Decomposition of the effects on regional climate from recent historical land cover changes in Europe

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Abstract

Land cover changes (LCC) show biophysical effect on regional climate because they modify the land surface albedo, evapotranspiration, and surface roughness. Many previous studies focused on the effects of individual land cover transitions, such as idealized large-scale scenarios of deforestation/afforestation or historical forest clearance, but the combined effects from the detected recent historical land cover changes in Europe have not been explored. In this study, we use a combination of a regional climate model (the Weather Research and Forecasting model, WRF, v3.9.1) with a high resolution land cover data to explore the effects on surface temperature of land cover changes between 1992 and 2015. Previous studies use one unrealistic large-scale simulation for each LCC to estimate its climate effects which present large variations especially in mid-latitudes. Our analysis introduces a new method simultaneously considering the effects of the mix of historical land cover changes in Europe and the individual one contribution. This approach, based on a ridge statistical regression, does not require an explicit consideration of the different components of the surface energy budget, and directly shows the temperature changes from each land transition. Around 70 Mha of land transitions occurred in Europe from 1992 to 2015. Approximately 25 Mha of agricultural land was left abandoned, which was only partially compensated by cropland expansion (about 20 Mha). Declines in agricultural land mostly occurred in favor of forests (15 Mha) and urban settlements (8 Mha). Compared to 1992, we find that the land covers of 2015 are associated with an average temperature cooling of -0.12±0.20 °C, with seasonal and spatial variations. At a continental level, the mean cooling is mainly driven by agriculture abandonment (cropland-to-forest transitions). Idealized simulations where cropland transitions to other land classes are excluded result in a mean warming of +0.10±0.19 °C, especially during summer. Conversions to urban land always resulted in warming effects, whereas the local temperature response to forest gains and losses shows opposite signs from the western and central part of the domain (where forests have cooling effects) to the eastern part (where forests are associated to warming). Gradients in soil moisture and local climate conditions are the main drivers of these differences. Our findings are a first attempt to quantify the regional climate response to historical LCC in Europe, and our method allows to unmix the temperature signal of a grid cell to the underlying LCCs (i.e., temperature impact per land transition). Further developing biophysical implications from LCCs for their ultimate consideration in land use planning can improve synergies for climate change adaptation and mitigation. Key words: land use/cover change; regional climate mode; biophysical climate; EURO-CORDEX

