# The effects of a world without snow on vegetation

*By Zhiqi Wang and Benjamin Vanbiervliet*

*Land-Climate Dynamics*

*20/12/2021*

## Introduction

The earth's climate is a complex system, with many parts of this system interacting with each other. In this research, we want to investigate the role of snow on vegetation and how different the world would look if there could be no snow on vegetation. Thanks to state-of-the-art climate models, we can now model how these effects would unspin both spatially and over time. Here we studied how the ground temperature, net primary production (NPP), and albedo would change if a layer of snow on vegetation would not be possible.

Our research consists of two main parts. In the first part we compared the results of the Community Land Model 5.0 (CLM) in its normal settings with observational data from the Global Land Evaporation Amsterdam Model (GLEAM) dataset to assess the usability of the model (Miralles et al., 2011; Martens et al.,2017). In the second part we then studied the effect of snow on vegetation by comparing the results from the model in standard settings with the results of an adapted model where show on vegetation was not possible. We found that the model performed well enough to be used for this type of analysis and that the largest differences between the normal scenario and the disturbed scenario without snow on vegetation are present in the most northern parts of the world.

## Methods

In our research, we want to study the effect of snow on vegetation on climate. To do this, the CLM was used to perform our simulation in High-performance computing (HPC). The model was run with two different settings, the standard settings, as well as with slightly disturbed settings where a snow layer on vegetation was not possible.

### High-performance Computing (HPC)

High-performance Computing (HPC) is a centralized computer cluster that has many CPUs and a lot of memory to run the climate model which requires massive calculations, due to it connecting with high-speed networks, so the efficiency of calculation is greatly improved. This research used the hydra cluster, which is the local VSC Tier-2 cluster managed by VUB-HPC ("Infrastructure — VUB-HPC," n.d.).

### Community Land Model (CLM)

The Community Land Model (CLM) is a land surface model that is used to help to understand how land processes and anthropogenic processes affect and interact with weather and climate. The biogeophysical processes simulated by CLM include the interaction of short and long-wave radiation with vegetation canopy and soil, the heat transfer and the hydrology of canopy, soil, and snow, as well as photosynthesis (Lawrence et al., 2011). CLM is one of several global land models of the Community Earth System Model (CESM), CESM is an international project dedicated to understanding and predicting the Earth's climate behavior, used to investigate the interactions between different earth systems across the time and space scales (Hurrell et al., 2013), mainly sponsored by the National Science Foundation and the U.S. Department of Energy. The model we ran was CLM 5.0 on a 1.9°x2.5° grid with a monthly time resolution for one year. The improvement of this model is that it is extended with a carbon-nitrogen (CN) biogeochemical model that is prognostic with the vegetation, litter, and soil carbon and nitrogen states (Lawrence et al., 2011). When we used CLM to create our personalized model, we chose commends from the namelists named: snowveg_flag, and set it in the condition of "ON" to meet the condition of our model. while merging all the output files, the variable EFLX_LH_TOT was selected from the CLM_historyfiled.

## The Global Land Evaporation Amsterdam Model (GLEAM)

The Global Land Evaporation Amsterdam Model (GLEAM) is a set of algorithms designed to estimate land evaporation and root-zone soil moisture from satellite data. This is an evaporation model driven only by remote sensing observations, and its observations are mainly derived from microwave sensors, such as soil moisture and vegetation optical depth. It divides land evaporation into several parts, namely transpiration, bare soil evaporation, boiling water evaporation, and interception loss and sublimation. Each grid unit includes four different land cover types: bare soil, low vegetation (such as grass), high vegetation (such as trees), and open water (such as lakes) (Martens et al., 2017).

To assess the usability and performance of our built model, it was compared with observational data from the GLEAM dataset, which represents the monthly evapotranspiration. But because the evapotranspiration is not directly available in CLM, the evaporation of built models was first calculated by dividing the latent heat with the latent heat of vaporization, then the GLEAM dataset was used for comparison.

## The parameters

Snow is an important part of the climate system as it regulates the temperature of the Earth's surface via its effect on surface albedo and surface fluxes. As mentioned before, we looked at the effect of snow on vegetation by comparing a normal climate with what would happen if there could be no snow layer on vegetation.

More specifically, we looked at the effects that are visible in the albedo, the ground temperature, and the net primary production (NPP). Because these three variables can present the visualization results from the perspective of the land climate model and provide a good explanation for the difference between a world where vegetation is not covered by snow.

