Implementation and validation of a new irrigation scheme in the ISBA land surface model

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Supplement S1

A new generation of vegetation description in ISBA: ECOCLIMAP-SG

The ISBA land surface model is included in the SURFEX modelling platform of Meteo-France. The model parameter mapping is ensured by the ECOCLIMAP (Masson et al. 2003) capability (Table S1.1). Since 2012, the description of vegetation in SURFEX is based on the 1 km^2 scale ECOCLIMAP-II land cover classification (Faroux et al. 2013). Initially 12 and then 19 land functional types composed this classification, together with nearly 400 ecosystem classes (Table S1.1). This description includes spatialized soil and vegetation parameters (soil composition, topography, leaf area index (LAI), visible and near infrared soil and vegetation albedo, height of trees and ground depths), which can be averaged at the spatial resolution of each simulation and defined for each nature type using look-up tables. Primary parameters such as LAI, plant rooting, depth, tree height, etc., are defined by cover (not spatially), with seasonal variability (one value every 10-day). These climatological values of LAI are used as forcing data for simulations of the ISBA model without a representation of photosynthesis and LAI evolution. A new version of ECOCLIMAP was recently developed: ECOCLIMAP-SG (Second Generation). This updated version has a better spatial resolution of 300 m × 300 m and is based on the

European Space Agency - Climate Change Initiative (ESA-CCI) land cover product (v.1.6.1; available at http://www.esa-landcover-cci.org/, last access 03/02/2021) described in http://maps.elie.ucl.ac.be/CCI/viewer/download/ESACCI-LC-Ph2-PUGv2_2.0.pdf. It includes nature tiles but also oceans, inland waters and towns, with only one surface type for each grid point of the 300 m-resolution map (i.e. there is no representation of the sub-grid variability). It contains more land functional types that in the previous version: 33 different surface types are represented (Table S1.2), amongst which 20 describe nature types (Calvet and Champeaux 2020). For each simulation, the model computes the fraction of surface types and the values of the associated primary parameters at the spatial resolution of the simulation. Default values of these parameters are provided with ECOCLIMAP-SG through global maps (e.g. from satellite-derived observations) instead of using look-up tables. The primary parameters can also be specified using user-defined input data. In parallel of the development of this new vegetation description, a new set of "patch aggregation rules" was proposed. The patches aggregation in ISBA aims at reducing the number of simulated nature types. This limits the computation time and cost. Originally, the number of simulated patches could vary from 1 to 12, 12 being the number of nature types used in of the first version of ECOCLIMAP, ECOCLIMAP-I (Champeaux et al. 2000). Considering the recent ECOCLIMAP-SG description and the development of the irrigation, a new set of aggregation rules for nature types (named "patch aggregation rules") was developed (Fig. S1.1). It was decided to maintain the main pre-existing patch distribution (based on 1, 2, 5, 9, or 12 patches as indicated in black in the first line of Fig. S1.1) to preserve continuity for users and to facilitate version comparison but also to add new ones. In addition, an aggregation by main ecophysiological characteristics (e.g. grouped by leaf types for trees) was implemented as it was more adapted and coherent with the new ECOCLIMAP-SG description (based on 1, 3, 7, 10, or 13 patches as indicated in black in the first line of Fig. S1.1). In order to distinguish between irrigated and non-irrigated vegetation, this patch aggregation rule requires an increase of the number of simulated patches when the irrigation is activated (red numbers in brackets in Fig. S1.1). A full description of the new vegetation description ECOCLIMAP-SG is available on: https://opensource.umr-cnrm.fr/projects/ecoclimap-sg/wiki.

Table S1.1 – Management of geographical information at a global scale in successive versions of ECOCLIMAP in the SURFEX modelling platform, in the 2000s, 2010s, 2020s (adapted from Calvet and Champeaux 2020).

Geographical information	Years 2000 Ecoclimap-I	Years 2010 Ecoclimap-II	Years 2020 Ecoclimap-SG
LAI	NDVI AVHRR (1992-1993)	LAI MODIS (2000-2005)	LAI Copernicus (2014-2016)
Land cover (LC)	IGBP Corine 1990 (Europe)	IGBP Corine 2000 and GLC2000 (Europe)	ESA-CCI (2008-2012) Corine 2012 (Europe)
Plant functional types (PFTs)	10	12	33
LC classes (« ecosystems »)	125 (outside Europe) 90 (Europe)	125 (outside Europe) 273 (Europe)	
Spatial resolution	1 km	1 km	300 m
Primary parameters (LAI, rooting depth, tree height, etc.)	Look up tables based on LC classes		Existing freely available databases
Secondary parameters - Biological (e.g. photosynthesis)	Look up tables based on PFTs		
Secondary parameters - Physical (e.g. bare soil fraction, roughness, IR emissivity, albedo, etc.)	Look up tables based on PFTs and primary parameters		

AVHRR, NDVI, LAI, MODIS, IGBP, ESA, CCI stand for "Advanced Very High Resolution Radiometer", "Normalized Difference Vegetation Index", "Leaf Area index", "Moderate Resolution Imaging Spectroradiometer", "International Geosphere–Biosphere Programme", "European Space Agency", "Climate Change Initiative", respectively.