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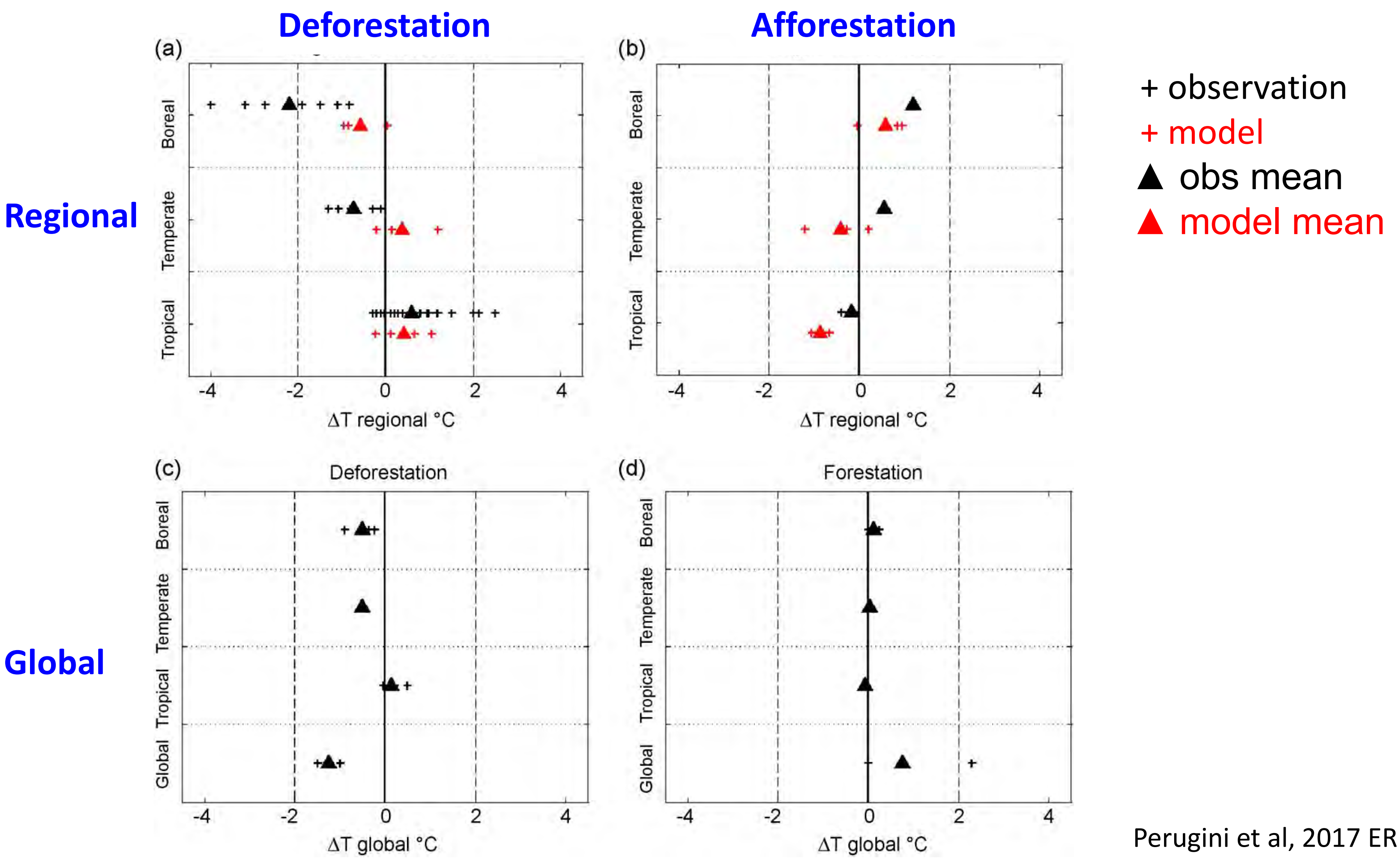
AGU2020, Session GC109

