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Acronym: UpClim

Deliverable 3.7
Model modifications including dynamic land use changes

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Table of contents

List of tables and figures

Terms, definitions and abbreviated terms

The following acronyms have been used across this document:

ACRONYM	FULL TERM
ARW	Advanced Research dynamic solver
C3S	Copernicus Climate Change Service
CCI	Climate Change Initiative
CDS	Climate Data Store
CMIP5	Coupled Model Intercomparison Project Phase 5
CMIP6	Coupled Model Intercomparison Project Phase 6
CORDEX	Coordinated Downscaling Experiment
D3.7	Deliverable number 7 belonging to WP 3
DKRZ	German Climate Computing Center
ECMWF	European Center for Medium-Range Weather Forecasts
ERA5	ECMWF reanalysis data
ESA	European Space Agency
FAA	Federal Aviation Administration
FPS	Flagship Pilot Study
GCM	General Circulation Model
LC	Land Cover
LUC	Land Use Change
LUCAS	Land Use and Climate Across Scales
LUH2	Land-Use Harmonization 2
LULCC	Land Use and Land Cover Changes
LUT	Land Use Translator
MODIS	Moderate Resolution Imaging Spectroradiometer
MYNN2	Mellor-Yamada Nakanishi and Niino Level 2.5
NCAR	National Center for Atmospheric Research
NCEP	National Centers for Environmental Prediction
NOAH	Nationwide Operational Assessment of Hazards
PBL	Planetary Boundary Layer
PFT	Plant Functional Type
RCM	Regional Climate Model
RCP	Representative Concentration Pathway
RRTMG	Rapid Radiative Transfer Model for GCM
SSP	Shared Socioeconomic Pathway
USGS	United States Geological Survey
WCRP	World Climate Research Program
WP	Working Package
WPS	WRF pre-processing system
WRF	Weather Research and Forecasting model

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1 Introduction

The purpose of this document is to describe Deliverable 3.7 (D3.7) of Task 3.1 ("Code developments to implement yearly land use change forcing"), under Working Package 3 (WP3, "Implementation of land use forcing") in the framework of the UpClim project.

Land surface modifications as a result of human land use activities are considered an important climate forcing, while their local and regional direct biophysical effects can be as large as those associated with global greenhouse gas forcing (de Noblet-Ducoudré et al. 2012). Several studies revealed that land use and land cover changes (LULCC) affect land-atmosphere processes through modifications of the surface energy balance (e.g. Mahmood et al. 2014; De Noblet-Ducoudré and Pitman 2021). For example, deforestation causes a systematic surface albedo increase all seasons leading to a reduction in the available energy accompanied by a decrease in the sum of turbulent fluxes (de Noblet-Ducoudré et al. 2012). Moreover, deforestation has led to a local warming of present-day hot extremes since pre-industrial time over Eurasia and North America (Lejeune et al. 2018). Last but not least, the importance of LULCC for regional climate trends and temperature extremes has been demonstrated in many studies conducted by leveraging CMIP5 data in the past (e.g., Kumar et al. 2013; Lejeune, Seneviratne, and Davin 2017).

Although the strongest impact of LULCC is found on finer regional scales (e.g., Mahmood et al. 2014; Davin et al. 2014), LULCC forcing has not been sufficiently accounted for in climate change projections conducted with regional climate models (RCMs). Specifically, RCMs within the European CORDEX community have not accounted so far for land-use changes in production simulations and thus, there is a systematic missing forcing agent related to land use change and the assessment of its impact on regional climate. The first coordinated downscaling experiments including land use changes were performed in the framework of the World Climate Research Program (WCRP) Coordinated Downscaling Experiment (CORDEX) Flagship Pilot Study (FPS) Land Use and Climate Across Scales (LUCAS) – phase I (e.g., Sofiadis et al. 2022; Davin et al. 2019; 2020; Mooney et al. 2022; Daloz et al. 2022). In addition, within the LUCAS initiative, a high-resolution dataset (LUCAS-LUC hereafter) with observed LULCC and projected future LULCC scenarios at yearly time-slices was created (Hoffmann et al. 2023) in order to be utilized as input for the upcoming RCM simulations during LUCAS – phase II.

One of the main objectives of UpClim project is to implement dynamic land use changes in a regional climate model to assess the impact on regional climate over Europe. To achieve this, we employ the Weather, Research and Forecasting (WRF) model and develop a tailor-made process to ingest the LUCAS-LUC information into the model.

2 The LUCAS Land Use Change (LUC) dataset

In this section a short description of the LUCAS-phase II protocol along with the LUCAS-LUC dataset is presented.

2.1 The LUCAS-phase II protocol

In LUCAS phase 2, realistic land use change experiments on a continental scale are performed, as transient simulations of regional climate models, driven by General Circulation Model (GCM) data from the Coupled Model Intercomparison Project Phase 6 (CMIP6). Land use change forcing is used from the LUCAS-LUC Version 1.1 (Hoffmann et al. 2023) land cover dataset for past and future land use changes. The LUCAS- LUC land cover distribution 2015 is based on the LANDMATE PFT dataset Version 1.1 derived from ESA CCI LC 2015. The information about land use transitions for past and future are derived from the Land-Use Harmonization 2 (LUH2) dataset (Hurtt et al. 2020). The reference simulation is done using a static land cover map with all RCMs using the same land cover distribution from LUCAS LUC V1.1 for the year 2015. All simulations cover the EURO-CORDEX domain at 0.11^{o} resolution (~12.5 km), EUR-11 domain.

The Historical-LUC simulations use annual land use land cover maps 1950-2014 from the LUCAS-LUC dataset Version 1.1 and they are driven by GCM CMIP6 simulation data from MPI-ESM1.2-HR for 1950-2014. The CORE simulations use MPI-ESM1.2-HR r1i1p1f1 member, optional Tier1 simulations use MPI-ESM1.2-HR r2i1p1f1 member. The Projection-LUC simulations are based on a low emission scenario and LUC forcing namely the SSP126. The SSP126-LUC simulations use annual land use land cover maps between 2015-2100 for SSP126 from the LUCAS-LUC dataset Version 1.1 and are driven by GCM CMIP6 simulation data from MPI-ESM1.2-HR for 2015-2100. The CORE simulations use MPI-ESM1.2-HR r1i1p1f1 member, optional Tier1 simulations use MPI-ESM1.2-HR r2i1p1f1 member.

2.2 The LUCAS-LUC dataset

The LUCAS Land Use and land Cover change (LUC) dataset version 1.1 at 0.1◦ resolution for Europe with annual land use land cover (LULC) maps from 1950 to 2100 (Hoffmann et al. 2023) is a tailored-generated dataset. Its purpose is to serve as input to state-of-the-art RCMs to investigate the impact of realistic LULCC on past and future climates. The plant functional type (PFT) distribution for the year 2015 is derived from the European Space Agency Climate Change Initiative Land Cover (ESA-CCI LC) dataset and the land use change information from the Land-Use Harmonization 2 (LUH2) dataset (Hurtt et al. 2020) is applied through a developed land use translator (LUT) to derive LULC distributions at high spatial resolution and at annual time steps from 1950 to 2100. The annual PFT maps for Europe for the period 1950 to 2015 are derived from the historical LUH2 dataset by applying the LUT backward from 2015 to 1950. Historical changes in the forest type changes are considered using an additional European forest species dataset. The historical changes in the PFT distribution of LUCAS LUC follow closely the land use changes given by LUH2 but differ in some regions compared to other annual LULCC datasets. From 2016 onward, annual PFT maps for future land use change scenarios based on LUH2 are derived for different shared socioeconomic pathway (SSP) and representative concentration pathway (RCP) combinations used in the framework of CMIP6. Figure 1 depicts the workflow of generating the LUCAS-LUC dataset. The LUCAS-LUC LULC dataset for Europe is available at the World Data Center for Climate at DKRZ[1,2].