Table S1.2 - Surface types in ECOCLIMAP-SG

Types of surface		No	Name
Water		1	Sea and oceans
		2	Lakes
		3	Rivers
Nature	No vegetation	4	Bare soil
		5	Bare rock
		6	Permanent snow
	Trees	7	Boreal broadleaf deciduous
		8	Temperate broadleaf deciduous
		9	Tropical broadleaf deciduous
		10	Temperate broadleaf evergreen
		11	Tropical broadleaf evergreen
		12	Boreal needleleaf evergreen
		13	Temperate needleleaf evergreen
		14	Boreal needleleaf deciduous
	Shrubs	15	Shrubs
	Herbaceous	16	Boreal grassland
		17	Temperate grassland
		18	Tropical grassland
		19	Winter C3 crops
		20	Summer C3 crops
		21	C4 crops
	Flooded	22	Tree cover, flooded
		23	Shrub or herbaceous cover, flooded
Urban		24	Compact high-rise
		25	Compact midrise
		26	Compact low-rise
		27	Open high-rise
		28	Open midrise
		29	Open low-rise
		30	Lightweight low-rise
		31	Large low-rise
		32	Sparsely built
		33	Heavy industry
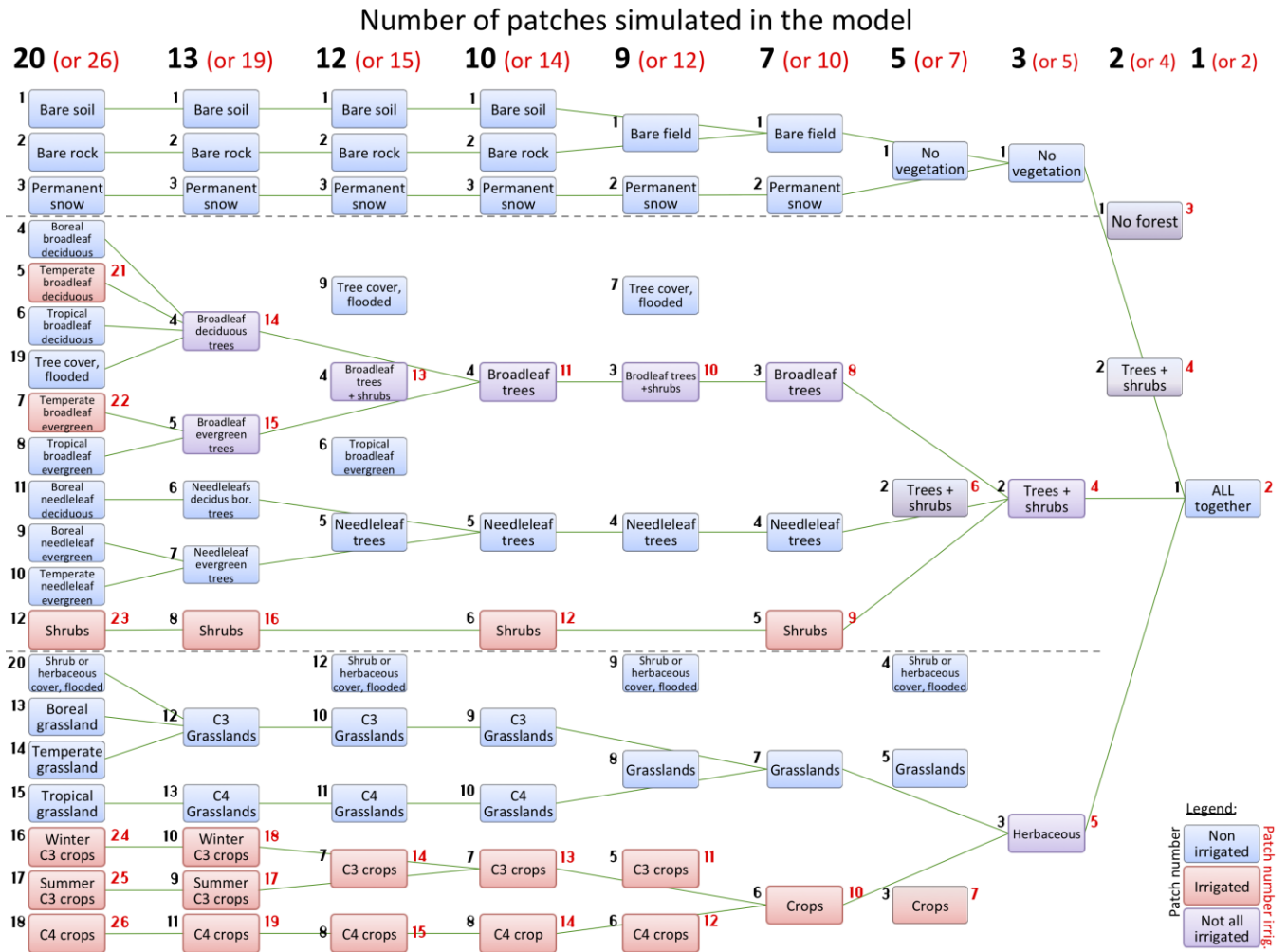
Figure S.1.1 - Patch aggregation rules of the twenty ECOCLIMAP-SG nature types. The nature surface type numbers into the patch are indicated in black without irrigation and in red with the 6 irrigated nature types used by default in this study. The first column contains the 20 nature surface types of Table S1.2 (1 to 20), together with the 6 types (21 to 26) that can be irrigated (in red). Add 3 to the rainfed patch numbers in the first column to retrieve the corresponding patch numbers of Table S1.2. The first line indicates the total number of nature types represented by the model. The green lines show the aggregation rules corresponding to 1, 3, 7, 10, or 13 patches indicated in black in the first line.

References

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Masson V., Champeaux J.-L., Chauvin F., Meriguet C., Lacaze R., 2003. A global database of land surface parameters at 1-km resolution in meteorological and climate models. J. Climate, 16, 1261-1282. https://doi.org/10.1175/1520-0442-16.9.1261

Supplement S2

Tests over southwestern France

In order to demonstrate the behaviour of the irrigation model, preliminary tests were performed for two contrasting years over an area in south western France (43.95°N, 0.25°E) corresponding to croplands. This point located in the southwest of France was chosen because of the large proportion of irrigated corn (C4) in this area. The vegetation type was considered as 100% C4 crops and two distinct offline simulations (non-coupled with the atmosphere) were carried out: with (ISBA_pheno_irr) and without (ISBA_ref) irrigation and crop phenology parameters. The crop phenology corresponded to crop emergence and harvesting dates, delimiting the period in which the development of the crop is possible. The simulations were forced by the Integrated Forecasting System (IFS) high-resolution operational analysis (IFS-HRES) forcing (0.10° × 0.10°). They were first initialised by a 20-year spin-up (repeating year 2017) and then run for 2017 and 2018 (Table S2.1). Years 2017 and 2018 presented dry and wet spring conditions and wet and dry summer conditions, respectively.

Table S2.1. Main set up of the two theoretical experiments. Irrigation practices introduce emergence and harvest dates (crop phenology) and additional water supply.

Experiment	Forcing	Spinup	Simulation	Crop phenology	Irrigation
ISBA_ref	IFS-HRES	20-yr	2017-2018	no	no
ISBA_pheno_irr				YES	YES

The emergence dates were set to 15 May 2017 and 15 May 2018 and the harvesting dates to 15 September 2017 and 15 September 2018. The dates of irrigation were dynamically calculated by the model between planting and harvesting dates, mostly dependent on the soil water stress, through the root zone SWI (up to 1.5 m for C4 crops), as explained in section 2.3.1. Figure S2.1 describes the

impact of irrigation on the SWI by comparing ISBA_ref and ISBA_pheno_irr simulations in 2017 and 2018.

On the emergence date of 15 May 2017, the instantaneous SWI_{root_zone} is below the first threshold (the default value is 70%), thereby triggering the first irrigation. After the minimum lapse of time between two irrigations (the default values is one week), the SWI_{root_zone} is still below the second SWI threshold (the default value is 55%), triggering a second irrigation. After one additional week, the SWI_{root_zone} value is now above the third SWI threshold (default value is 40%) and thus the model waits for this value to be reached (around three weeks afterwards) to trigger the third irrigation. Then, after one week the SWI_{root_zone} is checked against the last SWI threshold (the default value is 25%), which is used for the rest of the 2017 growing season. Finally, the irrigation is stopped two weeks (by default) before the harvest.

For the 2018 season, the whole process is repeated but involving other dates for the triggering of irrigations, due to the variation of SWI_{root_zone} mainly dependent on weather (and more particularly on rainfall) and evaporation. Note that prior to the emergence date, the SWI differences between the two experiments come from differences in LAI since LAI is fixed to its minimum value of 0.3 $m^2 m^{-2}$ until emergence in ISBA_pheno_irr.

Outputs of 2017 describing the crop behaviour (LAI and Gross Primary Productivity, GPP), evapotranspiration and surface temperature are compared below.

To present the behaviour of the crops with the newly implemented irrigation and crop phenology, we summarised the two theoretical simulation results for year 2017 in Figure S2.2 for several additional variables: LAI, GPP, EVAP and LST. Firstly, in ISBA_pheno_irr, as the beginning and the end of the season are fixed, the LAI and GPP before the emergence date and after the harvest are roughly constant and close to the minimum value of 0.3 $m^2 m^{-2}$. The growing season is longer in ISBA_ref. Therefore the LAI and the GPP values are higher before the emergence date and after the harvest in ISBA_ref, until they are caught up by ISBA_pheno_irr in August. After emergence, for the two years, the LAI keeps growing and stays higher in ISBA_pheno_irr until the harvest, while LAI and GPP decrease in ISBA_ref. To explain these differences, Fig. S2.1 shows the rainfall and the root zone