Forest changes impact on climate

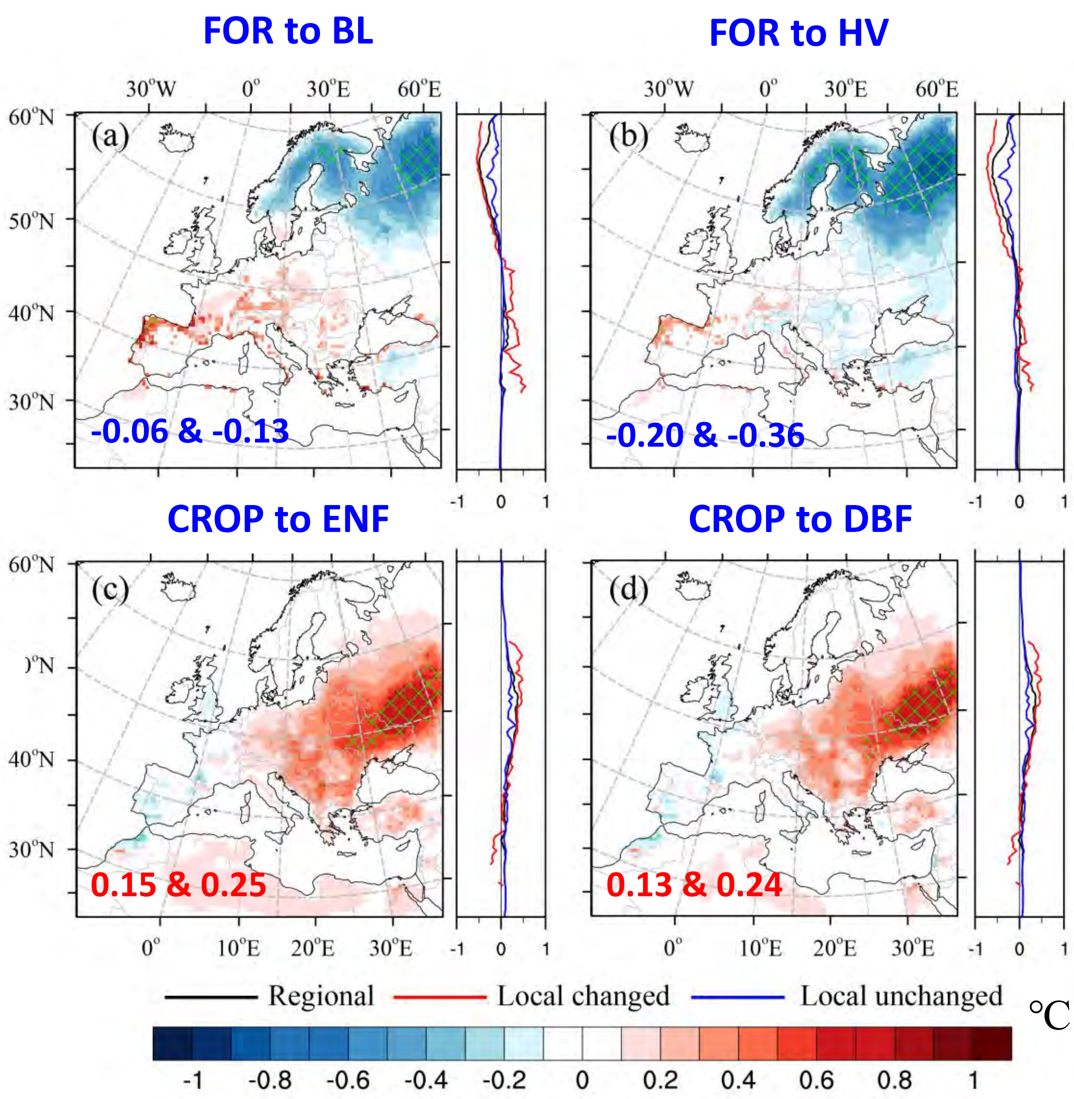


Perugini et al, 2017 ERL

Climate change under extreme land cover changes

Deforestation

Afforestation



Cooling

Latitudinal pattern (50° N)

Warming

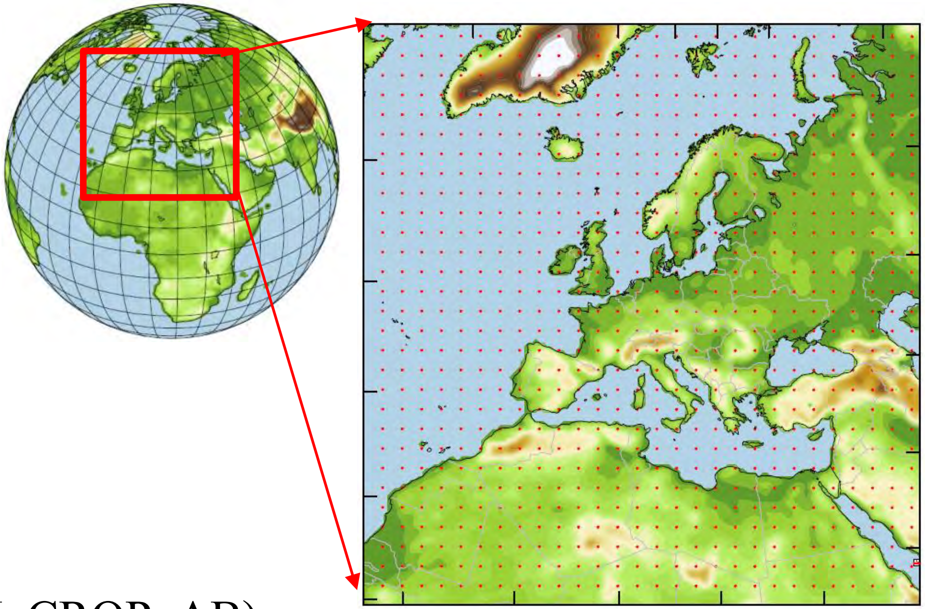
Longitudinal gradient (10° E)