In the northern hemisphere, seasonal snow cover plays an important role in the climate system through its influence on the surface albedo (Daloz et al., 2021), albedo was calculated by dividing the reflected solar radiation by the sum of the absorbed and the reflected solar radiation. As was shown in previous research, albedo can change considerably depending on the type of vegetation that is present at a certain location, resulting in other changes in the climate (Davin and de Noblet-Ducoudré, 2010). As such it is only logical that there is also a change in albedo when no more snow is possible on vegetation, as the albedo of snow is in general much larger than that of vegetation. We can thus also expect there will be an influence on the temperature, in addition, a snow layer on vegetation might also restrict the plant from photosynthesis, which is why we also study the change in NPP.

# Results

## Comparison model and observational data

First, the control run of the model was compared to the observational data. Over the whole land surface, the average difference in the mean daily evapotranspiration was -0.085 mm/day, which corresponds to a very small underestimation by the model of the evapotranspiration. When the global patterns in these differences are inspected, it becomes clear that for most of the land surface, the differences in mean daily evapotranspiration remain between -1 and 1 mm per day (Fig. 1).

For the maximal daily evapotranspiration, the globally-average difference is even smaller, with an underestimation of 0.04 mm per day by the model. While the global patterns for the differences in maximal values remain similar to those that can be observed with the mean daily evapotranspiration, the differences become larger for the individual pixels (Fig. 2). In both figures some extreme values can be seen, but that is probably more due to artefacts because of the interpolation that had to be performed than due to actual differences.

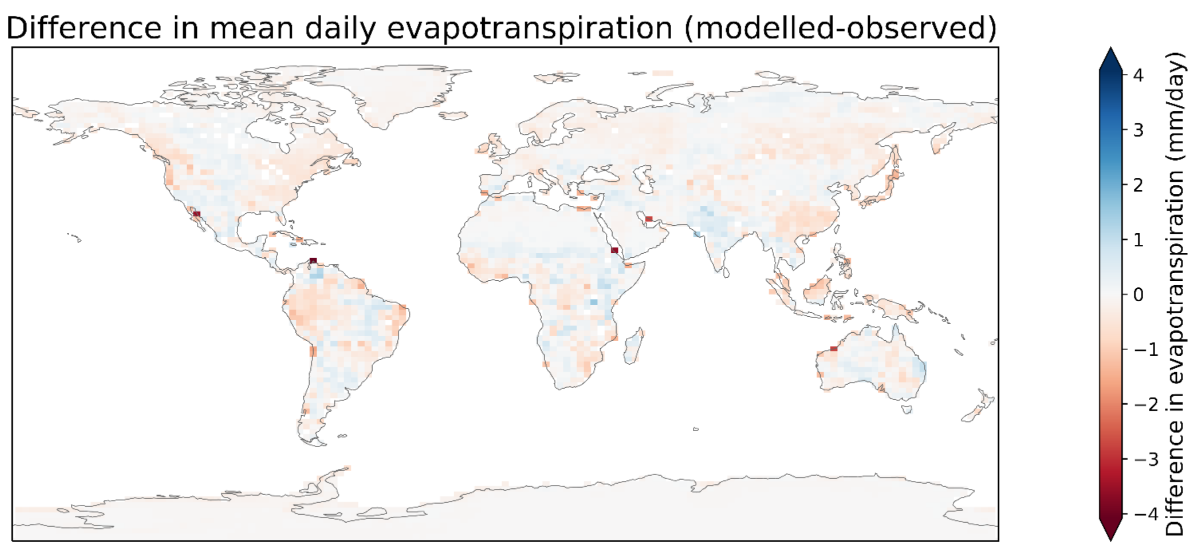


*Figure 1: The difference in mean daily evapotranspiration. Negative values mean the observed evapotranspiration is higher, positive values mean the model has higher values.*