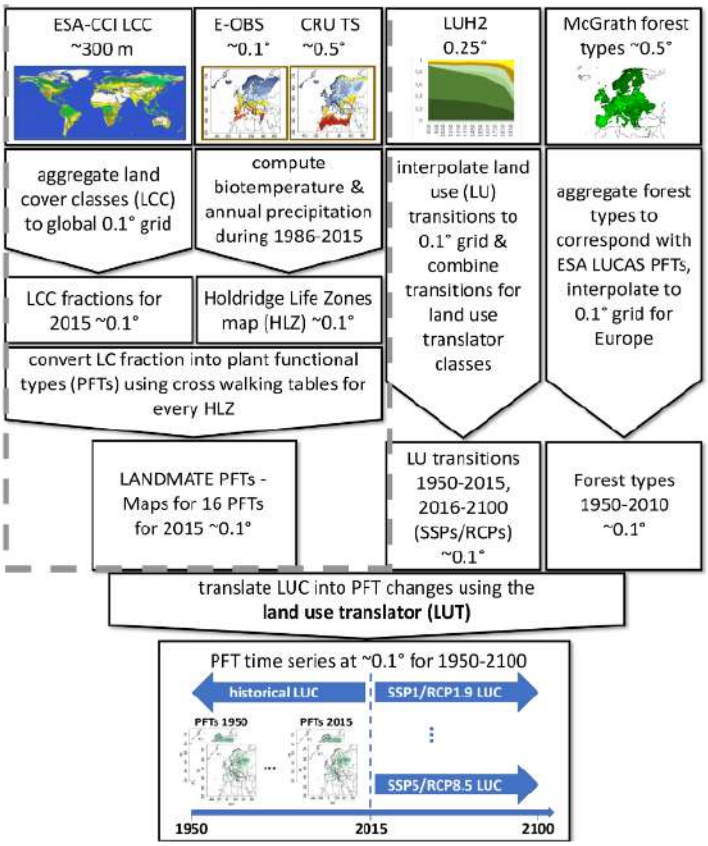

Figure 1. Workflow for generating the LUCAS LUC dataset (Hoffmann et al. 2023, their Figure 1).

3 The Weather, Research and Forecasting model

The Weather Research and Forecasting (WRF) Model (Powers et al. 2017; Skamarock et al. 2019) is a next-generation mesoscale numerical weather prediction system designed for both atmospheric research and operational forecasting applications. It features a data assimilation system, and a software architecture supporting parallel computation and system extensibility. The model serves a wide range of meteorological and climate applications across scales from tens of meters to thousands of kilometers. The effort to develop WRF began in the latter 1990's and was a collaborative partnership of the National Center for Atmospheric Research (NCAR), the National Oceanic and Atmospheric Administration (represented by the National Centers for Environmental Prediction (NCEP) and the Earth System Research Laboratory), the U.S. Air Force, the Naval Research Laboratory, the University of Oklahoma, and the Federal Aviation Administration (FAA). Additional information on the model itself can be found at https://www.mmm.ucar.edu/weather-research-and-forecasting model.

1 https://doi.org/10.26050/WDCC/LUC_hist_EU_v1.1
2 https://doi.org/10.26050/WDCC/LUC_future_EU_v1.1

The WRF model has been widely used as a regional climate model (e.g. Katragkou et al., 2015) and is an official model-member of the Ensemble Desing Matrix of CMIP6/EURO-CORDEX (Katragkou et al., 2024). For the purposes of Task 3.1 "Code developments to implement yearly land use change forcing", the non-hydrostatic Weather Research and Forecasting model with the Advanced Research dynamic solver (WRF-ARW, v4.5.1) has been utilized. More specifically, the selected model version is 4.5.1.4 (WRF451Q) which includes some additional modifications and improvements in NoahMP land use model (Niu et al. 2011), available from the CORDEX WRF community fork (git clone --recurse-submodules -b v4.5.1.4 https://github.com/CORDEX-WRF-community/WRF.git).

4 Implementation of LUCAS-LUC dataset into WRF

The official release of the WRF pre-processing system (WPS) currently supports static land use land cover (LULC) information. The user can choose between the USGS and MODIS datasets, which each of those two come with different category classes. Both datasets are considered outdated in terms of representing the current spatial information in each of their classes and several studies use alternative LULC datasets (e.g. CORINE) to tackle this problem (Kartsios et al. 2015; 2021; Lavin-Gullon et al. 2021; Pytharoulis et al. 2018; Ban et al. 2021; Pytharoulis et al. 2023; Soares et al. 2022; Breuer, Varga, and Zempléni 2021).

Although the possibility of ingesting an alternative LULC dataset exists, the USGS and MODIS classes are "hardcoded" inside the model and their associated properties (e.g. albedo, emissivity, roughness length) are described through lookup tables. Thus, one way forward is to translate the information of the alternative LULC dataset into MODIS or USGS classes (e.g. Pineda et al. 2004).

The program responsible for creating the simulated domain(s) along with all the static information (e.g. topography, land use, coordinates, land mask, sea mask, albedo) is the geogrid.exe. The LUCAS-LUC dataset comes with annual LULC maps which must be ingested properly into WPS. Prior to this it was decided that the MODIS classes will be used as the default LULC dataset (21 classes, Table 1) and the LUCAS-LUC PFTs will be translated into MODIS categories according to Table 2. The latter is in line with the LUCAS-phase II protocol and is applied in all participating modeling groups that use WRF. Finally, each MODIS class is represented as a fraction in each model grid-point, so their sum is equal to 1.

Table 1. MODIS classes as LULC input to WRF.

A/A	MODIS class name	A/A	MODIS class name
1	Evergreen Needleleaf Forest	12	Croplands
2	Evergreen Broadleaf Forest	13	Urban and Built-Up
3	Deciduous Needleleaf Forest	14	Cropland/natural vegetation mosaic
4	Deciduous Broadleaf Forest	15	Snow and Ice
5	Mixed Forests	16	Barren or Sparsely Vegetated
6	Closed Shrublands	17	Water
7	Open Shrublands	18	Wooded Tundra
8	Woody Savannas	19	Mixed Tundra
9	Savannas	20	Barren Tundra
10	Grasslands	21	Lakes
11	Permanent wetlands		

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Table 2. Translation of LUCAS-LUC PFTs to MODIS-WRF classes.

LUCAS-LUC PFT	PFT name	MODIS-WRF	MODIS class name
1	Tropical broadleaf evergreen	2	Evergreen Broadleaf Forest
2	Tropical broadleaf deciduous	4	Deciduous Broadleaf Forest
3	Temperate broadleaf evergreen	2	Evergreen Broadleaf Forest
4	Temperate broadleaf deciduous	4	Deciduous Broadleaf Forest
5	Evergreen coniferous	1	Evergreen Needleleaf Forest
6	Evergreen deciduous	3	Deciduous Needleleaf Forest
7	Evergreen shrubs	6	Closed Shrublands
8	Deciduous shrubs	6	Closed Shrublands
9	C3 grasses	10	Grasslands
10	C4 grasses	10	Grasslands
11	Tundra	19	Mixed Tundra
12	Swamps	11	Permanent wetlands
13	Crops	12	Croplands
14	Irrigated crops	-	
15	Urban	13	Urban and Built-Up
16	Bare	16	Barren or Sparsely Vegetated

Moreover, in LUCAS-LUC dataset there are some general remarks that had to be taken into consideration and are presented below:

1. LUCAS-LUC does not provide any land sea mask and RCM's land sea mask must be applied
2. Ice cover is not provided by LUCAS-LUC and alternative information must be provided
3. Swamps PFT must be converted into model specific types, most commonly into wetlands in most RCMs
4. C3 and C4 grasses PFTs are not differentiated in most RCMs and can be summed to a joint grassland type
5. Irrigated cropland and cropland are not distinguished in most RCMs and can be added to a joint cropland type

These considerations along with some specific related to WRF issues were treated properly by a tailor-made algorithm (F90 code, available in Appendix) that expanded the original annual LUCAS-LUC PFTs and performed the following tasks:

1. The missing "Irrigated crops" class in MODIS was filled with the USGS properties of "Irrigated Cropland and Pasture". This "new MODIS" class replaced the "Savannas" class (class 9, Table 1) and required changes in LANDUSE.TBL file to reflect correctly the new assigned physical properties.
2. PFTs C3 and C4 grass percentage were added to form a unified MODIS "Grassland" field (class 10, Table 1).
3. The percentage of the 3 types of tundra in MODIS (Wooded, Mixed, Baren) was converted into fraction of tundra types which were multiplied by PFT11 (Tundra) whenever PFT11 >0. This added 2 more PFT classes of tundra: Wooded Tundra and

Barren Tundra – namely PFT18 and PFT20.