Cherubini et al., 2018 ERL

Data and model simulations

- **Data**

▪ European Space Agency (ESA) Climate Change Initiatiue (CCI) land cover 2015
▪ E-OBS observation
▪ Duveiller et al., 2018 *Sci Data*

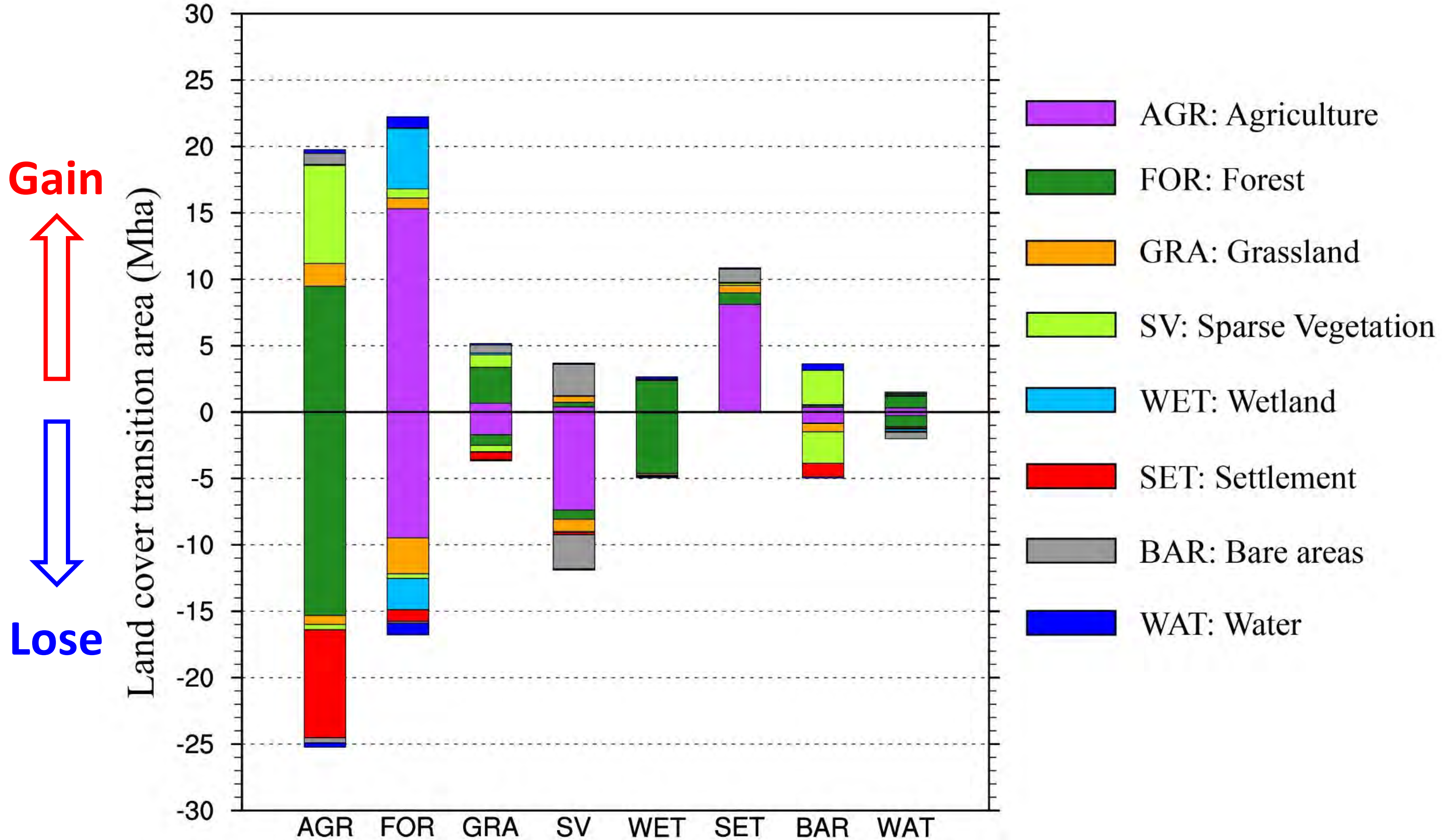


- **Model simulation**

▪ WRF v3.9.1, CLM4 land surfe model
▪ Driven data: ERA-Interim
▪ Horizontal resolution: 0.11° (~12km)
▪ Three simulations:
  - LC1992,
  - LC2015, and
  - No Cropland abandonment (NoCROP_AB)

