. On the other hand, this underestimation is an overall feature, since MAPE has a higher value than MPE. This means that some of the negative differences between observed and simulated were compensated by positive ones. The higher the difference between these two indexes, the more scattered the data, without a underestimation or overestimation, as for the Moore Park station in figure 4 right.

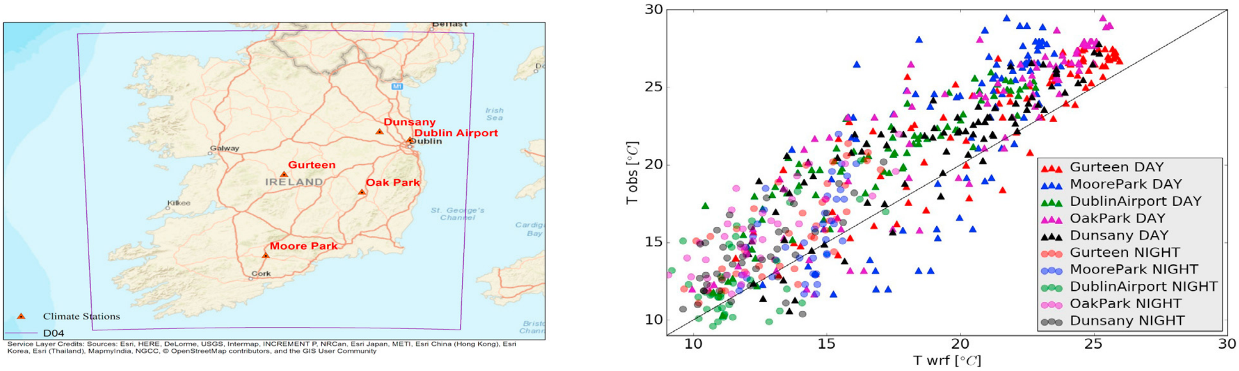

Fig. 4. Scatter plot for the T2, observed data versus CTR simulations in the stations location, which is shown on the left side. Stations in the west coast were not chosen due to the presence of the cliffs, that as discussed in the results, is not well modelled.

Furthermore, the points on the right side of figure 4 has been divided between night (21:00 to 4:00 UTC) and day (5:00 to 20:00 UTC). The underestimation previously described is mostly during the day and the hottest hours, while for the night time simulation approximate better the measures.

The underestimation observed in the simulation is expected due to the choice of the PBL scheme. In fact, from previous studies it is stated that summer periods show an underestimation of up to 2^oC for the maximum temperatures[29]. Despite this, it is the best scheme, from the literature, to be used for this region[29].

3.2. Meteorological variable

In this paper, only the 2-meter height temperature (T2 from hereafter) is presented as a direct output from the simulations performed. This parameter is directly influenced by both the boundary layer and the soil physics, as well as the mesoscale circulation. This section discusses the T2 as obtained from the VEG run and the difference between the two simulations, defined as $\Delta T2 = T2_{VEG} - T2_{CTR}$.

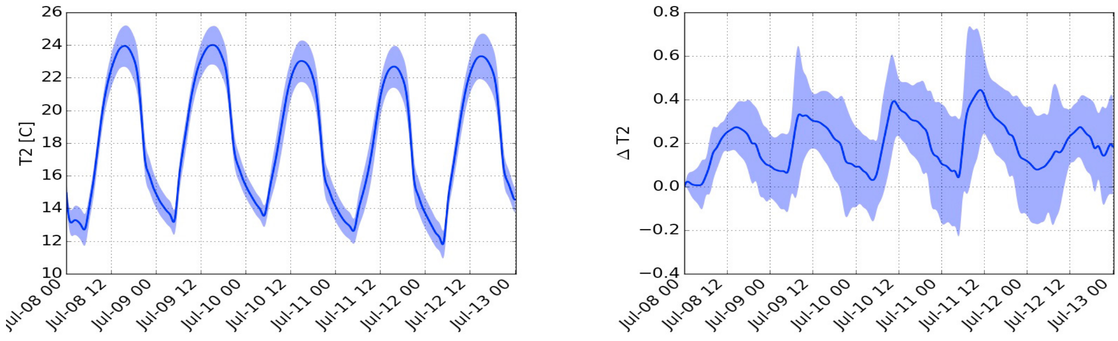

Fig. 5. Average over the land of the D04 for the T2 (VEG), on the left, and the difference between the run, on the right.