soil moisture. While the variations of the SWI are in both simulations mostly explained by the rainfall, differences between ISBA_ref and ISBA_pheno_irr simulations can be explained by the combination of (1) the large LAI values in ISBA_ref at the beginning and at the end of the season, associated to a larger evapotranspiration and root water extraction fluxes leading to a smaller value of SWI_{40cm}, and (2) the irrigation water supply in ISBA_pheno_irr increasing substantially the SWI. More water is therefore available for the crops in the ISBA_pheno_irr simulation, enabling a higher GPP and an increase of LAI in summer, and triggering a larger evapotranspiration (EVAP) flux. Finally, in Fig. S2.2 it is apparent that the maximum surface temperature difference between the simulations corresponds to the highest evapotranspiration differences. This temperature difference can reach up to 6 degrees, with higher temperatures at the end and at the beginning of the season in ISBA_pheno_irr, when LAI is smaller than in the ISBA_ref simulation. On the other hand, at the end of the summer (August and September), the surface temperature is smaller when the crop is irrigated. These cooler temperatures are especially well synchronised with the triggering of irrigation (Fig. S2.2).
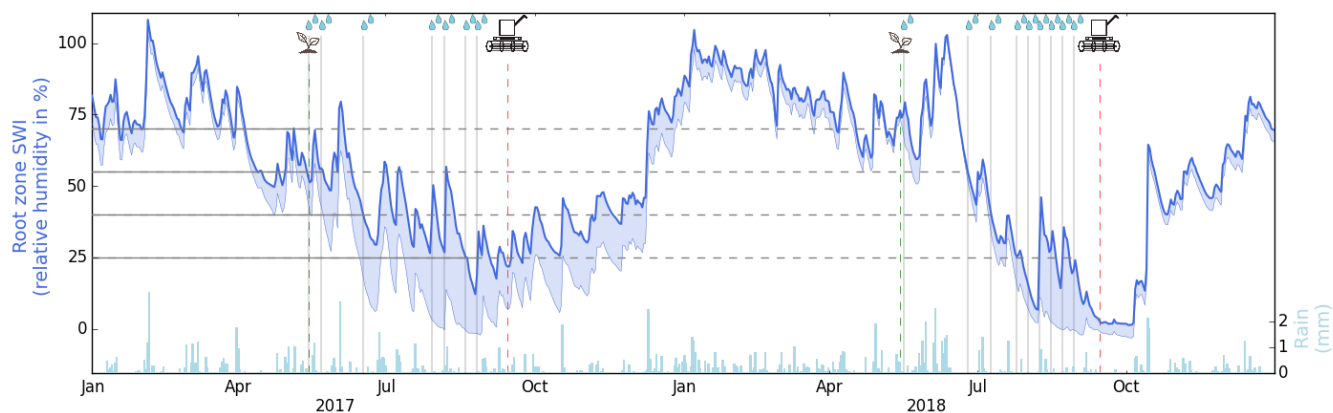
Figure S2.1 - Evolution of a C4 crop root zone SWI (in dark blue) with and without irrigation, in 2017 and 2018 in southwestern France. The thick line shows the simulation with irrigation (ISBA_pheno_irr, see Table S2.1), the thin line the reference (ISBA_ref, see Table S2.1), and the shaded area in between represents the difference of soil water storage. On the top of the plot, the plant logo (associated to the green vertical dotted line) and the harvester logo (associated to the red vertical dotted line) represent the emergence and harvesting dates, and the drops (associated to the grey vertical line) represent the irrigation events. The light blue bar plot on the bottom represents the rainfall, explaining an important part of SWI variation.
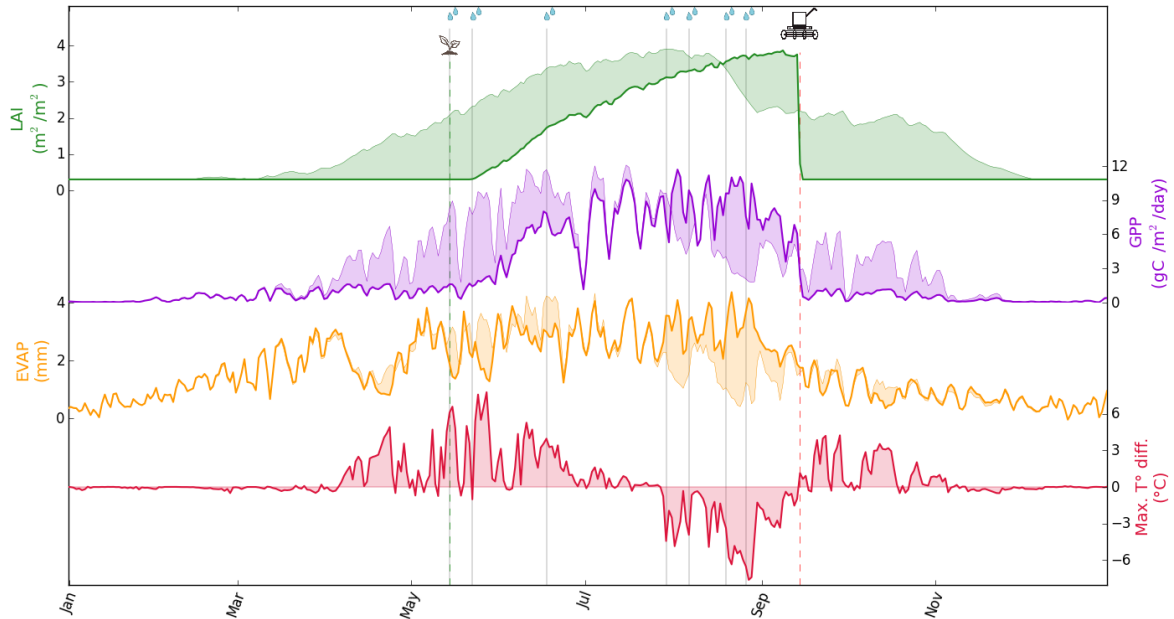
Figure S2.2 - Evolution of a C4 crop LAI, GPP, and evapotranspiration (EVAP) with and without irrigation in southwestern France, in 2017, from top to bottom, respectively. Differences in maximum daily surface temperatures are shown in the bottom sub-figure. For each variable the thick line shows the simulation with irrigation (ISBA_pheno_irr), the thin line the reference (ISBA_ref), and the shaded area in between represents the difference. On the top of the plot, the plant logo (associated to the green vertical dotted line) and the harvester logo (associated to the red vertical dotted line) represent the emergence and harvesting dates, and the drops (associated to the grey vertical line) represent the irrigation events. LAI is represented in green, GPP in purple, evapotranspiration (EVAP) in orange and the maximum temperature difference (ISBA_pheno_irr − ISBA_ref) in red.

Supplement S3

Tests over the Hampton irrigated area in Nebraska

The study presented in Supplement S2 over southwestern France was repeated over the Hampton irrigated area in Nebraska (see "Ha" dot in Fig. 1e) using the ERA5 atmospheric forcing.

The vegetation type was considered as 100% C4 crops and two distinct offline simulations (non-coupled with the atmosphere) were carried out: with (ISBA_pheno_irr) and without (ISBA_ref) irrigation and crop phenology parameters. The crop phenology corresponded to crop emergence and harvesting dates, delimiting the period in which the development of the crop is possible.

The emergence dates were set to 15 May 2017 and 15 May 2018 and the harvesting dates to 15 September 2017 and 15 September 2018. The dates of irrigation were dynamically calculated by the model between planting and harvesting dates, mostly dependent on the soil water stress, through the root zone SWI (up to 1.5 m for C4 crops), as explained in section 2.3.1. Figure S3.1 describes the impact of irrigation on the SWI by comparing ISBA_ref and ISBA_pheno_irr simulations in 2017 and 2018.