4. Shrubs PFT7 (evergreen) and PFT8 (deciduous) were added to form a unified "shrubland" PFT class similar to MODIS "Closed shrubland" class (class 6, Table 1). The percentage of the 3 types of shrubland in MODIS (open, closed, woody savannas) was converted into fraction of shrub types which were multiplied by the sum PFT7+PFT8 whenever PFT7+PFT8 >0. This added 2 more PFT classes of shrubs: "open shrubs" and "woody savannas" – PFT7, PFT8.
5. Since there is no LUCAS-LUC PFT for MODIS "Mixed Forests" class (class 5, Table 1), this MODIS class fraction was set to zero.
6. The same reasoning was followed for MODIS "Cropland/natural vegetation mosaic" class (class 14, Table 1), setting its fraction equal to zero.
7. A new PFT (namely PFT17) was added and assigned to MODIS "Water" class (class 17, Table 1). PFT17 was filled with MODIS class 17 originated from the "geo_em.d01.EUR-12-v4.1.nc" file[3], which is the official static data file for the WRF-CORDEX-EUR-11 simulations[4].
8. A new PFT (namely PFT21) was added for MODIS "Lakes" class (class 21, Table 1). This information came from ESA CCI dataset (valid for 2015). Inland water bodies (i.e., lakes and rivers) are staying constant throughout the simulated period (1950-2100).
9. Upon unavailability of any snow-ice PFT in LUCAS-LUC dataset, the MODIS "Snow and Ice" class (class 15, Table 1) was filled by ESA CCI permanent snow and ice class. It was decided that MODIS class 15 is going to be constant and equal to 1992's conditions from 1950-1992, then will follow the annual changes according to ESA-CCI data from 1992 to 2020 and will remain constant towards 2100.
10. All LUCAS-LUC PFT fractions adjusted to account for water, snow and ice following the equation, $\% PFT = \% PFT_{ori} \times (1. - (\% water + \%snow + \%ice))$.
11. The new LU_INDEX variable in each grid-point corresponds to the PFT with the maximum percentage in that grid-point. To let WRF (through real.exe) determine LU_INDEX from the percentages of the LANDUSEF variable, the user should set "surface_input_source = 1" in namelist.input file.

Table 3 summarizes the conversion process of annual LUCAS-LUC PFTs into MODIS-WRF land use categories, while Figure 2 presents the workflow of translating annual LUCAS-LUC PFTs into MODIS-WRF land use categories. Figure 3 depicts changes in land use fractions for some representative MODIS-WRF classes between 1950 and 2015.

Table 3. Conversion table between annual LUCAS-LUC PFTs and MODIS-WRF classes

No.	MODIS-WRF Land use categories	LUCAS-LUC PFT
1	'Evergreen Needleleaf Forest'	Evergreen coniferous (5)
2	'Evergreen Broadleaf Forest'	Temperate broadleaf evergreen (3)
3	'Deciduous Needleleaf Forest'	Evergreen deciduous (6)
4	'Deciduous Broadleaf Forest'	Temperate broadleaf deciduous (4)
5	'Mixed Forests'	0

3 This information is stored in LANDUSEF variable inside the file
4 https://github.com/CORDEX-WRF-community/euro-cordex-cmip6/tree/main/static_data

No.	MODIS-WRF Land use categories	LUCAS-LUC PFT
6	'Closed Shrublands'	% of (Evergreen shrubs (7) + Deciduous shrubs (8))
7	'Open Shrublands'	% of (Evergreen shrubs (7) + Deciduous shrubs (8))
8	'Woody Savannas'	% of (Evergreen shrubs (7) + Deciduous shrubs (8))
9	'Irrigated Cropland'	Irrigated Crops (14)
10	'Grasslands'	C_3 + C_4 grasses (9,10)
11	'Permanent wetlands'	Swamps (12)
12	'Croplands'	Non-irrigated crops (13)
13	'Urban and Built-Up'	Urban (15)
14	'Cropland/natural vegetation mosaic'	0
15	'Snow and Ice'	From ESA CCI Ice class
16	'Barren or Sparsely Vegetated'	Bare (16)
17	'Water'	From model Land-Sea mask
18	'Wooded Tundra'	% of tundra (11)
19	'Mixed Tundra'	% of tundra (11)
20	'Barren Tundra'	% of tundra (11)
21	'Lakes'	From ESA CCI Water class

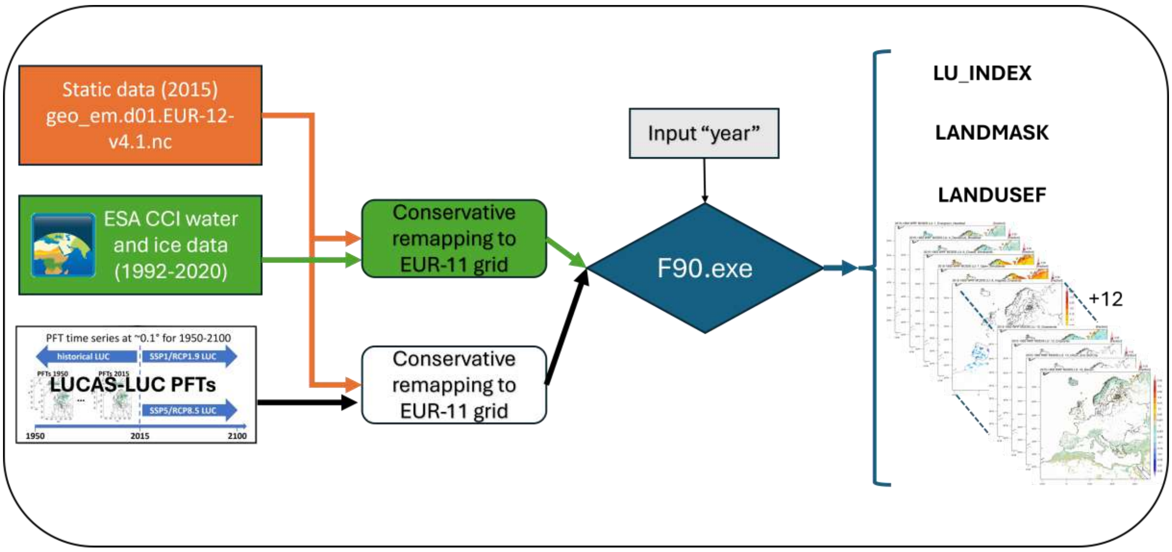

Figure 2. Workflow of translating annual LUCAS-LUC PFTs into MODIS-WRF classes.