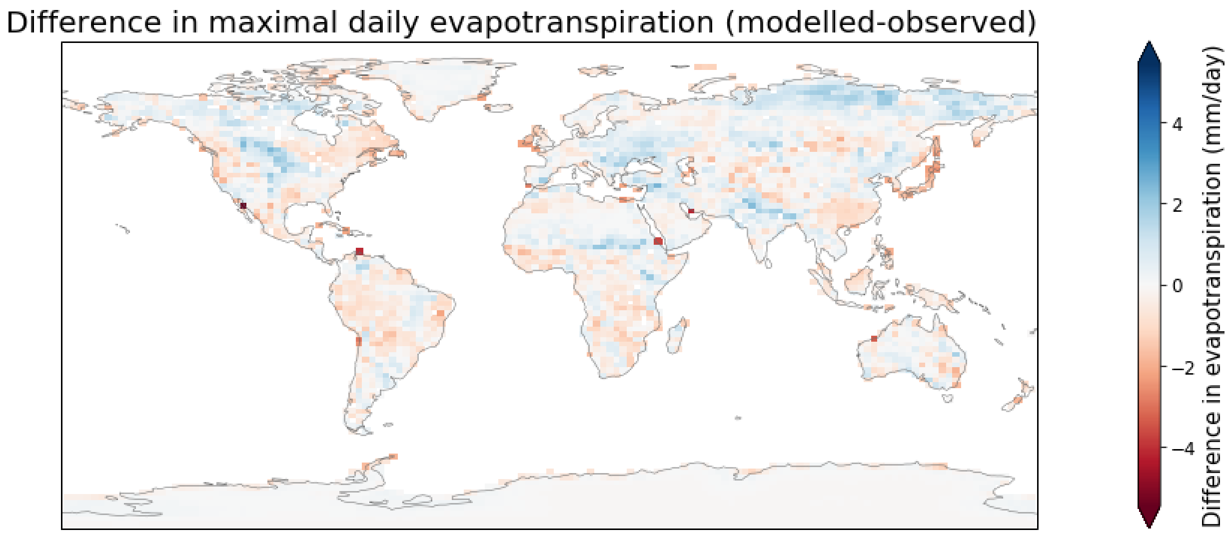


*Figure 2: The difference in evapotranspiration in the month with the highest mean daily evapotranspiration. Negative values mean the observed evapotranspiration is higher, positive values mean the model has higher values.*

## Comparison control run and disturbed run

The first variable for which we assessed the difference between the control run with the normal model settings and the disturbed run where no snow layer on vegetation was possible was the ground temperature. For the yearly mean ground temperature, we find higher temperatures in the more northern parts of the world for the disturbed run, with the highest differences in Siberia (Fig. 3). We also find them in some mountain ranges. Only a few pixels have higher temperatures in the results of the control run and there also does not seem to be a clear geographical pattern in this.

When we look at the month for which the ground temperature is maximal, there are hardly any pixels with a notable difference left, but there is some effect in the far-north-east of Russia (Fig. 4). In the month with lowest ground temperature, there are again bigger differences, but the areas with the biggest differences are at a lower latitude than they were for the yearly mean (Fig. 5). The differences in Figure 4 and Figure 5 might appear to be lower than those in Figure 3, but it should be noted that the colorbars have different values.

