Project Title: Upgrading a climate model to improve regional climate projections

Acronym: UpClim

Deliverable 3.8
Two 5-year simulations (with and without the land use change forcing)

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Technical References

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Principal Investigator	KATRAGKOU ELENI
Sub-action	Sub-action 2. Funding Projects in Leading-Edge Sectors – RRFQ: Basic Research Financing Horizontal Support for all sciences
Acronym	UpClim
Proposal Title (EN)	Upgrading a climate model to improve regional climate projections
Proposal Title (ΕΛ)	Αναβάθμιση ενός κλιματικού μοντέλου για τη βελτίωση περιοχικών κλιματικών προβολών
Thematic Area	ThA1. Physical Sciences, Engineering Sciences and Technology, Environment and Energy
Thematic Field	1.13 Development of high resolution earth system models for global and regional climate change projection
Host Institution (HI)	ARISTOTLE UNIVERSITY OF THESSALONIKI
Department	SCHOOL OF GEOLOGY
Beneficiary- Collaborating Organization	FOUNDATION FOR RESEARCH AND TECHNOLOGY-HELLAS (FORTH)
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List of tables and figures

Terms, definitions and abbreviated terms

The following acronyms have been used across this document:

ACRONYM	FULL TERM
D3.8	Deliverable number 8 belonging to WP 3
WCRP	World Climate Research Program
CORDEX	Coordinated Downscaling Experiment
FPS	Flagship Pilot Study
LUCAS	Land Use and Climate Across Scales
WRF	Weather Research and Forecasting
LU	Land Use
LUC	Land Use Change
CMIP6	Coupled Model Intercomparison Project (Phase 6)
ARW	Advanced Research dynamic solver
IFS	Integrated Forecasting System
MYNN2	Mellor-Yamada Nakanishi and Niino Level 2.5
ECMWF	European Center for Medium-Range Weather Forecast
C3S	Copernicus Climate Change Service
ERA5	ECMWF reanalysis data
WP	Working Package

1 Introduction

The purpose of this document is to describe Deliverable 3.8 (D3.8) of Task 3.2 ("Implementation of the new land use change forcing in production simulations"), under Working Package 3 (WP3, "Implementation of land use forcing") in the framework of the UpClim project. One of the primary objectives of the UpClim project is the implementation of dynamic land use changes into a regional climate model in order to assess their impacts on regional climate over Europe. For this purpose, the Weather Research and Forecasting (WRF) model is employed, complemented by the development of a tailored made process to ingest the Land Use Change (LUC) information into the model (described in detail in Deliverable 3.7 "Model modifications including dynamic land use changes"). Coordinated downscaling experiments including land use changes are 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).

2 Numerical Simulations

The WRF model has been widely used as a regional climate model (Katragkou et al. 2015; Fita et al. 2019; Ban et al. 2021) and is an official model-member of the Ensemble Desing Matrix of Coupled Model Intercomparison Project (CMIP6)/EURO-CORDEX (Katragkou et al. 2024). For the purposes of Task 3.2 "Implementation of the new land use change forcing in production simulations", the non-hydrostatic WRF 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 (Yang et al. 2011), available from the CORDEX WRF community fork (git clone --recursesubmodules -b v4.5.1.4 https://github.com/CORDEX-WRF-community/WRF.git).

3 Model configuration and numerical experiments

To evaluate the recent developments concerning the implementation of dynamic land-use changes in WRF, we conducted two historical climate simulations over the official EURO-CORDEX domain at 0.11° resolution (EUR-11), driven by ERA5 reanalysis data (Hersbach et al. 2020). The reference simulation (CNTRL) is performed using static LU information as in the official WRF-EURO-CORDEX CMIP6 simulations, while the second one (UpCLIM-LUC) uses the generated LUC information at annual intervals, incorporating the LUC dataset of Hoffmann et al. (2023), which is the official LUC dataset used in the EURO-CORDEX community. Both simulations cover a continuous five-year period, with the simulation window referring to the 1980-1984 period. Figure 1 shows the changes in land use fraction in MODIS-WRF "Cropland" class between 1980 and 1984.

Both simulations were 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 were 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 were employed up to 20 hPa (in hybrid vertical coordinate configuration) with the first sigma level at 35 m.