To present the behaviour of the crops with the newly implemented irrigation and crop phenology, we summarised the two theoretical simulation results for year 2017 in Figure S3.2 for several additional variables: LAI, GPP, EVAP and LST.
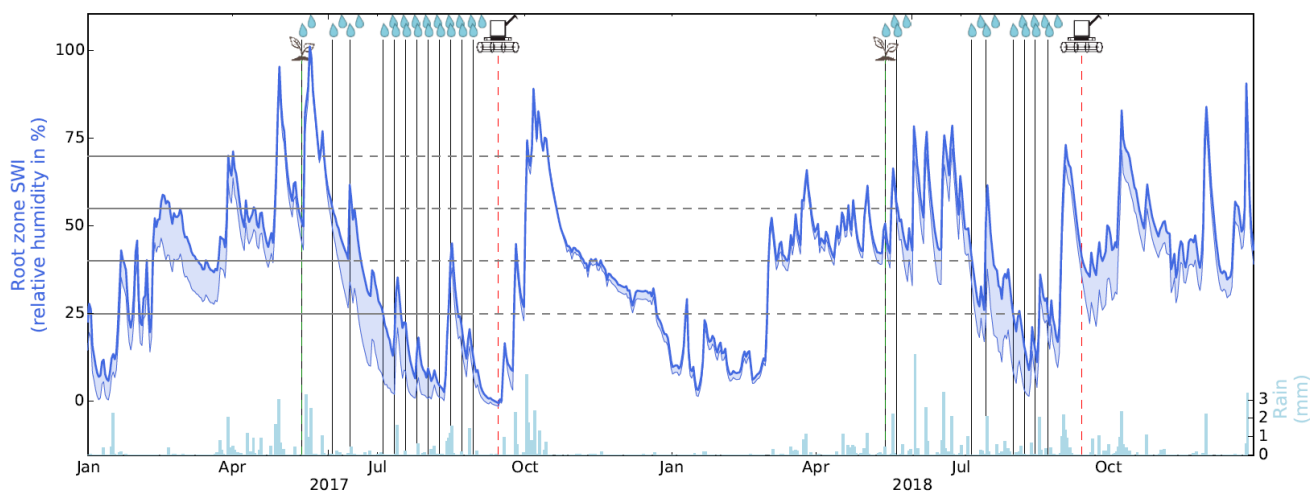
Figure S3.1 - Evolution of a C4 crop root zone SWI (in dark blue) with and without irrigation, in 2017 and 2018 in the Hampton irrigated area in Nebraska. The thick line shows the simulation with irrigation (ISBA_pheno_irr), the thin line the reference (ISBA_ref), and the shaded area in between represents the difference of soil water storage. On the top of the plot, the plant logo (associated to the green vertical dotted line) and the harvester logo (associated to the red vertical dotted line) represent the emergence and harvesting dates, and the drops (associated to the grey vertical line) represent the irrigation events. The light blue bar plot on the bottom represents the rainfall, explaining an important part of SWI variation.
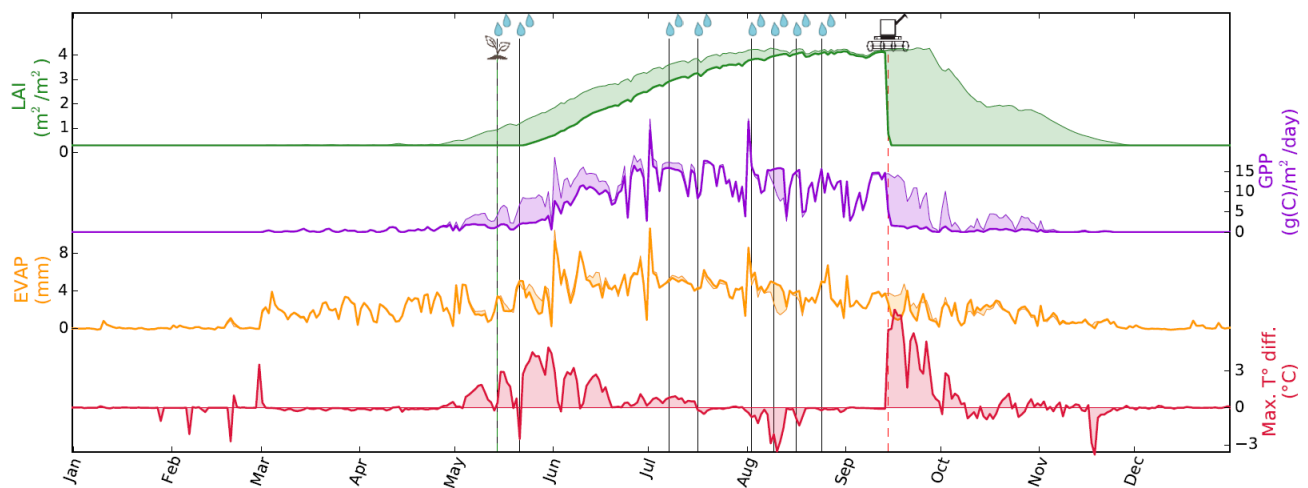
Figure S3.2 - Evolution of a C4 crop LAI, GPP, and evapotranspiration (EVAP) with and without irrigation in the Hampton irrigated area in Nebraska, in 2018, from top to bottom, respectively. Differences in maximum daily surface temperatures are shown in the bottom sub-figure. For each variable the thick line shows the simulation with irrigation (ISBA_pheno_irr), the thin line the reference (ISBA_ref), and the shaded area in between represents the difference. On the top of the plot, the plant logo (associated to the green vertical dotted line) and the harvester logo (associated to the red vertical dotted line) represent the emergence and harvesting dates, and the drops (associated to the grey vertical line) represent the irrigation events. LAI is represented in green, GPP in purple, evapotranspiration (EVAP) in orange and the maximum temperature difference (ISBA_pheno_irr − ISBA_ref) in red.

Figure S3.3 - Evolution of a C4 crop evapotranspiration (EVAP) with and without irrigation (ISBA_pheno_irr and ISBA_ref, top and bottom, respectively) in the Hampton irrigated area in Nebraska, in 2018. Evaporation components are indicated (soil, ice, snow, transpiration).
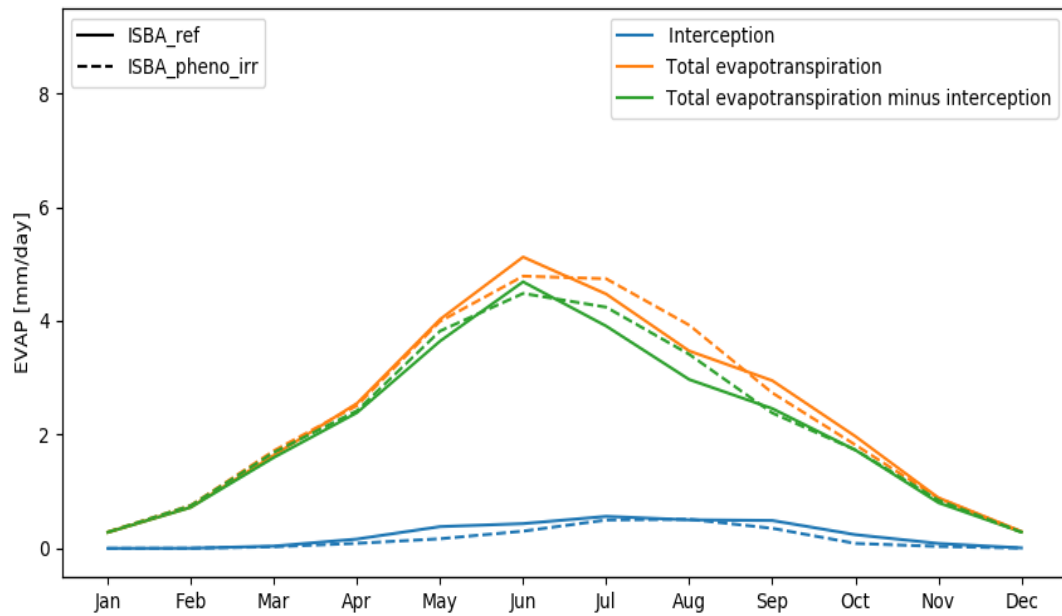
Figure S3.4 - Evolution of a C4 crop evapotranspiration (EVAP) with and without irrigation (ISBA_pheno_irr and ISBA_ref, respectively) in the Hampton irrigated area in Nebraska, from 2015 to 2018. The interception component is indicated.