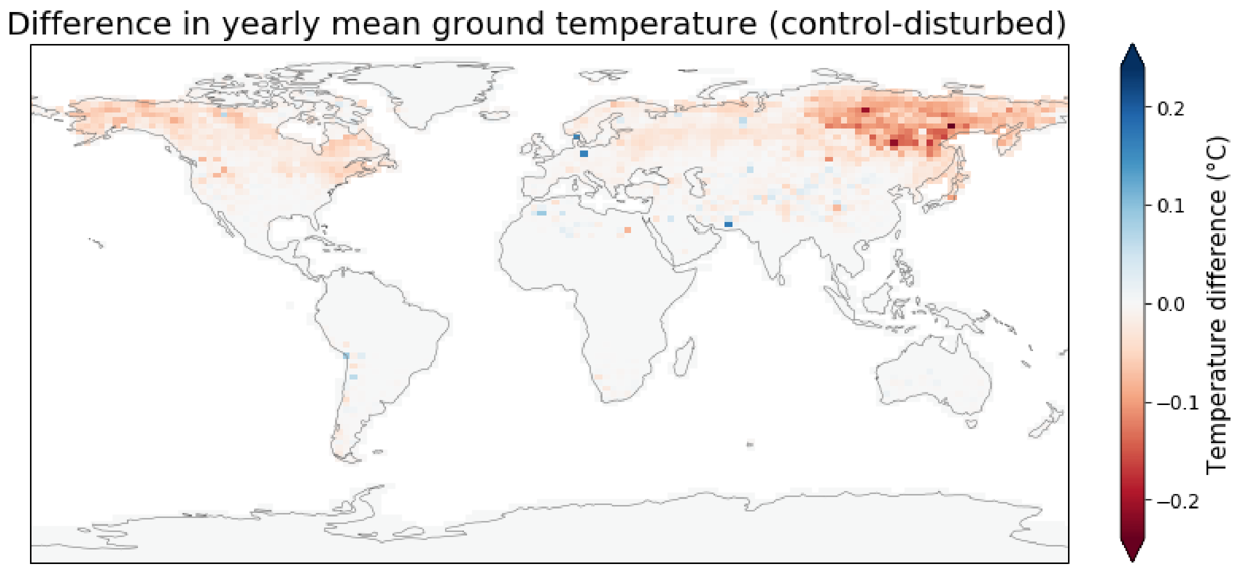


*Figure 3: Difference in the yearly mean ground temperature between the control and distubed run. Red pixels show higher temperatures in a no snow on vegetation world. Blue pixels indicate colder temperatures.*

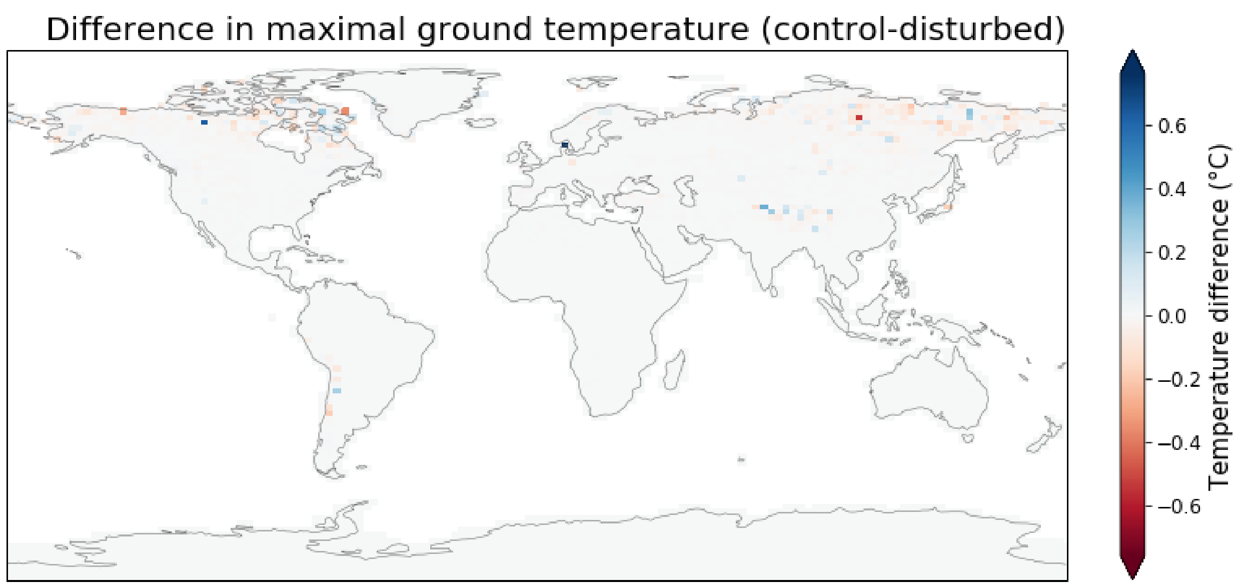


*Figure 4: Difference in ground temperature in the month with the highest ground temperature between the control run and the disturbed run.*