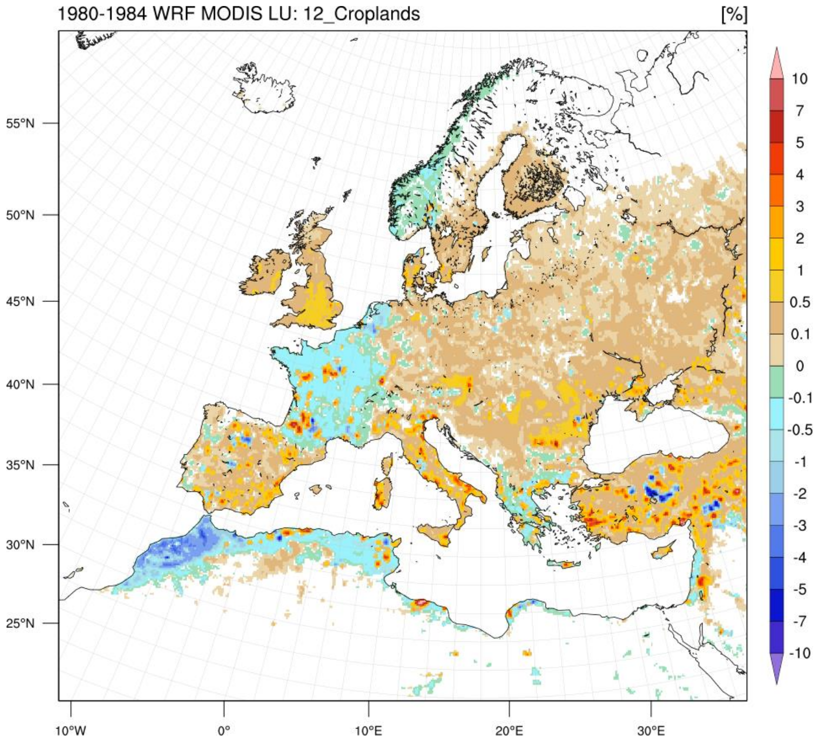

Figure 1 Changes in land use fraction in MODIS-WRF "Cropland" class between 1980 and 1984.

The ERA5 reanalysis data (Hersbach et al. 2020) product was used as initial and boundary conditions in 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 the European Center for Medium-Range Weather Forecasts (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) (Thepaut et al. 2018) at a horizontal grid-spacing of 0.25° x 0.25° (latitude-longitude).

4 Available simulated variables

In both simulations, depending on the variable, data are available at hourly, six-hourly or daily intervals (Table 1), while each variable is available in monthly chunks in NetCDF (CF-Compliant) format. The total amount of data from both experiments (CNTRL and UpCLIM-LUC) is approximately 2.37 TB. In Appendix, the interested reader can find the structure of a NetCDF file. The data are stored in the Aristotelis Data Center of AUTH, and are available upon request (mailto: katragou@geo.auth.gr).

Table 1. Variable List of UpClim simulations.

Output variable name	units	long_name	Frequency
clivi	kg m^{-2}	Ice Water Path	1hr
clt	%	Total Cloud Cover Percentage	1hr
clwvi	kg m^{-2}	Condensed Water Path	1hr
evspsbl	kg m^{-2} s^{-1}	Evaporation Including Sublimation and Transpiration	1hr
hfls	W m^{-2}	Surface Upward Latent Heat Flux	1hr
hfss	W m^{-2}	Surface Upward Sensible Heat Flux	1hr
hurs	%	Near-Surface Relative Humidity	1hr
huss	1	Near-Surface Specific Humidity	1hr
lai	1	Leaf Area Index	1hr
mrro	kg m^{-2} s^{-1}	Total Runoff	6hr
mrros	kg m^{-2} s^{-1}	Surface Runoff	6hr
mrso	kg m^{-2}	Total Soil Moisture Content	6hr
mrsol	kg m^{-2}	Total Water Content of Soil Layer	6hr, day
pr	kg m^{-2} s^{-1}	Precipitation	1hr
prc	kg m^{-2} s^{-1}	Convective Precipitation	1hr
ps	Pa	Surface Air Pressure	1hr
psl	Pa	Sea Level Pressure	1hr
rlds	W m^{-2}	Surface Downwelling Longwave Radiation	1hr
rsds	W m^{-2}	Surface Downwelling Shortwave Radiation	1hr
rlus	W m^{-2}	Surface Upwelling Longwave Radiation	1hr
rsus	W m^{-2}	Surface Upwelling Shortwave Radiation	1hr
sfcWind	m s^{-1}	Near-Surface Wind Speed	1hr
snc	%	Snow Area Percentage	6hr
snd	m	Snow Depth	6hr
snw	kg m^{-2}	Surface Snow Amount	6hr
tasmax	K	Daily Maximum Near-Surface Air Temperature	day
tasmin	K	Daily Minimum Near-Surface Air Temperature	day
ts	K	Surface Temperature	1hr
tsl	K	Temperature of Soil	6hr, day
uas	m s^{-1}	Eastward Near-Surface Wind	1hr
vas	m s^{-1}	Northward Near-Surface Wind	1hr