Supplement S4

Comparison of ERA5 precipitation with in situ observations over Nebraska
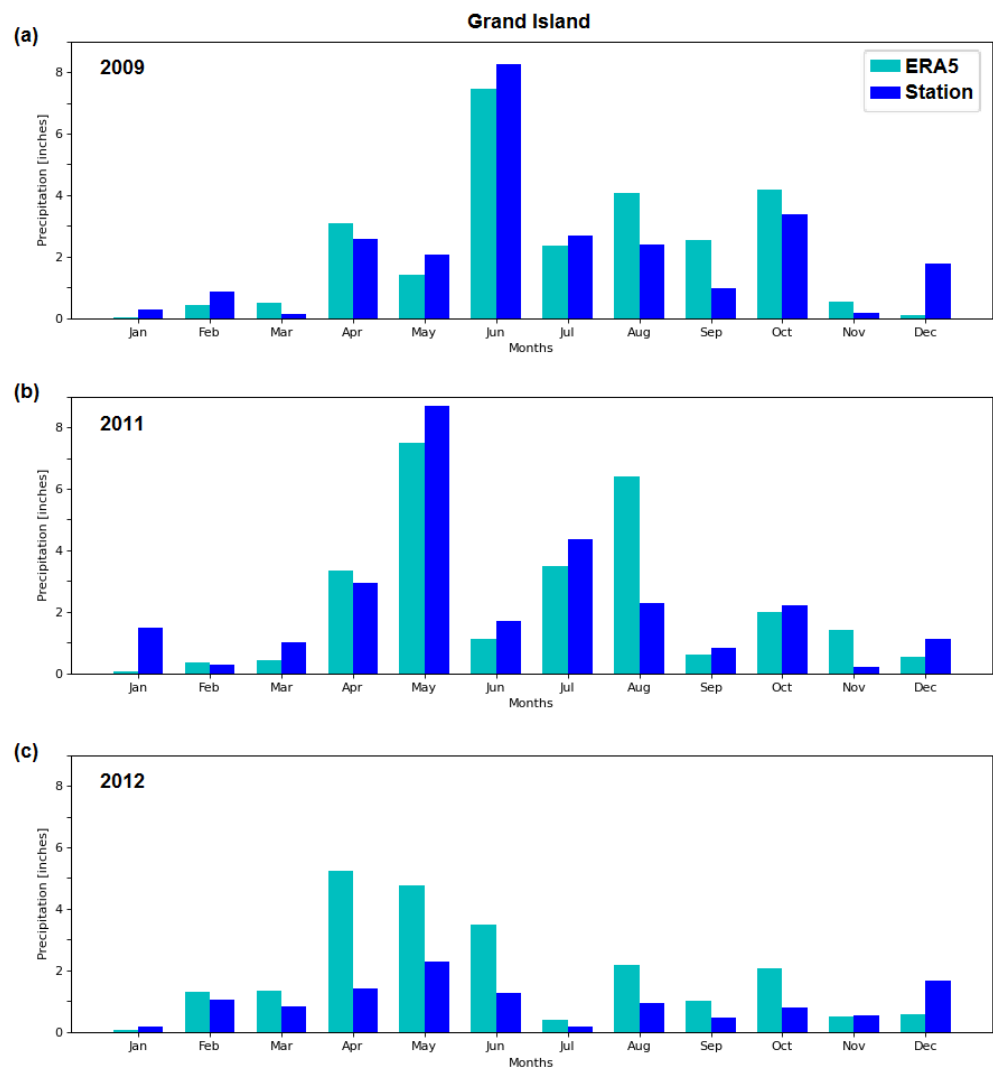
Figure S4.1 – ERA5 vs. in situ monthly precipitation at Grand Island: (a) 2009, (b) 2011, (c) 2012.
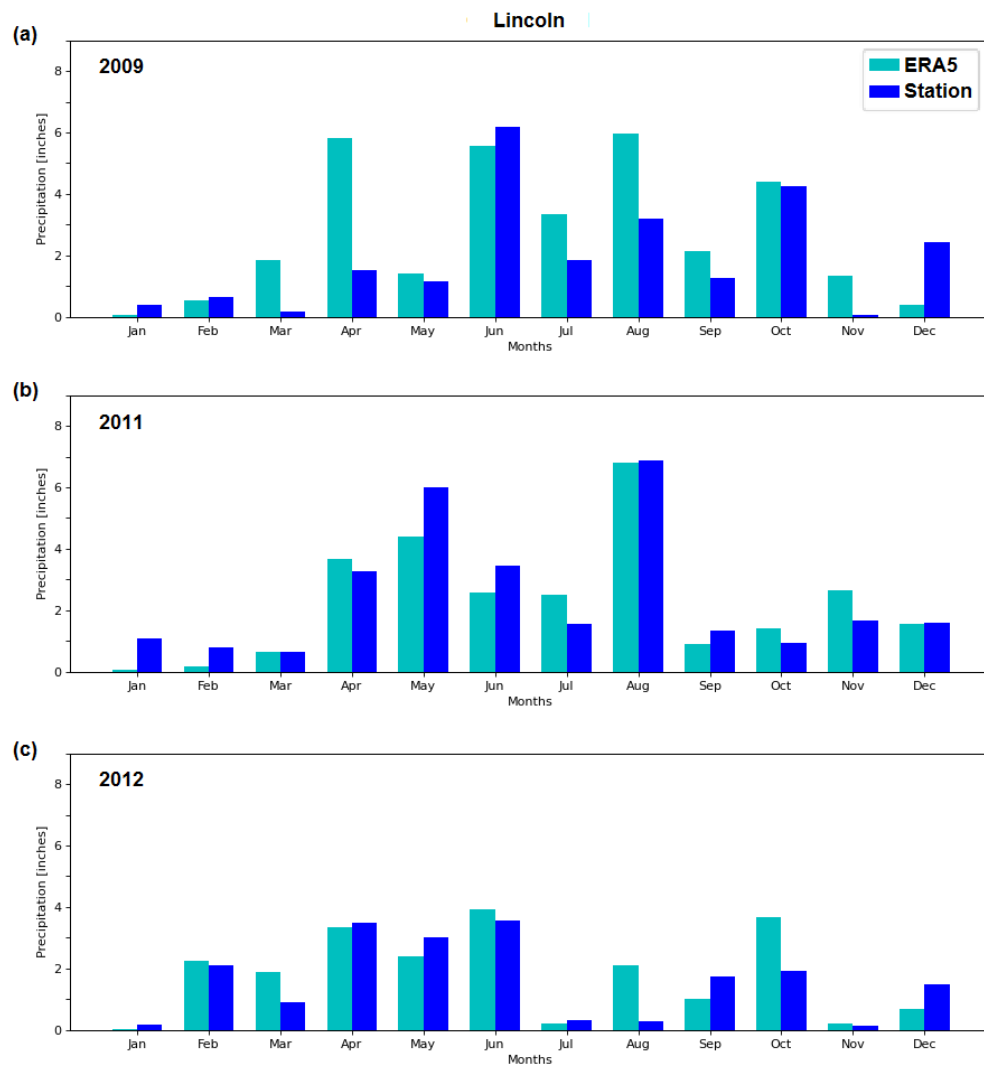
Figure S4.2 – ERA5 vs. in situ monthly precipitation at Lincoln: (a) 2009, (b) 2011, (c) 2012.