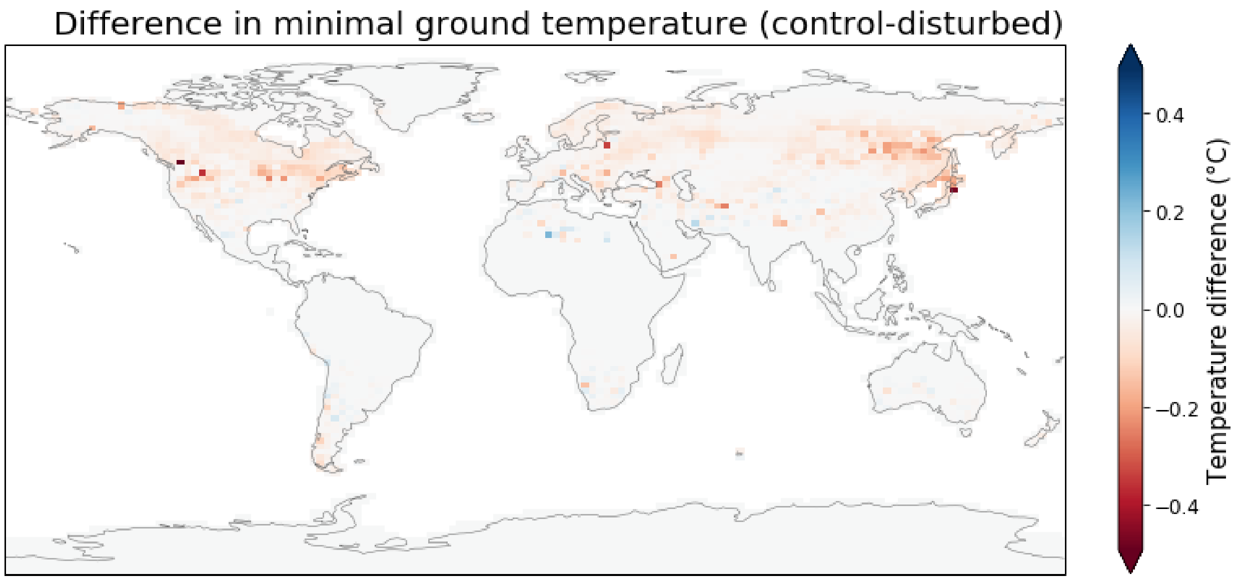


*Figure 5: Difference in ground temperature in the month with the lowest ground temperature between the control run and the disturbed run.*

Another parameter that changes in the disturbed run is the net primary production (NPP). Again the effect is the highest in the high-latitude regions, as well as some orography effects in the Himalayas, the Alps and the Andes (Fig. 6). At the locations where there are differences, the NPP tends to be about 0.04 gram carbon per square meter per day higher. This might not seem much, but this corresponds to 50 tons of carbon dioxide per year per square kilometer.

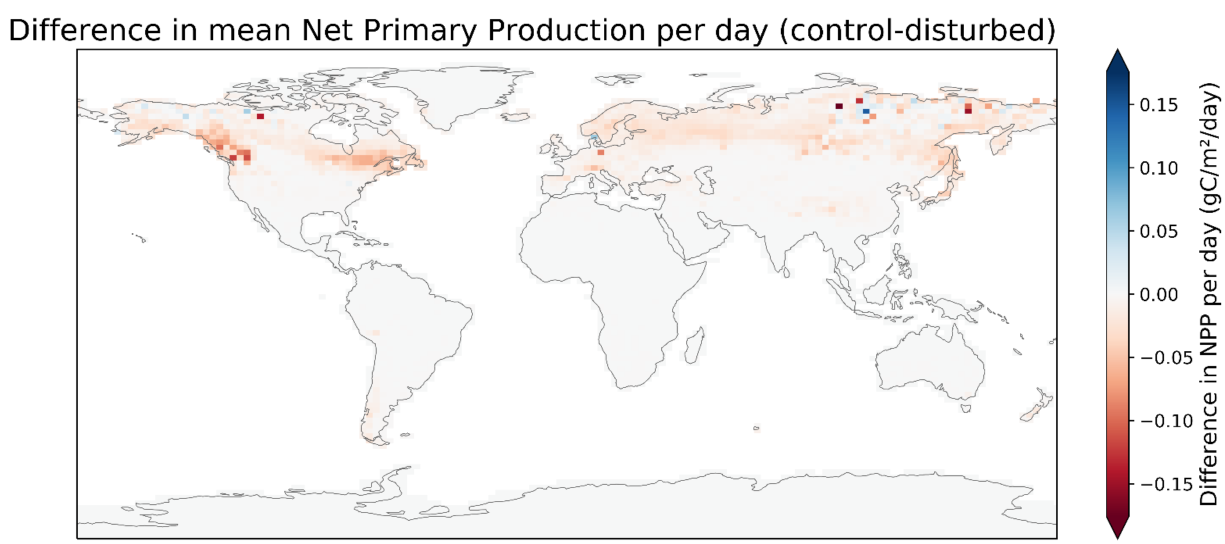


*Figure 6: The difference in the mean net primary production between the control run and the disturbed run, given in grams of Carbon per square meter per day.*