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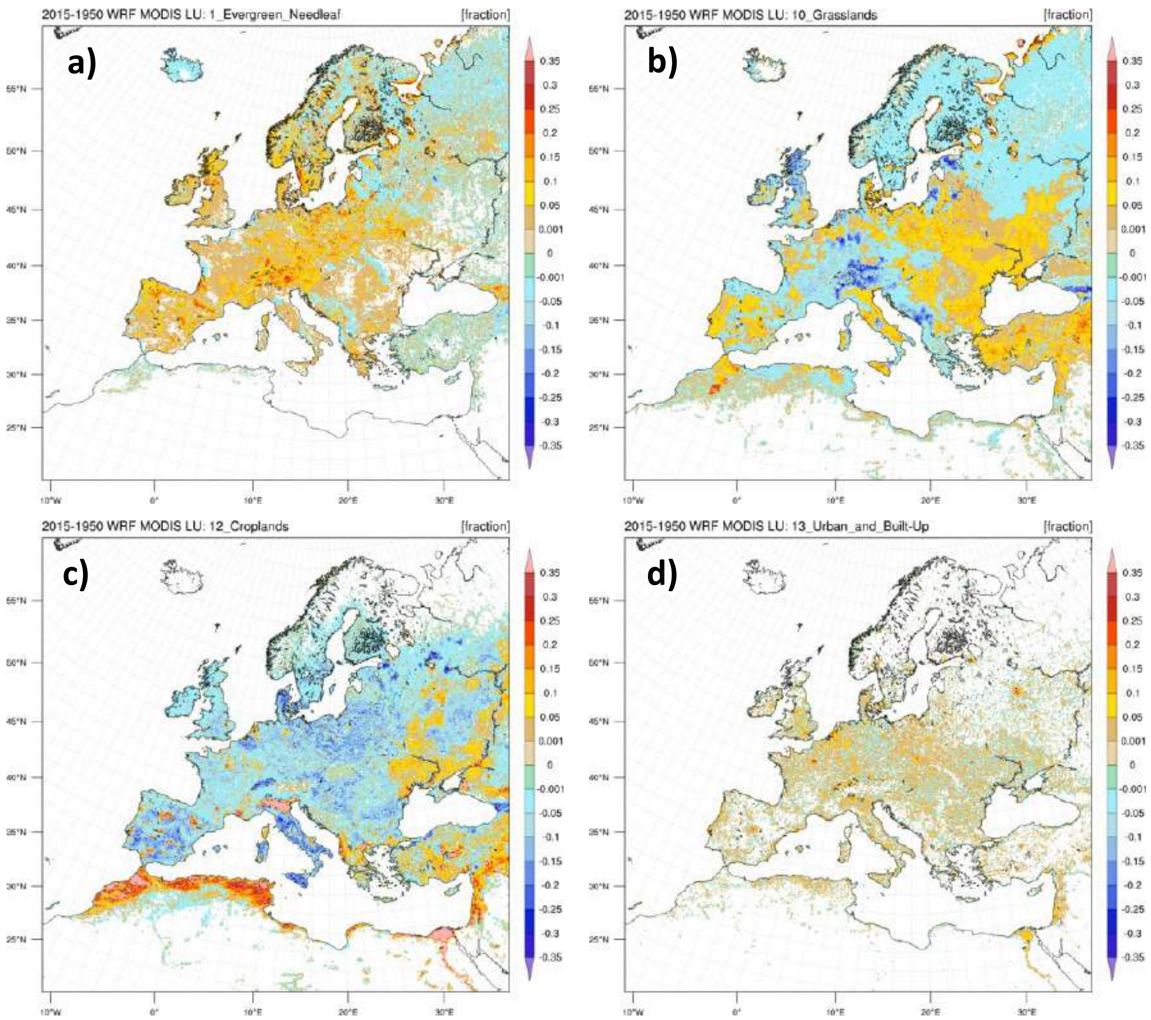

Figure 3. Changes in land use fractions in MODIS-WRF a) "Evergreen needleaf", b) "Grasslands", c) "Croplands" and d) "Urban and Built-up" class between 1950 and 2015.

5 Model configuration and numerical experiments

For the evaluation of the current developments regarding the dynamical land-use changes in WRF (see previous section), we are going to perform two past climate simulations over the official EURO-CORDEX domain at 0.11^o resolution (EUR-11), using reanalysis forcing (ERA5, Hersbach et al. 2020). The CNTRL simulation will be performed using the static LU information as in the official WRF-EURO-CORDEX CMIP6 simulations, while the second one (UpCLIM-LUC) will use the generated LUC information at annual intervals. Both simulations will be spanned for 5 consecutive years and the simulation window will be decided after some analysis of the generated LUC information to identify the optimum period.

Both simulations will be performed by utilizing the Thompson microphysical scheme (mp_physics = 8) (Thompson et al. 2008), the RRTMG scheme (Iacono et al. 2008) for the shortwave and longwave radiation, the Mellor-Yamada Nakanishi and Niino Level 2.5 (MYNN2) scheme (Nakanishi and Niino 2006; 2009) for representation of boundary layer properties and the Kain-Fritcsh scheme (Kain 2004) for the parameterization of sub-grid convection. Surface layer processes will be parameterized by the Nakanishi and Niino PBL's surface layer scheme and land-atmosphere interactions by the Noah-MP Land Surface Model (Niu et al. 2011; Yang et al. 2011) with special treatment of groundwater. In vertical, 54 sigma levels will be employed up to 20 hPa (in hybrid vertical coordinate configuration) with the first sigma level at 35 m.

The ERA5 reanalysis (Hersbach et al. 2020) product will be used as initial and boundary conditions in the both simulations (CNTRL, UpCLIM-LUC). ERA5 embodies a detailed record of the global atmosphere, land surface and ocean waves from 1950 onwards. It is produced by ECMWF, and it is based on the Integrated Forecasting System (IFS) Cy41r2 with horizontal resolution of 31 km, 137 vertical layers and hourly output. In addition, it utilizes an uncertainty estimate from an ensemble to assess the evolution of the ingested observing systems. The ERA5 is available from the Copernicus Climate Change Service (C3S) (Thépaut et al. 2018) at a horizontal grid-spacing of 0.25° x 0.25° (latitude-longitude).

First results of regional climate model simulations indicate a proper performance of the modeling system. Figure 4 shows four basic climatic variables: air temperature at 1st model level, surface temperature, water vapor path d) Precipitation for the starting historical year 1950. Similarly in Figure 5 for projection year 2015.

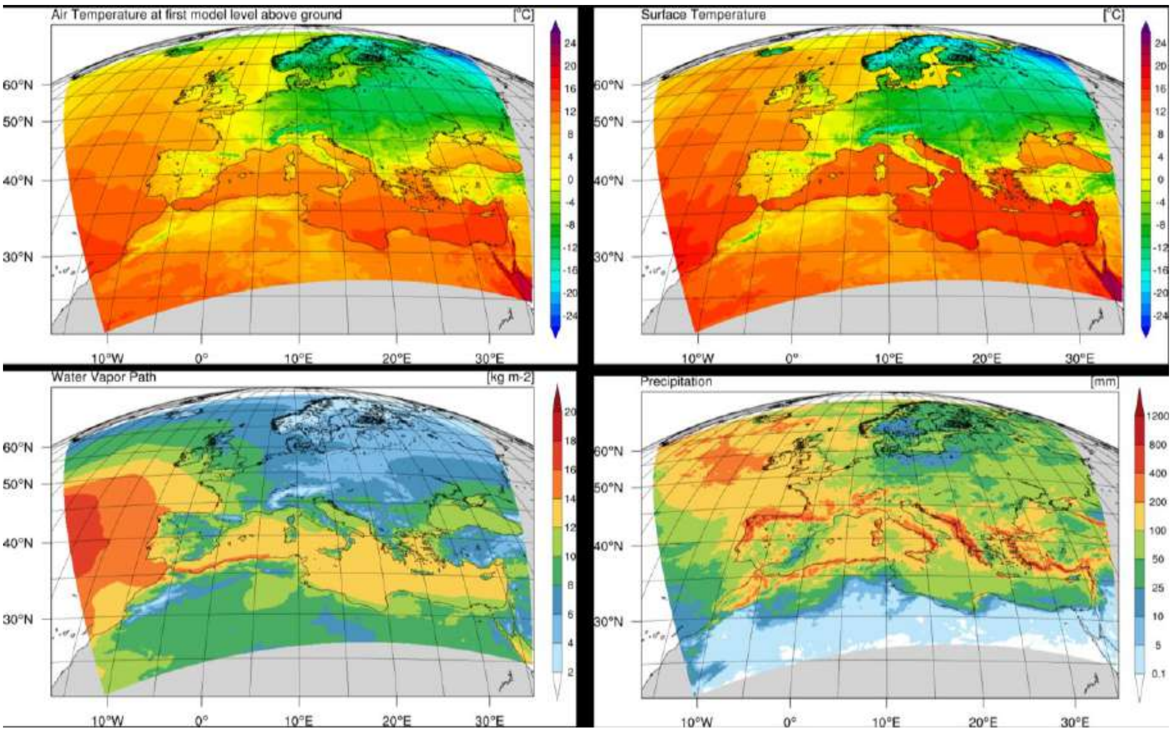

Figure 4 **Preliminary results of WRF simulations including land use changes for a) air temperature at 1st model level (°C) b) surface temperature (°C) c) Water Vapor Path (Kg/m²) d) Precipitation (mm) for year 1950 .**