Figure 5 shows the time serie of $T2_{VEG}$ and $\Delta T2$ averaged over the land of the smallest domain, with the spatial standard deviation. On average, the increase in vegetation causes an increase of the T2 ($\Delta T2 > 0$) with the daily cycle (Figure 5 on the right). Even if the maximum of the T2 daily cicle is always after 12 UTC, the maximum of the differences is before: between 8 UTC and 11 UTC. The only exception is the first simulated day, but that could be due to the lack of a warm-up to let the perturbation reach its equilibrium. T2 shows a low spatial variability, mostly less than 0.3^oC, with some regions with negative values of $\Delta T2$ during the night-time.

Since the induced variation in the landuse has not a regular patter (figure 3), a specific spatial feature is not to be expected. Figure 6 shows the results obtained for the T2, averaged on the hottest hours of the days in the analysed period. From the data in figure 5 right, it is obtained that the maximum in the T2 mainly are from 12 UTC to 17 UTC. The simulation has a strong horizontal temperature gradient across the sea-line, more pronounced for the west coast than the east and south ones. Most of the lands in the domain have high temperatures, from 5 to 7^oC above the 1981-2010 July average.

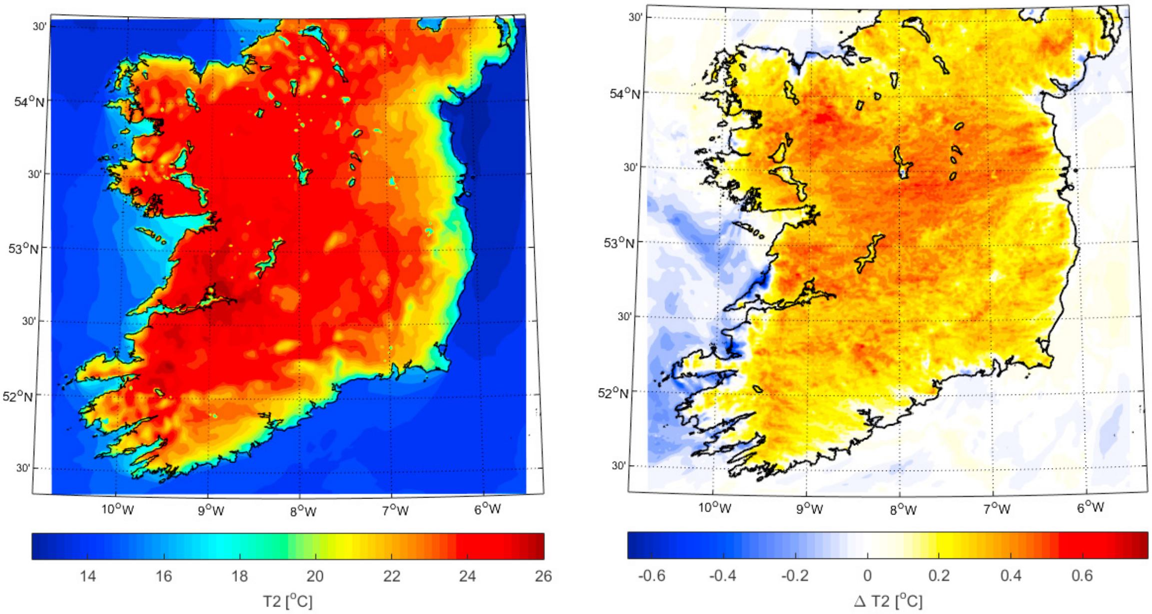

Fig. 6. Spatial distribution of the T2 (VEG) during the hottest hours of the day (averaged from 12 UTC to 17 UTC), on the left, and the difference between the run, on the right.

The increase in the vegetation cover leads to a positive $\Delta T2$ all over the land, which is more pronounced in the area with a higher occurrence. Even areas without landuse changes has an average increase of at least 0.2^oC during the hottest hours of the day, i.e. Dublin County and southern part of Cork County.

On the other hand, over the ocean there is mainly no change in the temperature, with the only exception the area near the west coast with a high negative difference. This could be due to the presence of the cliffs and therefore changes in the local circulation caused by complex terrain interactions. However, this aspect is analyzed because it has a nonlinear feature and cannot be assessed with a single perturbation run.