The last parameter we look at is the albedo. Figure 7. shows the evolution of the relative difference in albedo between the control and disturbed run throughout the year. The albedo is higher in the control run for all pixels, which is logical as a snow layer typically increases the albedo. Just as for the other variables, it is important to note that the colorbar has different values for the different plots. Only for July there are no notable differences in the northern hemisphere, but there are some in the most southern part of South-America, where it is winter then. The largest relative differences in albedo can be found in Siberia in October, but then the differences remain mostly confined to the highest latitudes and a bit of the Himalaya. In contrast, there are also differences in albedo in the mainland of Europe and the USA in January. The same patterns stay in April, although the magnitude of the differences is then smaller. It is also remarkable that the largest differences in albedo are present between 55° and 65°, but become lower again at even higher latitudes.

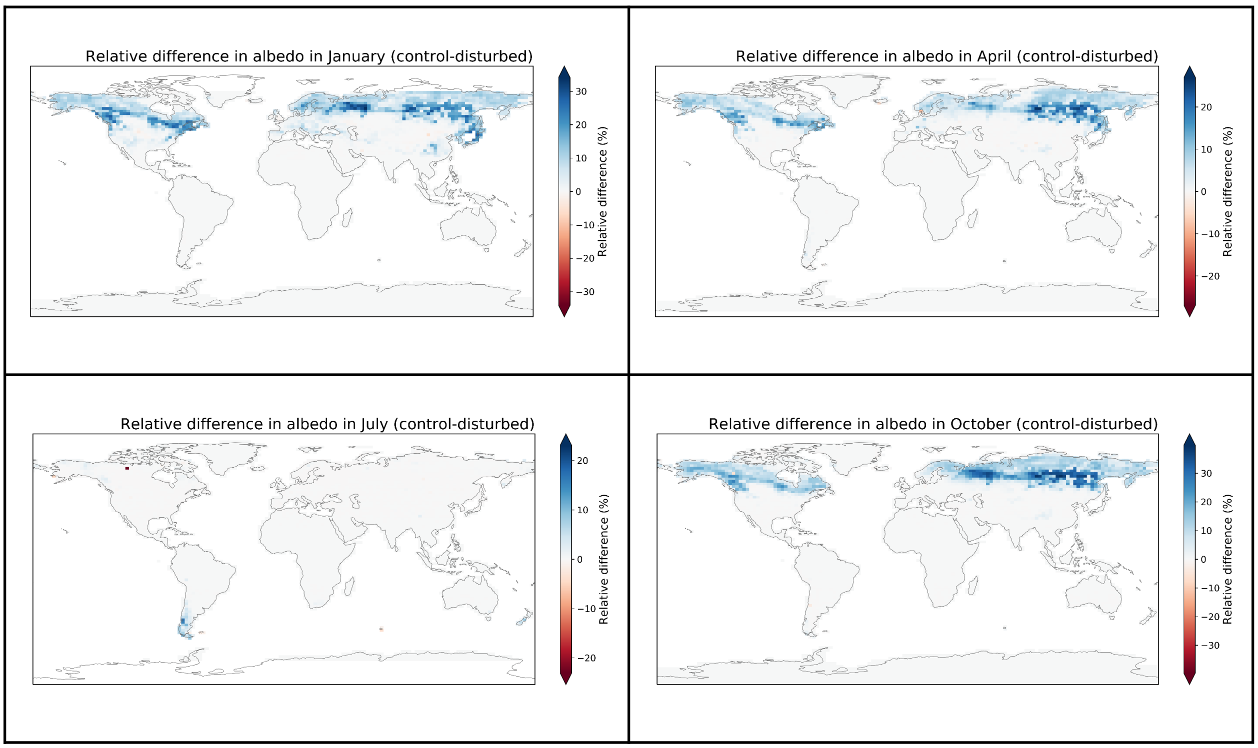


*Figure 7: Evolution of the relative difference in albedo between the control and disturbed model throughout the year.*

## Discussion and conclusion

First, when we compared the observational data with the results from the control-model, we found that the difference between both in global evapotranspiration was rather small, with a very small underestimation by the model.

While comparing the control run and disturbed run with the help of the three selected variables, we concluded that the most dominant variable for visualizing the differences between models is albedo, it is a fundamental element in the energy balance, and will thus also influence the temperature. From a regional perspective, it shows obvious differences in high latitude regions and mountainous areas. From seasonal analysis, the albedo in winter will show greater relative differences than other seasons, especially in Siberia. This result is logical as a snow layer typically increases the albedo.