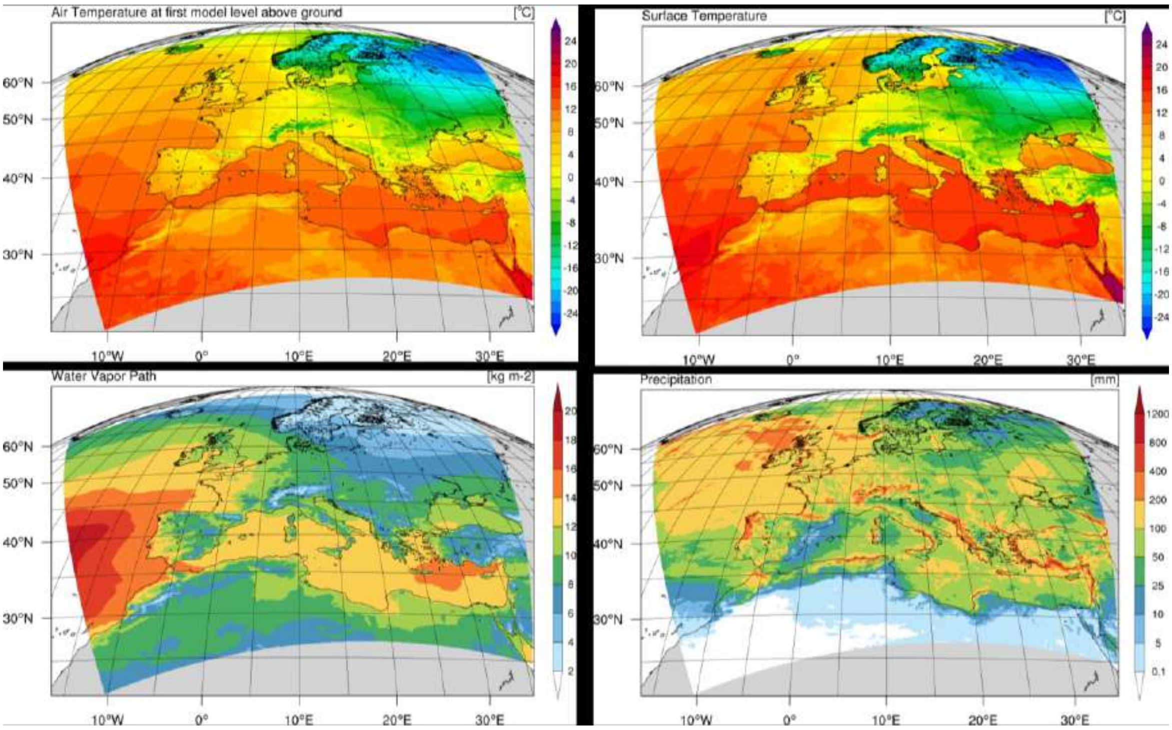

Figure 5 Preliminary results of WRF simulations including land use changes for a) air temperature at 1st model level (°C) b) surface temperature (°C) c) Water Vapor Path (Kg/m^2) d) Precipitation (mm) for year 2015.

6 Conclusions

This deliverable (D3.7) presented the methodology and developments for ingesting dynamical land use land cover (LULC) changes into regional climate model WRF in a most convenient way without compromising the integrity of the LUCAS-phase II protocol. By inserting LULC changes during the pre-processing stage of a climate simulation through WPS geogrid.exe program, this simplifies the effort by the user and ensures that no-additional changes in other utilities and core programs is required.

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8 Appendix

```
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
! Original code developed by Rita Margarida Cardoso, contact: rmcardoso@ciencias.ulisboa.pt
! Minor changes added by Josipa Milovac, contact: milovacj@unican.es
! Minor changes and integration to UpClim project by Stergios Kartsios, contact: kartsios@geo.auth.gr
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!

module datvar

integer, parameter :: npft=16,nluse=21
integer :: nt,nlon,nlat,nt2,nlon2,nlat2,nlon3,nlat3,nlon4,nlat4
integer :: ncid,varid,status,inyear
integer :: latid,lonid,timeid,levid,timedim,latdim,londim,levdim
integer, dimension(npft) :: PFT

real :: dummy
real, dimension(:), allocatable :: time
real, dimension(:,:), allocatable :: lon,lat,landsea,LU_diff,LU_1950,LU_2015, var2d
real, dimension(:,:,:), allocatable :: var,water,ice,water_ice_per,PFTf,PFT_per,PFT_landmask
real, dimension(:,:,:), allocatable :: seaice,water_ice
real, dimension(:,:,:,:), allocatable :: PFTi,PFTw,PFTw_f

character*4 cyear
character*6 avar
character*10 vaid1,vaid2,vaid3,varid1,varid2,varid3
character*400 landfile,lfile,outfile,fnameout,sifile

data PFT/2,4,2,4,1,3,6,6,10,10,19,11,12,14,13,16/
end module datvar

program landuse
use datvar
use netcdf

if (iargc().lt.1) then
      print*,' Usage: calc year(XXXX)'
      stop
else
      call getarg(1,cyear)
      read(cyear,'(i4)') inyear
endif

lfile='LANDMATE_PFT_v1.1_Europe_'//cyear//'.nc'
landfile=lfile(1:len_trim(lfile))

write(*,*)'Working with LANDMATE_PFT_v1.1_Europe_'//cyear//'.nc...'
status=nf90_open(landfile,nf90_write,ncid)
status=nf90_inq_dimid(ncid,'time',timeid)
status=nf90_inq_dimid(ncid,'y',latid)
status=nf90_inq_dimid(ncid,'x',lonid)
status=nf90_inquire_dimension(ncid=ncid,dimid=timeid,len=timedim)
nt=timedim
status=nf90_inquire_dimension(ncid=ncid,dimid=latid,len=latdim)
nlat=latdim
```

```

status=nf90_inquire_dimension(ncid=ncid,dimid=lonid,len=londim)
nlon=londim

write(*,*)'PFT lon:',nlon,' PFT lat:',nlat,' PFT time:',nt

allocate(time(nt))
allocate(lon(nlon,nlat))
allocate(lat(nlon,nlat))

status=nf90_inq_varid(ncid,'time',varid)
status=nf90_get_var(ncid,varid,time,(/1/),(/nt/),(/1/))
status=nf90_inq_varid(ncid,'lon',varid)
status=nf90_get_var(ncid,varid,lon,(/1,1/),(/nlon,nlat/),(/1,1/))
status=nf90_inq_varid(ncid,'lat',varid)
status=nf90_get_var(ncid,varid,lat,(/1,1/),(/nlon,nlat/),(/1,1/))

allocate(PFTi(nlon,nlat,npft,nt))

status=nf90_inq_varid(ncid,'landCoverFrac',varid)
status=nf90_get_var(ncid,varid,PFTi,(/1,1,1,1/),(/nlon,nlat,npft,nt/),(/1,1,1,1/))

allocate(landsea(nlon,nlat))

landsea=0.
do iy=1,nlat
  do ix=1,nlon
    do it=1,nt
      sum=0.
      do ip=1,npft
        if(PFTi(ix,iy,ip,it)> 0.)then
          landsea(ix,iy)=1.
        endif
        sum=sum+PFTi(ix,iy,ip,it)
      enddo
      do ip=1,npft
        PFTi(ix,iy,ip,it)=PFTi(ix,iy,ip,it)/sum
      enddo
    enddo
  enddo
enddo
write(*,*)'!!!!!!!! DONE WITH LANDMATE PFT FILE !!!!!!!!!!!!'

lfile='LANDUSEF_WRF.nc'
landfile=lfile(1:len_trim(lfile))
!
status=nf90_open(landfile,nf90_write,ncid)
status=nf90_inq_dimid(ncid,'Time',timeid)
status=nf90_inq_dimid(ncid,'south_north',latid)
status=nf90_inq_dimid(ncid,'west_east',lonid)
status=nf90_inquire_dimension(ncid=ncid,dimid=timeid,len=timedim)
nt2=timedim
status=nf90_inquire_dimension(ncid=ncid,dimid=latid,len=latdim)
nlat2=latdim
status=nf90_inquire_dimension(ncid=ncid,dimid=lonid,len=londim)
nlon2=londim
```