3.3. *Thermal heat comfort index for livestock*

Most of the changes in temperature discussed in the previous section are in areas with a high density of livestock, and not humans. For example, in the area located between 53 N and 54 N (high positive Δ T2), there is a bovine density that varies from around 110 hundreds to 183 hundreds per km^2 [17] and for sheeps, in the westmost part of that area, a population of around 370 houndreds[3]. Since also animals can experience thermal stress, this study will focus on the impact of the vegetation on the livestock throughout the change in the meteorological parameters, not in the pastures. In order to quantify this effect, the Thermal heat comfort index for livestock (THIC, hereafter)[30] is calculated from the simulation output fields. THIC is an empiric function of the T2 and the wet bulb temperature, calibrated for pigs[30], and is obtained with the following formula:

$$THIC = 0.72 \cdot T2 + 0.72 \cdot T_{wb} + 40.6 \qquad (1)$$

All the variables in eq.1 are in degree Celsius and T_{wb} is obtained with a built-in function of the NCL libraries. This index is obtained from the hourly model output data. The same procedure used for the T2 is applied for the THIC to discuss the results.

The time serie of the THIC, in the VEG run, is shown in figure 7 on the left, while the difference between the two run ($\Delta THIC$) is in figure 7 on the right. Both quantities are averaged over the land of the D04. The THIC, calculated for the VEG run, shows a daily cycle that is quite similar to the T2 one (figure 5 left). The index varies from 60, during nighttime, to 71 for the peak hours. These values are not an immediate danger for the animals, but still are quite high, considering that 75 in the limit for the "Alert" level[30]. The spatial standard deviation is at most 1, which is a low spread for the index value, and is highest during the both the minima and the maxima of the daily cycle.

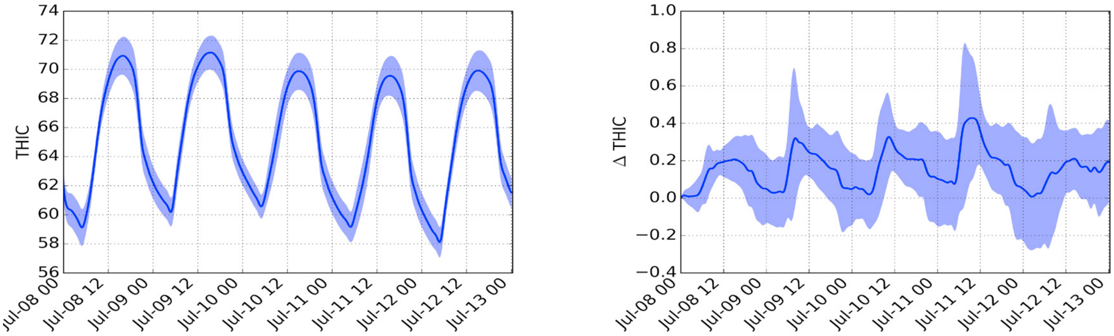

Fig. 7. Average over the land of the D04 for the THIC calculated for VEG, on the left, and the difference between the run, on the right.

The influence of the increase in the vegetation on the heat comfort for the livestock will be assessed throught $\Delta THIC$. The vegetation lead to an increase of the THIC, with a different amplitude during the day. In fact, the effect is higher