Supplement S5

New variables implemented for irrigation in the ISBA LSM within SURFEX

Technical description of keys and namelists to activate irrigation

Namelist: NAM_AGRI

Fortran name	Fortran type	Values	Default value
LAGRIP	logical	.TRUE./.FALSE	.FALSE.
LIRRIGMODE	logical	.TRUE./.FALSE	.FALSE.
NVEG_IRR	integer	[0-NVEGTYPE]	with ECOCLIMAP-SG and LIRRIGMODE: 6 without ECOCLIMAP-SG (not used): 0
NPATCH_TREE	integer	Between: 1, 2, 3, 5, 7, 9, 10, 12, 13 or NVEGTYPE	- (not needed without ECOCLIMAP-SG or if default values of NVEG_IRR and NVEG_IRR_USE are used)
XTHRESHOLD	float, dimension(4)	[0,1]	(/0.70,0.55,0.40,0.25/)
NIRR_STOP_BTR	integer	[0,365]	14 (days)

- LAGRIP: flag to activate crop phenology (emergence and harvest), only for herbaceous (deactivate for wood-species in any case)
- LIRRIGMODE: flag to activate irrigation.

With LAGRIP and/or LIRRIGMODE, if ECOCLIMAP-SG is activated (LECOSG = T in namelist NAM_FRAC) the associated nature types (defined with NUNIF_VEG_IRR_USE, see below) are duplicated. By default you need nothing more without ECOCLIMAP-SG, although with ECOCLIMAP-SG it is recommended to use the map "irrigcover_vX" provided with ECOCLIMAP-SG forcing (i.e. CFNAM_IRRIGFRAC and CFTYP_IRRIGFRAC in namelist NAM_DATA_ISBA). The number of simulated patches NPATCH (from namelist NAM_ISBA) has to be adapted to indicate how many patches are finally considered. With 6 default irrigated nature type, NPATCH possible values are 2, 4, 5, 7, 10, 12, 14, 15, 19 or 26 (see the red numbers on top of Fig. S1.1).

- NVEG_IRR: if LAGRIP or/and LIRRIGMODE are activated, it corresponds to the number of patch irrigated or/and with crop phenology. The default value is 6 with ECOCLIMAP-SG and LIRRIGMODE, 0 without ECOCLIMAP-SG. Note that if you indicate 0, the default value is used.

- NPATCH_TREE: with ECOCLIMAP-SG and if LAGRIP or/and LIRRIGMODE are activated, it corresponds to the "tree" patch distribution rules without irrigation and crop phenology. By default (if default values of NVEG_IRR and NVEG_IRR_USE are used) it takes automatically a value corresponding to NPATCH, else the value of patch aggregation rules without irrigation use has to be indicated (1, 2, 3, 5, 7, 9, 10, 12, 13 or NVEGTYPE).

- XTHRESHOLD: if LIRRIGMODE is activated, XTHRESHOLD corresponds to the 4 successive threshold values to trigger the irrigation. For example, with default values, the first irrigation will be triggered only if the root zone SWI is below 0.7, the second one below 0.55, then below 0.4 and from the 4th onward below 0.25 (1 corresponds to a water saturated soil, and 0 a dry soil). This key can be overwritten by more specific values in the NAM_DATA_ISBA namelist (see below).

- NIRR_STOP_BTR: Number of days corresponding to the time when the irrigation stops before harvest.

Namelist: NAM_DATA_ISBA

Fortran name	Fortran type	Default value	Values / units
NUNIF_VEG_IRR_USE	integer, dimension(NVEG_IRR)	**(/5,7,12,16,17,18/)** with ECOCLIMAP-SG and LIRRIGMODE (/9/) (=NVT_IRR) with ECOCLIMAP	
XUNIF_IRRIGTYPE_C	real	**1** (for sprinkler) with ECOCLIMAP_SG **1** (for sprinkler) for irrigated nature type NVT_IRR (=9), 0 else with ECOCLIMAP	(0,1,2,3)
XUNIF_IRRIGTYPE	real, dimension(NVEGTYPE)	XUNDEF	
CFNAM_IRRIGTYPE	character(len=28), dimension(NVEGTYPE)	' '	
CFTYP_IRRIGTYPE	character(len=6), dimension(NVEGTYPE)	' '	
XUNIF_IRRIGFRAC_C	real	0.05 (but **use by default the map "irrigcover_vX" provided with ECOCLIMAP-SG**!)	[0-1]
XUNIF_IRRIGFRAC	real, dimension(NVEGTYPE)	XUNDEF	
CFNAM_IRRIGFRAC	character(len=28), dimension(NVEGTYPE)	' '	
CFTYP_IRRIGFRAC	character(len=6), dimension(NVEGTYPE)	' '	
XUNIF_IRRIGFREQ_CTYPE	real, dimension(NIRR_TYPE)	**(/604800,0,604800/)**	(s)
XUNIF_IRRIGFREQ_C	real	XUNDEF	
XUNIF_IRRIGFREQ	real, dimension(NVEGTYPE)	XUNDEF	

CFNAM_IRRIGFREQ	character(len=28), dimension(NVEGTYPE)	' '	
CFTYP_IRRIGFREQ	character(len=6), dimension(NVEGTYPE)	' '	
XUNIF_IRRIGTIME_C	real	**28800**	(s)
XUNIF_IRRIGTIME	real, dimension(NVEGTYPE)	XUNDEF	
CFNAM_IRRIGTIME	character(len=28), dimension(NVEGTYPE)	' '	
CFTYP_IRRIGTIME	character(len=6), dimension(NVEGTYPE)	' '	
XUNIF_WATSUP_C	real	**30**	(mm)
XUNIF_WATSUP_CTIME	real, dimension(NTIME_MAX)	XUNDEF	
XUNIF_WATSUP	real, dimension(NVEGTYPE, NTIME_MAX)	XUNDEF	
CFNAM_WATSUP	character(len=28), dimension(NVEGTYPE, NTIME_MAX)	' '	
CFTYP_WATSUP	character(len=6), dimension(NVEGTYPE, NTIME_MAX)	' '	
XUNIF_F2THRESHOLD_C	real	XUNDEF (cf NAM_AGRI)	[0-1]
XUNIF_F2THRESHOLD_CTIME	real, dimension(NTIME_MAX)	XUNDEF	

XUNIF_F2THRESHOLD	real, dimension(NVEGTYPE, NTIME_MAX)	XUNDEF	
CFNAM_F2THRESHOLD	character(len=28), dimension(NVEGTYPE, NTIME_MAX)	' '	
CFTYP_F2THRESHOLD	character(len=6), dimension(NVEGTYPE, NTIME_MAX)	' '	
XUNIF_SEED_M_C	real	**3**	[1, 12]
XUNIF_SEED_M	real, dimension(NVEGTYPE)	XUNDEF	
CFNAM_SEED_M	character(len=28), dimension(NVEGTYPE)	' '	
CFTYP_SEED_M	character(len=6), dimension(NVEGTYPE)	' '	
XUNIF_SEED_D_C	real	**15**	[1, 31]
XUNIF_SEED_D	real, dimension(NVEGTYPE)	XUNDEF	
CFNAM_SEED_D	character(len=28), dimension(NVEGTYPE)	' '	
CFTYP_SEED_D	character(len=6), dimension(NVEGTYPE)	' '	
XUNIF_REAP_M_C	real	**8**	[1, 12]
XUNIF_REAP_M	real, dimension(NVEGTYPE)	XUNDEF	
CFNAM_REAP_M	character(len=28), dimension(NVEGTYPE)	' '	