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```
if(nlon /= nlon2 .or. nlat /= nlat2)then
  write(*,*)nlon,nlon2,nlat,nlat2
  write(*,*)'diferent dimensions. program stoped'
  stop
endif

allocate(PFTw(nlon2,nlat2,nluse,nt2))
write(*,*)'PFTw allocate OK'

status=nf90_inq_varid(ncid,'LANDUSEF',varid)

status=nf90_get_var(ncid,varid,PFTw,(/1,1,1,1/),(/nlon2,nlat2,nluse,nt2/),(/1,1,1,1/))
write(*,*)'PFTw variable read OK'
write(*,*)'!!!!!!!! DONE WITH LANDUSEF FILE !!!!!!!!!!!!'

lfile='ESACCI-LC-L4-PFT-Map_0.11Deg_water_2015_f.nc'
landfile=lfile(1:len_trim(lfile))

write(*,*)'Working with ESACCI-LC-L4-PFT-Map_0.11Deg_water_2015_f.nc file'
status=nf90_open(landfile,nf90_write,ncid)

status=nf90_inq_dimid(ncid,'y',latid)

status=nf90_inq_dimid(ncid,'x',lonid)

status=nf90_inquire_dimension(ncid=ncid,dimid=latid,len=latdim)
nlat3=latdim

status=nf90_inquire_dimension(ncid=ncid,dimid=lonid,len=londim)
nlon3=londim

if(nlon3 /= nlon2 .or. nlat3 /= nlat2)then
  write(*,*)nlon3,nlon2,nlat3,nlat2
  write(*,*)'diferent dimensions. program stoped'
  stop
endif

allocate(var2d(nlon3,nlat3))
allocate(water(nlon3,nlat3,nt))

status=nf90_inq_varid(ncid,'WATER',varid)

status=nf90_get_var(ncid,varid,var2d,(/1,1/),(/nlon3,nlat3/),(/1,1/))
do iy=1,nlat
  do ix=1,nlon
   if(var2d(ix,iy).eq.-127)var2d(ix,iy)=0
  enddo
enddo

water=0.
do iy=1,nlat
  do ix=1,nlon
    if(var2d(ix,iy)>0. .and. var2d(ix,iy) <= 1.)then
        water(ix,iy,1)=var2d(ix,iy)
    endif
```

```
  enddo
enddo
write(*,*)'!!!!!!!! DONE WITH ESA-CCI WATER FILE !!!!!!!!!!!!'

lfile='ESACCI-LC-L4-PFT-Map_0.11Deg_snowice_'//cyear//'_f.nc'
landfile=lfile(1:len_trim(lfile))

write(*,*)'Working with ESACCI-LC-L4-PFT-Map_0.11Deg_snowice_'//cyear//'_f.nc'

status=nf90_open(landfile,nf90_write,ncid)

status=nf90_inq_dimid(ncid,'y',latid)
status=nf90_inq_dimid(ncid,'x',lonid)

status=nf90_inquire_dimension(ncid=ncid,dimid=latid,len=latdim)
nlat4=latdim

status=nf90_inquire_dimension(ncid=ncid,dimid=lonid,len=londim)
nlon4=londim

write(*,*)nlon4,nlat4
if(nlon4 /= nlon3 .or. nlat4 /= nlat3)then
  write(*,*)nlon4,nlon3,nlat4,nlat3
  write(*,*)'diferent dimensions. program stoped'
  stop
endif
!
allocate(ice(nlon4,nlat4,nt))
status=nf90_inq_varid(ncid,'SNOWICE',varid)
status=nf90_get_var(ncid,varid,var2d,(/1,1/),(/nlon4,nlat4/),(/1,1/))

ice=0.
do iy=1,nlat
  do ix=1,nlon
   if(var2d(ix,iy).eq.-127)var2d(ix,iy)=0
  enddo
enddo

do iy=1,nlat
  do ix=1,nlon
    if(var2d(ix,iy)>0. .and. var2d(ix,iy) <= 1.)then
        ice(ix,iy,1)=var2d(ix,iy)
    endif
  enddo
enddo
deallocate(var2d)
write(*,*)'!!!!!!!! DONE WITH ESA-CCI SNOWICE FILE !!!!!!!!!!!!'

allocate(water_ice_per(nlon3,nlat3,nt))
allocate(water_ice(nlon3,nlat3,nt))

water_ice_per=water+ice

do iy=1,nlat
  do ix=1,nlon
    if(water_ice_per(ix,iy,1)>1.)then
```

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```
      water_ice_per(ix,iy,1)=1.
     end if
   enddo
  enddo
  !
  write(*,*)'!!!!!!!! DONE WITH water_ice_per variable !!!!!!!!!!!!'
  allocate(PFTw_f(nlon2,nlat2,nluse,nt))
  !
  PFTw_f=0.
  do it=1,nt
   do iy=1,nlat
     do ix=1,nlon
      if(landsea(ix,iy)>0.)then
        PFTw_f(ix,iy,1,it)=PFTi(ix,iy,5,it)*(1.-water_ice_per(ix,iy,it))
        PFTw_f(ix,iy,2,it)=PFTi(ix,iy,3,it)*(1.-water_ice_per(ix,iy,it))
        PFTw_f(ix,iy,3,it)=PFTi(ix,iy,6,it)*(1.-water_ice_per(ix,iy,it))
        PFTw_f(ix,iy,4,it)=PFTi(ix,iy,4,it)*(1.-water_ice_per(ix,iy,it))
        PFTw_f(ix,iy,5,it)=0.d0
        PFTw_f(ix,iy,6,it)=(PFTi(ix,iy,7,it)+PFTi(ix,iy,8,it))*(1.-water_ice_per(ix,iy,it))
        PFTw_f(ix,iy,7,it)=0.d0
        PFTw_f(ix,iy,8,it)=0.d0
        PFTw_f(ix,iy,9,it)=PFTi(ix,iy,14,it)*(1.-water_ice_per(ix,iy,it))
        PFTw_f(ix,iy,10,it)=(PFTi(ix,iy,9,it)+PFTi(ix,iy,10,it))*(1.-water_ice_per(ix,iy,it))
        PFTw_f(ix,iy,11,it)=PFTi(ix,iy,12,it)*(1.-water_ice_per(ix,iy,it))
        PFTw_f(ix,iy,12,it)=PFTi(ix,iy,13,it)*(1.-water_ice_per(ix,iy,it))
        PFTw_f(ix,iy,13,it)=PFTi(ix,iy,15,it)*(1.-water_ice_per(ix,iy,it))
        PFTw_f(ix,iy,14,it)=0.d0
        PFTw_f(ix,iy,15,it)=ice(ix,iy,it)
        PFTw_f(ix,iy,16,it)=PFTi(ix,iy,16,it)*(1.-water_ice_per(ix,iy,it))
        PFTw_f(ix,iy,18,it)=0.d0
        PFTw_f(ix,iy,19,it)=PFTi(ix,iy,11,it)*(1.-water_ice_per(ix,iy,it))
        PFTw_f(ix,iy,20,it)=0.d0
      endif
      PFTw_f(ix,iy,17,it)=PFTw(ix,iy,17,1)
      if(PFTw(ix,iy,17,1) == 0)PFTw_f(ix,iy,21,it)=water(ix,iy,it)
     enddo
   enddo
  enddo

  do it=1,nt
   do iy=1,nlat
     do ix=1,nlon
      if(PFTw_f(ix,iy,21,it)>0.)then
       if (ix>1 .and. PFTw(ix-1,iy,17,1)>0)then
         PFTw_f(ix,iy,17,it)=water(ix,iy,it)
         PFTw_f(ix,iy,21,it)=0
       else if (ix<nlon .and. PFTw(ix+1,iy,17,1)>0)then
         PFTw_f(ix,iy,17,it)=water(ix,iy,it)
         PFTw_f(ix,iy,21,it)=0
       else if (iy>1 .and. PFTw(ix,iy-1,17,1)>0)then
         PFTw_f(ix,iy,17,it)=water(ix,iy,it)
         PFTw_f(ix,iy,21,it)=0.
       else if (ix<nlat .and. PFTw(ix,iy+1,17,1)>0)then
         PFTw_f(ix,iy,17,it)=water(ix,iy,it)
         PFTw_f(ix,iy,21,it)=0.
       else if (ix>1 .and. iy>1 .and. PFTw(ix-1,iy-1,17,1)>0)then
```