z0	m	Surface Roughness Length	1hr
zmla	m	Height of Boundary Layer	1hr
orog	m	Surface Altitude	-
sftlf	%	Percentage of the Grid Cell Occupied by Land	-
ta	K	Air Temperature at first model level above ground	1hr
hus	1	Specific Humidity at first model level above ground	1hr
hur	%	Relative Humidity at first model level above ground	1hr
zg	m	Geopotential Height at first model level above ground	1hr
ua1000	$m\ s^{-1}$	Eastward Wind	6hr
ua925	$m\ s^{-1}$	Eastward Wind	6hr
ua850	$m\ s^{-1}$	Eastward Wind	6hr
ua700	$m\ s^{-1}$	Eastward Wind	6hr
ua600	$m\ s^{-1}$	Eastward Wind	6hr
ua500	$m\ s^{-1}$	Eastward Wind	6hr
ua400	$m\ s^{-1}$	Eastward Wind	6hr
ua300	$m\ s^{-1}$	Eastward Wind	6hr
ua250	$m\ s^{-1}$	Eastward Wind	6hr
ua200	$m\ s^{-1}$	Eastward Wind	6hr
va1000	$m\ s^{-1}$	Northward Wind	6hr
va925	$m\ s^{-1}$	Northward Wind	6hr
va850	$m\ s^{-1}$	Northward Wind	6hr
va700	$m\ s^{-1}$	Northward Wind	6hr
va600	$m\ s^{-1}$	Northward Wind	6hr
va500	$m\ s^{-1}$	Northward Wind	6hr
va400	$m\ s^{-1}$	Northward Wind	6hr
va300	$m\ s^{-1}$	Northward Wind	6hr
va250	$m\ s^{-1}$	Northward Wind	6hr
va200	$m\ s^{-1}$	Northward Wind	6hr
ta1000	K	Air Temperature	6hr
ta925	K	Air Temperature	6hr
ta850	K	Air Temperature	6hr
ta700	K	Air Temperature	6hr
ta600	K	Air Temperature	6hr
ta500	K	Air Temperature	6hr
ta400	K	Air Temperature	6hr
ta300	K	Air Temperature	6hr
ta250	K	Air Temperature	6hr
ta200	K	Air Temperature	6hr
hus1000	1	Specific Humidity	6hr
hus925	1	Specific Humidity	6hr
hus850	1	Specific Humidity	6hr
hus700	1	Specific Humidity	6hr
hus600	1	Specific Humidity	6hr

hus500	1	Specific Humidity	6hr
hus400	1	Specific Humidity	6hr
hus300	1	Specific Humidity	6hr
hus250	1	Specific Humidity	6hr
hus200	1	Specific Humidity	6hr
zg1000	m	Geopotential Height	6hr
zg925	m	Geopotential Height	6hr
zg850	m	Geopotential Height	6hr
zg700	m	Geopotential Height	6hr
zg600	m	Geopotential Height	6hr
zg500	m	Geopotential Height	6hr
zg400	m	Geopotential Height	6hr
zg300	m	Geopotential Height	6hr
zg250	m	Geopotential Height	6hr
zg200	m	Geopotential Height	6hr
ua50m	$m\ s^{-1}$	Eastward Wind at 50m	1hr
ua100m	$m\ s^{-1}$	Eastward Wind at 100m	1hr
ua150m	$m\ s^{-1}$	Eastward Wind at 150m	1hr
va50m	$m\ s^{-1}$	Northward Wind at 50m	1hr
va100m	$m\ s^{-1}$	Northward Wind at 100m	1hr
va150m	$m\ s^{-1}$	Northward Wind at 150m	1hr