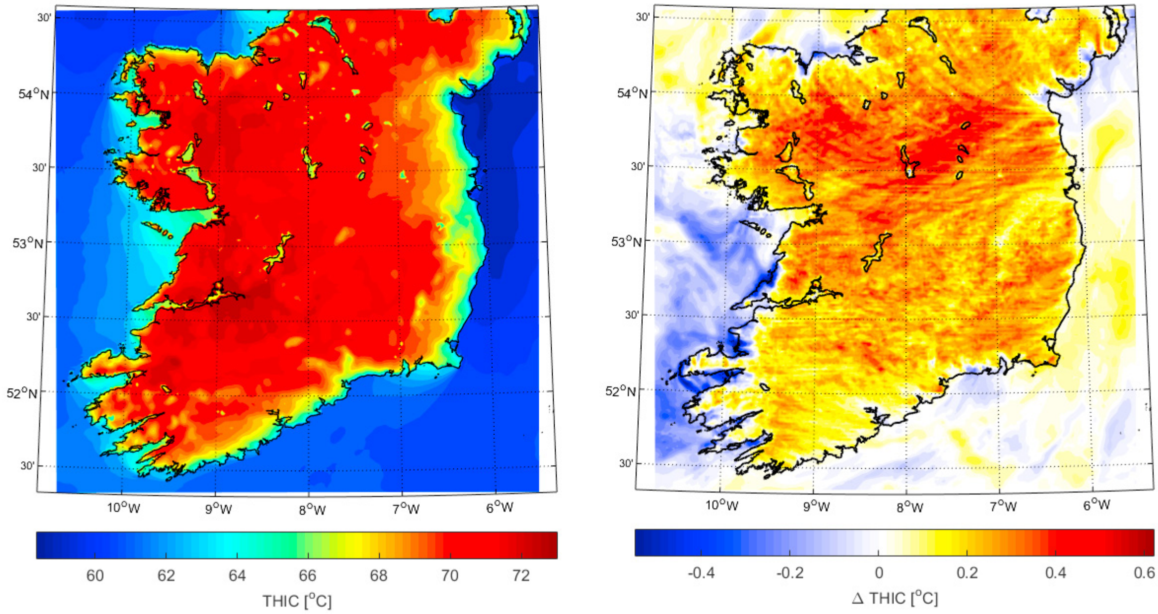

Fig. 8. Spatial distribution of THIC during the hottest hours of the day (averaged from 12 UTC to 17 UTC), on the left, and the difference between the run, on the right.

during the hottest hours of the day, rather than the nighttime. In particular, $\Delta THIC$ does not follow the same daily cycle of the THIC: the maxima of the differences are earlier the day, as they are observed between 9 and 11 UCT. Moreover, $\Delta THIC$ has a high standard deviation, therefore it is of interest to investigate further in the spatial distribution of this index.

As the index is a threshold one, the spatial distribution of the time-average of the index maxima is here analysed, using the timespan used in the T2 case. Results are shown in figure 8 for both the VEG run, on the left, and for $\Delta THIC$, on the right.

THIC calculated on the variables of the VEG run, on the left, shows high values all over the west part of the country, most of the region over 72. These areas of the country with high values has also a high density and number of livestock animals[17 3]. As for the T2, also THIC has lower values for the eastern and southern coast, from 4 to 8 points lower.

The influence of the changes in the vegetation, as for the T2, are scattered over the land and causes positive values of Δ THIC. The amplitude of the positive ΔTHIC varies between less than 0.2 and 0.5; the maxima are more spread over the land than for the Δ T2, in figure 6 right. The increase of THIC interest a lot of areas that has a high density of animals, as County Mayo and Galway as well as County Limerick and County Longford.

All the values of ΔTHIC over the ocean are not to be considered since this index is applied to livestock only. The negative values observed on the coast of the western part are mainly caused by the negative Δ T2, and their significativity was already discussed in the previous section.

4. Conclusions

The observed temperature increase in the past decades due to anthropogenic influence, will continue and escalates in future scenarios. Actions and protocols are made to mitigate the greenhouse emissions. However, their consequences have not been examined by policy makers against their impacts on climate as a whole, which as showed here with a simplified approach, may lead to undesired side effects.

This work aims to assess, through numerical modelling, the effect of the Irish Reforestation policy on the atmosphere and climate parameters, as well as the repercussions on the livestock. This has been performed as a sensitivity study using WRF model, changing the MODIS land use. The area land which is characterized as cropland and vegetative mosaic are substituted with evergreen broadleaf, which increases the forest cover from 19.7% to 36.2% of the land in the analysed domain. It is found that an increase in the vegetation cover over Ireland is likely to cause an overall increase in the 2-meter air temperature. This feature is observed all over the land, even in areas without a change in the land use with mostly zero variation over the ocean. The variation of the temperature shows a strong daily cycle, with a more pronounced influence during the late morning. The thermal heat comfort for the livestock is simulated as part of this study. This index shows high peak values with a strong daily cycle that resembles the temperature one. As for the temperature, the index has the maximum differences during the late morning but also midday. Moreover, during the peak temperature, it is possible to observe an overall increase in the heat discomfort in the whole domain, with different magnitude. The evidences from this study suggest that an increment in the vegetation cover would lead to an increase in both the surface temperature and enhance the livestock heat discomfort during the summer season. However, further works need to be done to establish the magnitude of the increase in those parameters caused by the vegetation and change in land use and land-cover caused by the application of the Irish Reforestation policy. An implication of these findings is that land use impact on climate should be considered more closely in the policy making process. In fact, while the reforestation will increase carbon dioxide extraction from the atmosphere, it will add to the global increase trend a local increment of air temperature. This aspect needs to be looked in especially in consideration of its influence on thermal comfort of livestock.

Further studies are planned to assess the dependency of the result to the forest percentage and location, as well as the impact for longer periods and in other seasons. Moreover, it will be investigated the direct effect on air pollution and humans.

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