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```
          PFTw_f(ix,iy,17,it)=water(ix,iy,it)
          PFTw_f(ix,iy,21,it)=0.
        else if (ix<nlat .and. iy<nlon .and. PFTw(ix+1,iy+1,17,1)>0)then
          PFTw_f(ix,iy,17,it)=water(ix,iy,it)
          PFTw_f(ix,iy,21,it)=0.
        else if (ix>1 .and. iy<nlon .and. PFTw(ix-1,iy+1,17,1)>0)then
          PFTw_f(ix,iy,17,it)=water(ix,iy,it)
          PFTw_f(ix,iy,21,it)=0.
        else if (ix<nlat .and. iy>1 .and. PFTw(ix+1,iy-1,17,1)>0)then
          PFTw_f(ix,iy,17,it)=water(ix,iy,it)
          PFTw_f(ix,iy,21,it)=0.
        endif
      endif
    enddo
  enddo
enddo

allocate(var(nlon2,nlat2,nluse))
var=0.

do iy=1,nlat2
  do ix=1,nlon2
    var(ix,iy,18)=PFTw(ix,iy,18,1)/(PFTw(ix,iy,18,1)+PFTw(ix,iy,19,1)+PFTw(ix,iy,20,1))
    var(ix,iy,19)=PFTw(ix,iy,19,1)/(PFTw(ix,iy,18,1)+PFTw(ix,iy,19,1)+PFTw(ix,iy,20,1))
    var(ix,iy,20)=PFTw(ix,iy,20,1)/(PFTw(ix,iy,18,1)+PFTw(ix,iy,19,1)+PFTw(ix,iy,20,1))
  enddo
enddo

do iy=1,nlat2
  do ix=1,nlon2
    if(PFTw(ix,iy,6,1) >0.)then
      var(ix,iy,6)=PFTw(ix,iy,6,1)/(PFTw(ix,iy,6,1)+PFTw(ix,iy,7,1)+PFTw(ix,iy,8,1))
    endif
    if(PFTw(ix,iy,7,1) >0.)then
      var(ix,iy,7)=PFTw(ix,iy,7,1)/(PFTw(ix,iy,6,1)+PFTw(ix,iy,7,1)+PFTw(ix,iy,8,1))
    endif
    if(PFTw(ix,iy,7,1) >0.)then
      var(ix,iy,8)=PFTw(ix,iy,8,1)/(PFTw(ix,iy,6,1)+PFTw(ix,iy,7,1)+PFTw(ix,iy,8,1))
    endif
  enddo
enddo
!
do it=1,nt
  do iy=1,nlat2
    do ix=1,nlon2
      if(var(ix,iy,18)>0.)then
        PFTw_f(ix,iy,18,it)=PFTw_f(ix,iy,19,it)*var(ix,iy,18)
      endif
      if(var(ix,iy,19)>0.)then
        PFTw_f(ix,iy,19,it)=PFTw_f(ix,iy,19,it)*var(ix,iy,19)
      endif
      if(var(ix,iy,20)>0.)then
        PFTw_f(ix,iy,20,it)=PFTw_f(ix,iy,19,it)*var(ix,iy,20)
      endif
      if(var(ix,iy,6)>0.)then
        PFTw_f(ix,iy,6,it)=PFTw_f(ix,iy,6,it)*var(ix,iy,6)
```

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```
      endif
      if(var(ix,iy,7)>0.)then
        PFTw_f(ix,iy,7,it)=PFTw_f(ix,iy,6,it)*var(ix,iy,7)
      endif
      if(var(ix,iy,8)>0.)then
        PFTw_f(ix,iy,8,it)=PFTw_f(ix,iy,6,it)*var(ix,iy,8)
      endif
    enddo
  enddo
enddo

allocate(PFTf(nlon2,nlat2,nt))
allocate(PFT_per(nlon2,nlat2,nt))
allocate(PFT_landmask(nlon2,nlat2,nt))
PFTf=0.
PFT_per=0.

do it=1,nt
  do iy=1,nlat2
    do ix=1,nlon2
      dummy=0.
      do ip=1,nluse
!       if(ip /= 17)then
          dummy=max(PFTw_f(ix,iy,ip,it),dummy)
          if(PFTw_f(ix,iy,ip,it).eq.dummy)then
            PFTf(ix,iy,it)=ip
            PFT_per(ix,iy,it)=PFTw_f(ix,iy,ip,it)
            if(PFTf(ix,iy,it).eq.17.or.PFTf(ix,iy,it).eq.21)then
              PFT_landmask(ix,iy,it)=0
            else
              PFT_landmask(ix,iy,it)=1
            end if
        endif
      enddo
    enddo
  enddo
enddo
!
nlon=nlon2
nlat=nlat2

outfile='WRF_LUCAS_LANDMATE_PFT_v1.1_Europe_'//cyear//'_LU_INDEX_v2.nc'
fnameout=outfile(1:len_trim(outfile))
vaid1='LU_INDEX'
varid1=vaid1(1:len_trim(vaid1))
vaid2='PFT_per'
varid2=vaid2(1:len_trim(vaid2))
call write_netcdf_3D(PFTf,PFT_per,nt,time)

outfile='WRF_LUCAS_LANDMATE_PFT_v1.1_Europe_'//cyear//'_LANDUSEF_v2.nc'
fnameout=outfile(1:len_trim(outfile))
vaid1='LANDUSEF'
varid1=vaid1(1:len_trim(vaid1))
call write_netcdf_4D(PFTw_f,nt,time,cyear)

outfile='WRF_LUCAS_LANDMATE_PFT_v1.1_Europe_'//cyear//'_LANDMASK_v2.nc'
```

```
fnameout=outfile(1:len_trim(outfile))
vaid1='LANDMASK'
varid1=vaid1(1:len_trim(vaid1))
vaid2='PFT_per'
varid2=vaid2(1:len_trim(vaid2))
call write_netcdf_3D(PFT_landmask,PFT_per,nt,time)

end

subroutine ncerror(status,info)
use netcdf
integer :: status
character(len=*),optional :: info

if( status /= 0 ) then
  print *, trim(nf90_strerror(status))
  if( present(info) ) print*,trim(info)
  stop 99
endif

end subroutine ncerror

subroutine write_netcdf_2D(uvar1,uvar2,uvar3)
use netcdf
use datvar

integer :: LatDimID,LonDimID,rlonDimID,rlatDimID
integer :: LonVarID,LatVarID,rlatVarId,rlonVarID,uVarID1,uVarID2,uVarID3
real, dimension(nlon,nlat) :: uvar1,uvar2,uvar3
real, parameter :: FillValue=-1.e+20

status = nf90_create(fnameout, nf90_clobber, ncid)
call handle_err(status)

status = nf90_def_dim(ncid, "rlat", nlat, LatDimID)
status = nf90_def_dim(ncid, "rlon", nlon, LonDimID)

status = nf90_def_var(ncid, "lat", nf90_double, &
                      (/ LonDimId, LatDimID /), LatVarId)
status = nf90_def_var(ncid, "lon", nf90_double, &
                      (/ LonDimId, LatDimID /), LonVarId)
status = nf90_def_var(ncid, varid1, nf90_float, &
                      (/ LonDimId, LatDimID /), uVarId1)
status = nf90_def_var(ncid, varid2, nf90_float, &
                      (/ LonDimId, LatDimID /), uVarId2)
status = nf90_def_var(ncid, varid3, nf90_float, &
                      (/ LonDimId, LatDimID /), uVarId3)
call handle_err(status)

status = nf90_put_att(ncid, uVarID1, "coordinates","lon lat")
status = nf90_put_att(ncid, uVarID1, "_FillValue",FillValue)
status = nf90_put_att(ncid, uVarID1, "missing_value",FillValue)

status = nf90_put_att(ncid, uVarID2, "coordinates","lon lat")
status = nf90_put_att(ncid, uVarID2, "_FillValue",FillValue)
status = nf90_put_att(ncid, uVarID2, "missing_value",FillValue)
```