5 References

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APPENDIX

```
netcdf mrsol_EUR-11_ECMWF-ERA5_evaluation_r1i1p1_AUTH-MC-WRF451Q_x0n1-
v1_day_19800101-19800131 {
dimensions:
	time = UNLIMITED ; // (31 currently)
	bnds = 2 ;
	rlon = 424 ;
	rlat = 412 ;
	soil_layer = 4 ;
variables:
	double time(time) ;
		time:standard_name = "time" ;
		time:long_name = "Time" ;
		time:bounds = "time_bnds" ;
		time:units = "days since 1949-12-01 00:00:00" ;
		time:calendar = "standard" ;
		time:axis = "T" ;
	double time_bnds(time, bnds) ;
	double lon(rlat, rlon) ;
		lon:standard_name = "longitude" ;
		lon:long_name = "Longitude" ;
		lon:units = "degrees_east" ;
		lon:_CoordinateAxisType = "Lon" ;
	double lat(rlat, rlon) ;
		lat:standard_name = "latitude" ;
		lat:long_name = "Latitude" ;
		lat:units = "degrees_north" ;
		lat:_CoordinateAxisType = "Lat" ;
	double rlon(rlon) ;
		rlon:standard_name = "projection_x_coordinate" ;
		rlon:long_name = "Longitude in rotated pole grid" ;
		rlon:units = "degrees" ;
		rlon:axis = "X" ;
	double rlat(rlat) ;
		rlat:standard_name = "projection_y_coordinate" ;
		rlat:long_name = "Latitude in rotated pole grid" ;
		rlat:units = "degrees" ;
		rlat:axis = "Y" ;
	float soil_layer(soil_layer) ;
		soil_layer:standard_name = "depth" ;
		soil_layer:long_name = "Soil layer depth" ;
		soil_layer:units = "m" ;
		soil_layer:positive = "down" ;
		soil_layer:axis = "Z" ;
		soil_layer:bounds = "soil_layer_bnds" ;
	float soil_layer_bnds(soil_layer, bnds) ;
	float mrsol(time, soil_layer, rlat, rlon) ;
		mrsol:standard_name = "moisture_content_of_soil_layer" ;
		mrsol:long_name = "Total water content of soil layer" ;
		mrsol:units = "Kg m-2" ;
		mrsol:coordinates = "lat lon" ;
		mrsol:_FillValue = 1.e+20f ;
		mrsol:missing_value = 1.e+20f ;
		mrsol:cell_methods = "time: mean" ;

// global attributes:
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:Conventions = "CF-1.4" ;
:source = "WRF 4.5.1Q" ;
:institution = "Aristotle University of Thessaloniki, Dept. of Meteorology & Climatology" ;
:comment_nesting = "these are results of the 1st nest" ;
:nesting_levels = "direct_downscaling" ;
:conventionsURL = "http://www.cfconventions.org" ;
:comment = "simulation and processing: Stergios Kartsios, kartsios@geo.auth.gr ; postprocessing: wrfout_to_cf.ncl v2.0.1; excl. 10 grid point boundary relaxation zone" ;
:title = "AUTH-MC-WRF451Q model output prepared for UpClim" ;
:references = "http://www.auth.gr" ;
:product = "output" ;
:CORDEX_domain = "EUR-11" ;
:rcm_version_id = "x0n1-v1" ;
:model_id = "AUTH-MC-WRF451Q" ;
:institute_id = "AUTH-MC" ;
:frequency = "day" ;
:comment_1stNest = "ECMWF-ERA5 driven simulation (direct downscaling) for EUR-11 domain" ;
:driving_experiment_name = "evaluation" ;
:driving_model_ensemble_member = "r1i1p1" ;
:driving_model_id = "ECMWF-ERA5" ;
:driving_experiment = "ECMWF-ERA5, evaluation, r1i1p1" ;
:experiment_id = "evaluation" ;
:experiment = "Evaluation run with ERA5 forcing" ;
:contact = "Eleni Katragkou, katragou@geo.auth.gr" ;
:creation_date = "2025-08-07T10:53:46Z" ;
:tracking_id = "a2e0955d-cb63-4681-8992-afd135dd40cb" ;
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