CFTYP_REAP_M	character(len=6), dimension(NVEGTYPE)	' '	
XUNIF_REAP_D_C	real	**31**	[1, 31]
XUNIF_REAP_D	real, dimension(NVEGTYPE)	XUNDEF	
CFNAM_REAP_D	character(len=28), dimension(NVEGTYPE)	' '	
CFTYP_REAP_D	character(len=6), dimension(NVEGTYPE)	' '	
XUNIF_SEED_S2_M_C	real	XUNDEF	[1, 12]
XUNIF_SEED_S2_M	real, dimension(NVEGTYPE)	XUNDEF	
CFNAM_SEED_S2_M	character(len=28), dimension(NVEGTYPE)	' '	
CFTYP_SEED_S2_M	character(len=6), dimension(NVEGTYPE)	' '	
XUNIF_SEED_S2_D_C	real	XUNDEF	[1, 31]
XUNIF_SEED_S2_D	real, dimension(NVEGTYPE)	XUNDEF	
CFNAM_SEED_S2_D	character(len=28), dimension(NVEGTYPE)	' '	
CFTYP_SEED_S2_D	character(len=6), dimension(NVEGTYPE)	' '	
XUNIF_REAP_S2_M_C	real	XUNDEF	[1, 12]
XUNIF_REAP_S2_M	real, dimension(NVEGTYPE)	XUNDEF	
CFNAM_REAP_S2_M	character(len=28),	' '	

	dimension(NVEGTYPE)		
CFTYP_REAP_S2_M	character(len=6), dimension(NVEGTYPE)	' '	
XUNIF_REAP_S2_D_C	real	XUNDEF	[1, 31]
XUNIF_REAP_S2_D	real, dimension(NVEGTYPE)	XUNDEF	
CFNAM_REAP_S2_D	character(len=28), dimension(NVEGTYPE)	' '	
CFTYP_REAP_S2_D	character(len=6), dimension(NVEGTYPE)	' '	
XUNIF_SEED_S3_M_C	real	XUNDEF	[1, 12]
XUNIF_SEED_S3_M	real, dimension(NVEGTYPE)	XUNDEF	
CFNAM_SEED_S3_M	character(len=28), dimension(NVEGTYPE)	' '	
CFTYP_SEED_S3_M	character(len=6), dimension(NVEGTYPE)	' '	
XUNIF_SEED_S3_D_C	real	XUNDEF	[1, 31]
XUNIF_SEED_S3_D	real, dimension(NVEGTYPE)	XUNDEF	
CFNAM_SEED_S3_D	character(len=28), dimension(NVEGTYPE)	' '	
CFTYP_SEED_S3_D	character(len=6), dimension(NVEGTYPE)	' '	
XUNIF_REAP_S3_M_C	real	XUNDEF	[1, 12]
XUNIF_REAP_S3_M	real, dimension(NVEGTYPE)	XUNDEF	

CFNAM_REAP_S3_M	character(len=28), dimension(NVEGTYPE)	' '	
CFTYP_REAP_S3_M	character(len=6), dimension(NVEGTYPE)	' '	
XUNIF_REAP_S3_D_C	real	XUNDEF	[1, 31]
XUNIF_REAP_S3_D	real, dimension(NVEGTYPE)	XUNDEF	
CFNAM_REAP_S3_D	character(len=28), dimension(NVEGTYPE)	' '	
CFTYP_REAP_S3_D	character(len=6), dimension(NVEGTYPE)	' '	
XUNIF_SEED_D_DELTA	real	0	(day)
XUNIF_REAP_D_DELTA	real	0	(day)

- NUNIF_VEG_IRR_USE: if LAGRIP or/and LIRRIGMODE are activated, it corresponds to the nature types irrigated or/and with crop phenology (size: NVEG_IRR). By default if LECOCLIMAP-SG and LIRRIGMODE (with or without LAGRIP), it is (/5,7,12,16,17,18/) (temperate broadleaf deciduous, temperate broadleaf evergreen, shrubs, C3 winter crops, C3 summer crops and C4 crops. With ECOCLIMAP, the default value is (/9/), the value of the NVT_IRR nature type.

For the other following parameters, there is a standard nomenclature for the parameters associated to the same variable and a hierarchy to select the value is taken into account. If the name of the key is XUNIF_*_C, the same (constant) value is used for all irrigated nature types. If the key is XUNIF_*, a value per irrigated nature type is used. If the key is XUNIF_*_CTIME, different values are used per 10-day time periods (36 for one year). If a file is used as an input, the name of the file, starting by

'CFNAME_*', has to be indicated. The type of the file has to be indicated as well, starting with 'CFTYPE_*', and to be chosen among the following list: 'DIRECT', 'BINLLF', 'BINLLV' or 'ASCLLV'.

In the case when several datasets are available, the model will use in decreasing order of priority: the map (CFNAME_* and CFTYPE_*), the value per irrigated type (XUNIF_*), the constant values per 10-day periods of time (XUNIF_*_CTIME), and lastly a unique constant value (XUNIF_*_C).

- XUNIF_IRRIGTYPE_C, XUNIF_IRRIGTYPE, CFNAM_IRRIGTYPE, CFTYP_IRRIGTYPE: if LIRRIGMODE is activated, these keys indicate the irrigation type: 0 for none, 1 for sprinkling, 2 for dripping and 3 for flooding. By default with ECOCLIMAP-SG is 1 (but take into account only for irrigated nature type) and with ECOCLIMAP for irrigated nature type is 1 (sprinkler) and the others 0.

- XUNIF_IRRIGFRAC_C, XUNIF_IRRIGFRAC, CFNAM_IRRIGFRAC, CFTYP_IRRIGFRAC: if LECOCLIMAP-SG and LIRRIGMODE are activated, they indicate the irrigation fraction [0-1] for each nature type (but only the nature types indicated in NUNIF_VEG_IRR_USE will be irrigated). Please by default use the map of irrigation (**"irrigcover_vX"**) provided with ECOCLIMAP-SG forcing.

- XUNIF_IRRIGFREQ_C, XUNIF_IRRIGFREQ_CTYPE, XUNIF_IRRIGFREQ, CFNAM_IRRIGFREQ, CFTYP_IRRIGFREQ: If LIRRIGMODE, keys to indicate the minimum time (in s) between two irrigation triggers. By default it is defined with XUNIF_IRRIGFREQ_CTYPE: values for the 3 types of irrigation, respectively sprinkling, dripping and flooding.

- XUNIF_IRRIGTIME_C, XUNIF_IRRIGTIME, CFNAM_IRRIGTIME, CFTYP_IRRIGTIME: If LIRRIGMODE, keys to indicate the duration of irrigation (in s).

- XUNIF_WATSUP_C, XUNIF_WATSUP_CTIME, XUNIF_WATSUP, CFNAM_WATSUP, CFTYP_WATSUP: If LIRRIGMODE, keys to indicate the irrigation amount (mm) for one irrigation.

- XUNIF_F2THRESHOLD_C, XUNIF_F2THRESHOLD_CTIME, XUNIF_F2THRESHOLDC, FNAM_F2THRESHOLD, CFTYP_F2THRESHOLD: If LIRRIGMODE, keys to indicate the threshold [0-1] for irrigation triggering. By default the value given by XTHRESHOLD in the namelist NAM_AGRI is used, but the value can be overwritten here.

- XUNIF_SEED_M_C, XUNIF_SEED_M, CFNAM_SEED_M, CFTYP_SEED_M: if LAGRIP or/and LIRRIGMODE are activated, they correspond to the emergence month and/or the month of the beginning of irrigation [1-12].