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Greece 2.0 NATIONAL RECOVERY AND RESILIENCE PLAN
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```

status = nf90_put_att(ncid, uVarID3, "coordinates","lon lat")
status = nf90_put_att(ncid, uVarID3, "_FillValue",FillValue)
status = nf90_put_att(ncid, uVarID3, "missing_value",FillValue)

status = nf90_put_att(ncid, LatVarID, "units","degrees_north")
status = nf90_put_att(ncid, LatVarID, "long_name","latitude")
status = nf90_put_att(ncid, LatVarID, "standard_name","latitude")
call handle_err(status)

status = nf90_put_att(ncid, LonVarID, "units","degrees_east")
status = nf90_put_att(ncid, LonVarID, "long_name","longitude")
status = nf90_put_att(ncid, LonVarID, "standard_name","longitude")
call handle_err(status)

status = nf90_enddef(ncid)

status = nf90_put_var(ncid, LatVarId, lat )
call handle_err(status)
status = nf90_put_var(ncid, LonVarId, lon )
call handle_err(status)
status = nf90_put_var(ncid, uVarId1, uvar1 )
call handle_err(status)
status = nf90_put_var(ncid, uVarId2, uvar2 )
call handle_err(status)
status = nf90_put_var(ncid, uVarId3, uvar3 )
call handle_err(status)

status = nf90_close(ncid)
call handle_err(status)
!
return
end

subroutine write_netcdf_3D(uvar,uvar2,mtime,utime)
use netcdf
use datvar

integer :: LatDimID,LonDimID,rlonDimID,rlatDimID,HDimID,BDimID,HeDimID
integer                                                                  ::
LonVarID,LatVarID,TBVarID,TVarID,rlatVarId,rlonVarID,uVarID,uvar2VarID,uvar3VarID,HVarID,rpVarID
real, dimension(mtime) :: utime
real, dimension(nlon,nlat,mtime) :: uvar,uvar2
real, parameter :: FillValue=-1.e+20

status = nf90_create(fnameout, nf90_clobber, ncid)
call handle_err(status)

status = nf90_def_dim(ncid, "Time", nf90_unlimited, HDimID)
status = nf90_def_dim(ncid, "west_east", nlon, LonDimID)
status = nf90_def_dim(ncid, "south_north", nlat, LatDimID)

status = nf90_def_var(ncid, "Times", nf90_double, &
                    (/ HDimID /), TVarId)
status = nf90_def_var(ncid, varid1, nf90_float, &
                    (/ LonDimId, LatDimID, HDimID /), uVarId)
```

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```
call handle_err(status)

status = nf90_put_att(ncid, TVarID, "standard_name","time")
status = nf90_put_att(ncid, TVarID, "units","months since 1950-1-1 12:00:00")
status = nf90_put_att(ncid, TVarID, "calender","standard")
status = nf90_put_att(ncid, TVarID, "axis","T")

status = nf90_put_att(ncid, uVarID, "_FillValue",FillValue)
status = nf90_put_att(ncid, uVarID, "FieldType",104)
status = nf90_put_att(ncid, uVarID, "MemoryOrder","XY")
status = nf90_put_att(ncid, uVarID, "units","category")
status = nf90_put_att(ncid, uVarID, "description","Dominant category")
status = nf90_put_att(ncid, uVarID, "stagger","M")
status = nf90_put_att(ncid, uVarID, "sr_x",1)
status = nf90_put_att(ncid, uVarID, "sr_y",1)

status = nf90_enddef(ncid)

status = nf90_put_var(ncid, TVarId, utime )
call handle_err(status)

status = nf90_put_var(ncid, uVarId, uvar )
call handle_err(status)

status = nf90_close(ncid)
call handle_err(status)

return
end

subroutine write_netcdf_4D(uvar,mtime,utime,nyear)
use netcdf
use datvar

integer :: LatDimID,LonDimID,LanDimID,rlatDimID,HDimID,BDimID,HeDimID
integer ::
LonVarID,LatVarID,TBVarID,TVarID,rlatVarId,rlonVarID,uVarID,uvar2VarID,uvar3VarID,HVarID,rpVarID
real, dimension(mtime) :: utime
real, dimension(nlon,nlat,nluse,mtime) :: uvar
real, parameter :: FillValue=-1.e+20
character*19 autime
character*4 nyear

status = nf90_create(fnameout, nf90_clobber, ncid)
call handle_err(status)

status = nf90_def_dim(ncid, "Time", nf90_unlimited, HDimID)
status = nf90_def_dim(ncid, "west_east", nlon, LonDimID)
status = nf90_def_dim(ncid, "south_north", nlat, LatDimID)
status = nf90_def_dim(ncid, "land_cat", nluse, LanDimID)

status = nf90_def_var(ncid, varid1, nf90_float, &
                  (/ LonDimId, LatDimID, LanDimID, HDimID /), uVarId)
call handle_err(status)

status = nf90_put_att(ncid, uVarID, "_FillValue",FillValue)
```

```
status = nf90_put_att(ncid, uVarID, "FieldType",104)
status = nf90_put_att(ncid, uVarID, "MemoryOrder","XYZ")
status = nf90_put_att(ncid, uVarID, "units","category")
status = nf90_put_att(ncid, uVarID,
"description","LUCAS_LANDMATE_PFT_v1.1_Europe_0.11deg_"//nyear//"_Land_cat_v2_bi")
status = nf90_put_att(ncid, uVarID, "stagger","M")
status = nf90_put_att(ncid, uVarID, "sr_x",1)
status = nf90_put_att(ncid, uVarID, "sr_y",1)

status = nf90_enddef(ncid)
status = nf90_put_var(ncid, uVarId, uvar )
call handle_err(status)

status = nf90_close(ncid)
call handle_err(status)

return
end

subroutine handle_err(status)

use netcdf

integer, intent ( in) :: status

if(status /= nf90_noerr) then
  print*, trim(nf90_strerror(status))
  stop "Stopped"
end if
end subroutine handle_err
```