Besides, we found that the average annual ground temperature is mainly affected by latitude and altitude, the temperature in the high latitudes and some mountain ranges of the northern hemisphere was affected the most, and is higher when the vegetation is without the snow cover. From the seasonal analysis, there is no notable difference between the two models in the hottest month, and the ground temperature difference in the coldest month is larger than the annual average difference. This is easy to explain because the absence of snow can only affect areas where there is a large temperature difference, and it has a limited impact on areas where the temperature is too high for snow anyways. As for the difference between net primary production (NPP), again the effect is the highest in the high-latitude regions and mountains.

At the same time, we also observed the relationship between different parameters. The interesting phenomenon is that albedo influences the temperature, the temperature might have an influence on the NPP, as well as the snow might hinder the sunlight that is required for photosynthesis. This also explains that the biggest differences of these three parameters are far-north and in winter, which is quite logical as these are the regions of the world where there is a lot of snow, so globally the effect is limited but the effect is larger where there is a lot of snow.

What is also remarkable are the diminishing differences above 65°N for some variables. However, this can be explained because of the orientation of the earth to the sun. Above the polar circle, radiation from the sun is limited during winter, which might reduce the impact on the variables we chose.

There are however also some short-comings in the model approach we used. There was no spin-up period for the model, which might have influenced the results of the first month. Apart from that we also used a monthly time resolution, while snow cover is something that is often only present for short periods, especially at lower latitudes than the high-north that was most prominent now. This now also gives the results from only one year and one model, while it might be more interesting to look at longer time periods or compare different models when making this kind of analysis.

# References


Davin, E. L., & de Noblet-Ducoudré, N. (2010). Climatic impact of global-scale deforestation: Radiative versus nonradiative processes. *Journal of Climate*, *23*(1), 97-112.

Martens, B., Miralles, D. G., Lievens, H., Van Der Schalie, R., De Jeu, R. A., Fernández-Prieto, D., ... & Verhoest, N. E. (2017). GLEAM v3: Satellite-based land evaporation and root-zone soil moisture. *Geoscientific Model Development*, *10*(5), 1903-1925.

Miralles, D. G., Holmes, T. R. H., De Jeu, R. A. M., Gash, J. H., Meesters, A. G. C. A., & Dolman, A. J. (2011). Global land-surface evaporation estimated from satellite-based observations. *Hydrology and Earth System Sciences*, *15*(2), 453-469.

Daloz, A.S., Schwingshackl, C., Mooney, P., Strada, S., Rechid, D., Davin, E.L., Katragkou, E., de Noblet-Ducoudré, N., Belda, M., Halenka, T., Breil, M., Cardoso, R.M., Hoffmann, P., Lima, D.C.A., Meier, R., Soares, P.M.M., Sofiadis, G., Strandberg, G., Toelle, M.H., Lund, M.T., 2021. [preprint under review] Land-atmosphere interactions in sub-polar and alpine climates in the CORDEX FPS LUCAS models: I.

Evaluation of the snow-albedo effect. Cryosphere Discuss. 1–33. https://doi.org/10.5194/tc-2021-290
Infrastructure — VUB-HPC [WWW Document], n.d. URL https://hpc.vub.be/docs/infrastructure/ (accessed 12.20.21).

Lawrence, D.M., Oleson, K.W., Flanner, M.G., Thornton, P.E., Swenson, S.C., Lawrence, P.J., Zeng, X., Yang, Z.-L., Levis, S., Sakaguchi, K., Bonan, G.B., Slater, A.G., 2011. Parameterization improvements and functional and structural advances in Version 4 of the Community Land Model. J. Adv. Model. Earth Syst. 3. https://doi.org/10.1029/2011MS00045

Martens, B., Miralles, D.G., Lievens, H., van der Schalie, R., de Jeu, R.A.M., Fernández-Prieto, D., Beck, H.E., Dorigo, W.A., Verhoest, N.E.C., 2017. GLEAM v3: satellite-based land evaporation and root-zone soil moisture. Geosci. Model Dev. 10, 1903–1925. https://doi.org/10.5194/gmd-10-1903-2017

# Appendix

When we used CLM to create our personalized model, we chose commends from the namelists named: snowveg_flag, and set it in the condition of "ON" to meet the condition of our model. while merging all the output files, the variable EFLX_LH_TOT was selected from the CLM_historyfiled.