- XUNIF_SEED_D_C, XUNIF_SEED_D, CFNAM_SEED_D, CFTYP_SEED_D: if LAGRIP or/and LIRRIGMODE are activated, they correspond to the emergence day and/or the day of the beginning of irrigation [1-31].

- XUNIF_REAP_M_C, XUNIF_REAP_M, CFNAM_REAP_M, CFTYP_REAP_M: if LAGRIP or/and LIRRIGMODE are activated, they correspond to the harvest month and/or the month corresponding to 2 weeks after the end of irrigation [1-12].

- XUNIF_REAP_D_C, XUNIF_REAP_D, CFNAM_REAP_D, CFTYP_REAP_D: if LAGRIP or/and LIRRIGMODE are activated, they correspond to the harvest day and/or the day corresponding to 2 weeks after the end of irrigation [1-31].

Note: It is possible to deactivate these emergence/harvest/irrigation dates, by indicating a start date on 1 January and an end date on 31 December.

Note: In a similar way to the previous keys, it is possible to define the dates for a second or third agricultural season. The nomenclature is identical, with "_S2" or "_S3" added. There is no default value (by default only one season is considered)

- XUNIF_SEED_D_DELTA: if LAGRIP or/and LIRRIGMODE are activated and date values given with 'XUNIF_*', this key changes the emergence date (= start date of irrigation) and adds a random value around the previously defined date (in a range equal to +/- XUNIF_SEED_D_DELTA). Take care: with this option each PGD will be different.

- XUNIF_REAP_D_DELTA: if LAGRIP or/and LIRRIGMODE are activated and date values given with 'XUNIF_*', this key changes the harvest date (= 2 weeks after the end of irrigation) and adds a random value around the previously defined date (in a range equal to +/- XUNIF_SEED_D_DELTA). Take care: with this option each PGD will be different.

Examples of namelists to activate irrigation with ECOCLIMAP-SG

Example 1. Default values for irrigation with ECOCLIMAP-SG

In this example, NPATCH=19, which corresponds to 6 patches irrigated or partially irrigated and 13 patches non irrigated (see the patch aggregation rules). Irrigation dates, emergence dates, harvest dates are the default values. The irrigation type is only sprinkling (default value for irrigation type). The irrigated fractions are directly obtained from the irrigation map provided with ECOCLIMAP-SG.

To use default values for irrigation with ECOCLIMAP-SG, you have to use the map of irrigation (provided with ECOCLIMAP-SG: irrigcover_v0.dir and irrigcover_v0.hdr) and add/change in the OPTIONS.nam:

```
&NAM_AGRI LAGRIP = T,      !(not required but extremely recommended by
                           ! default)
LIRRIGMODE = T,
...
/
&NAM_ISBA NPATCH = 19 ! You can choose (see Fig. S1.1)  one of the default value as
! explained above and shown in the patch agreggation rules available below: 2, 4, 5, 7, 10, 12,
! 14, 15, 19 or 26 (red numbers in the patch agreggation rules for irrigation)
...
/
&NAM_DATA_ISBA XUNIF_IRRIGTYPE_C = 1 ! Only sprinkling
CFNAM_IRRIGFRAC = 'irrigcover_v0' ! Read irrigated fractions
CFTYP_IRRIGFRAC = 'DIRTYP'
...
/
```

Note: If on your domain you have an idea of the irrigation season (e.g. from the 15 March to 31 August), it is **recommended** to specify the season by adding:

```
&NAM_DATA_ISBA XUNIF_SEED_M_C = 3 ,
XUNIF_SEED_D_C = 15 ,
XUNIF_REAP_M_C = 8 ,
XUNIF_REAP_D_C = 31 ,
XUNIF_SEED_D_DELTA = 15 ,  ! not required: only used for random emergence
                           ! date around the indicated date
XUNIF_REAP_D_DELTA = 15,   ! not required: only used for random harvest
                           ! date around the indicated date
...
/
```

Note: If you used one delta, each dates made in your PGD will be not constant between two runs (only when you make the PGD).

Example 2. Customizing irrigation practices

In this example, the user wants to irrigate only winter C3 crops, summer C3 crops and C4 crops, and wants to work with 10 "original" patch.

The user wants to choose which nature type will be irrigated with ECOCLIMAP-SG (by example the winter C3 crops, summer C3 crops and C4 crops, nature type numbers 16, 17 and 18). First you have to choose the "original" patch aggregation rules (black numbers in the patch aggregation rules for irrigation) that you would like to use. Here, for example, NPATCH_TREE = 10. Then, you have check how many "original" patches contain patches now irrigate. In our case the patches 7 and 8 indicate that 2 supplementary patches will be irrigated (see patch aggregation rules below). So, you have to indicate NPATCH = 12.

Then you have to use the map of irrigation (provide with ecoclimap-sg: irrigcover_v0.dir and irrigcover_v0.hdr) and add/change in the OPTIONS.nam as indicated in example 1:

```
&NAM_ISBA NPATCH = 12 ! As found before

...

/

&NAM_AGRI LAGRIP = T, ! (not required but recommended by default)

LIRRIGMODE = T,

NVEG_IRR = 3 !3 type of nature irrigated (16,17,18)

NPATCH_TREE = 10

...

/

&NAM_DATA_ISBA XUNIF_IRRIGTYPE_C = 1 ! Only sprinkling

CFNAM_IRRIGFRAC = 'irrigcover_v0'

CFTYP_IRRIGFRAC = 'DIRTYP'

NUNIF_VEG_IRR_USE(1) = 16

NUNIF_VEG_IRR_USE(2) = 17

NUNIF_VEG_IRR_USE(3) = 18

...

/
```

Note:

(1) The possibilities for NPATCH (with the same irrigated nature type 16/17/18) could have been 23, 16, 14, 12, 11, 8, 4, 3 or 2, associated with the respective correspond NPATCH_TREE: 20, 13, 12, 10, 9, 7, 3, 2, 1 (see Fig. S1.1).

(2) As in example 1, if on your domain you have an idea of irrigation season, it is **recommended** to specify dates as indicated in Example 1 (p. 21).

(3) An explicit list of the composition of the patches is written in the PGD file.

Patch aggregation rules for irrigation

When irrigation is activated, the nature types irrigated are duplicated (irrigated and non irrigated). Consequently, to work with patches (aggregation of nature type together, to reduce computing time), it is important to consider this patch aggregation rules tree (Figure S.1). It permits to understand how many patches have to be considered and indicated in namelist, according to the nature types irrigated.

For example, a user wants to continue to work with 9 patches (called 'original patches', in black in the tree) and wants to irrigate 4 nature types: temperate, boreal and tropical grasslands and shrubs. Whit these 9 patches, the irrigated nature types are included in 2 different patches ("3: Broadleaf trees +shrubs" and "8: Grasslands"). So, with irrigation, these 2 patches are duplicated. And finally, the user has to indicate in namelist NPATCH_TREE=9 and NPATCH=11 (see example 2 of namelist).

Irrigation map within ECOCLIMAP-SG

A map of irrigation (binary file irrigtype.dir / irrigtype.hdr) is provided with the ECOCLIMAP-SG database. It is a global map, at 1 km × 1 km spatial resolution. This map was obtained from Meier et al. 2018.

For each pixel, a type of ECOCLIMAP-SG cover (between 1 and 33) is associated to a type of irrigation (0 = no irrigation / 1 = sprinkler irrigation). Currently, there is no explicit difference between sprinkling (=1) / dripping (=2) / flooding (=3). Thus, by default, irrigated surfaces are considered as sprinkling.

To use the default values for irrigation with ECOCLIMAP-SG, it is recommended to use this irrigation map.