## Bash-codes

```
module list
mkdir cases
git clone -b  release-cesm2.1.3 https://github.com/ESCOMP/cesm.git cesm
cd cesm
./manage_externals/checkout_externals
update-cesm-machines cime/config/cesm/machines /data/brussel/vo/000/bvo00012/cesm/config_files/machines

scripts
./create_newcase --case ~/cases/control   --res f19_g17 --compset I2000Clm50BgcCrop --mach hydra
cases
cd control
ls

./case.setup
./case.build
./xmlchange DOUT_S=FALSE
micro env_run.xml
###### Then we changed the following in the env_run.xml file (STOP_N=12, STOP_OPTION=nmonths)
###### in the namelist we also added snowveg_flag='ON'
micro user_nl_clm
./case.submit
work
cd control/run


#===============================================================================
# main script which postprocesses CLM output
#===============================================================================
```

```
# First, deal with the first h0 file which has more variables (because select fails) to merge all files
# echo 'reducing the number of variables in ' "control.clm2.h0.0001-01.nc"
mv control.clm2.h0.0001-01.nc orig_control.clm2.h0.0001-01.nc 2>/dev/null  # create backup
cdo shifttime,-1mon -replace control.clm2.h0.0001-02.nc orig_control.clm2.h0.0001-01.nc
control.clm2.h0.0001-01.nc # create January file with the same vars as February


# merge the 12 files
# to be filled

cdo mergetime control.clm2.h0.0001-**.nc control.clm2.h0.0001.merged.nc

#the same was done for the personalised runs
bash postprocessing_CLM.sh
cdo selname,EFLX_LH_TOT control.clm2.h0.0001.merged.nc control.clm2.h0.latentheatflux.nc
cdo remapbil,control.clm2.h0.latentheatflux.nc gleam_V31A.all.et.2000_monthly.nc gleam_remapbil.nc
cdo selname,TG personalised.clm2.h0.0001.merged.nc personalised.clm2.h0.groundtemp.nc
# then a lot of times selname was done with different variables and new names for the outputfiles
```

## Python-codes

```
#load in packages
import xarray as xr
import cartopy.crs as ccrs
import matplotlib.pyplot as plt
import numpy as np

#open dataset
filename = 'control.clm2.h0.latentheatflux.nc'
filename2 = 'gleam_remapbil.nc'
        # change to for example filename = 'control.clm2.h0.groundtemp.nc'
ds = xr.open_dataset(filename, decode_times=False)
ds2 = xr.open_dataset(filename2,decode_times=False)
# look what's inside the dataset (click data variables)

# load the evapotranspiration variable and check its attributes
da = ds['EFLX_LH_TOT']
db = ds2['e']
        #Change to for example da=ds['TG'] or NPP or FSR of FSA

# calculate mean over the time dimension
da_mean = da.mean('time')*0.03456
db_mean = db.mean('time')
        #other variables might need other coefficients, or min or max can be used for other datasets

# define plotting parameters
# variable
da_toplot = da_mean-db_mean
```

```
	# for percentage change, divide this difference by one of the two
test=da_toplot.values[:,:]
# title
	#change title and label according to variables
title = 'Difference in maximal daily evapotranspiration (modelled-observed)'
# define colormap (more info on colormaps: https://matplotlib.org/users/colormaps.html)
cmap = 'RdBu'
# define colorbar label (including unit!)
cbar_label = 'Difference in evapotranspiration (mm/day)'
# define the projection
projection = ccrs.PlateCarree()
#calculate global average
test2=np.nanmean(test)
test2
# define figure, projection and axes object
fig = plt.figure(figsize=(15,6))
proj=ccrs.PlateCarree()

ax = plt.subplot(111, projection=proj, frameon=False)
# do plotting based on data array to plot and add colorbar, adjust label sizes
im = da_toplot.plot(ax=ax, cmap=cmap, extend='both', add_colorbar=False, add_labels=False)
cb = plt.colorbar(im,fraction= 0.04, pad= 0.08, extend='both')
cb.set_label(label = cbar_label, size=15)
cb.ax.tick_params(labelsize=12)
# set the title and coastlines
ax.set_title(title, loc='right', fontsize=20)
ax.coastlines(color='dimgray', linewidth=0.5)

#save
fig.savefig('gleam.png', dpi=600)
#change name
```