- **Ridge-regression model**

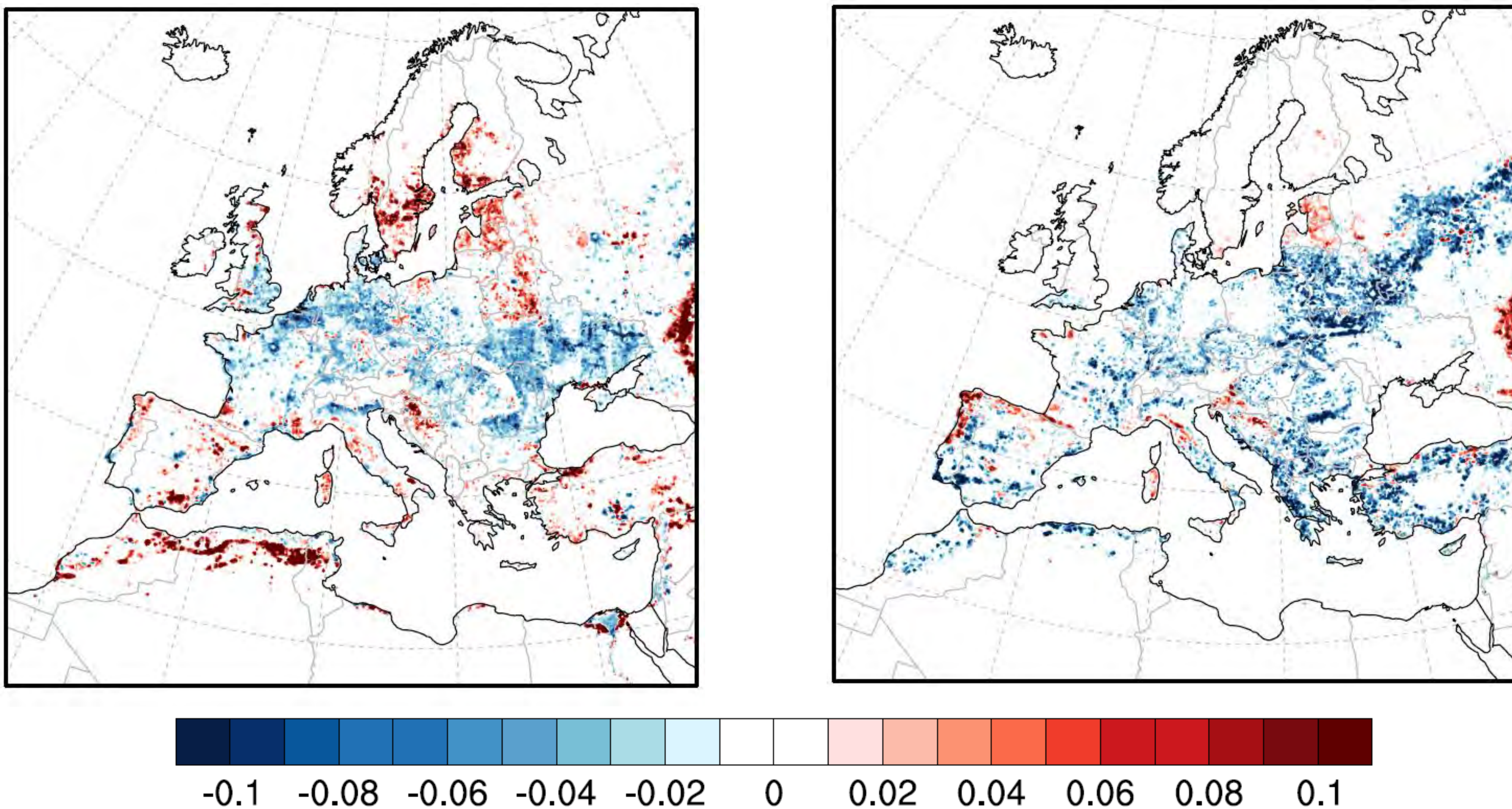
Land cover change in Europe



Huang et al, 2020 *Nat Commun*

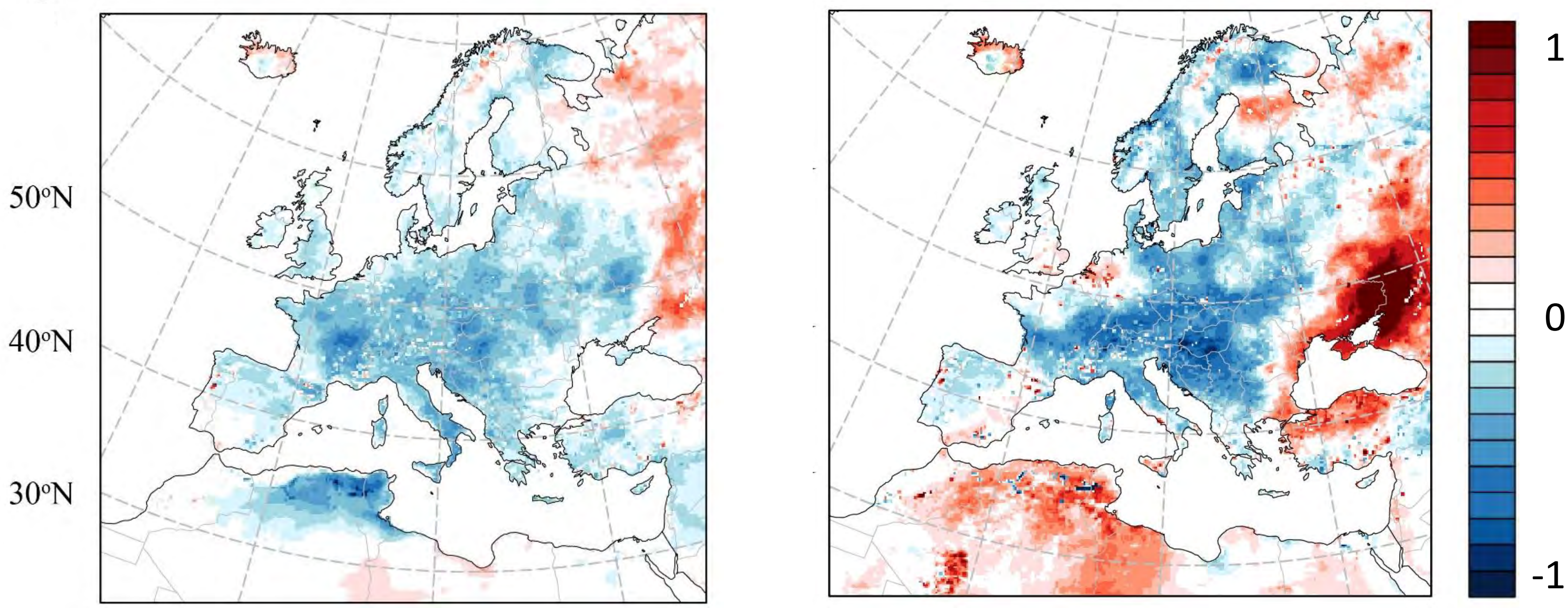
Cropland fraction difference between 2015 and 1992

Cropland | **Cropland/Natural vegetation**



Climate change due to land cover change

Temperature **Equivalent Temperature**

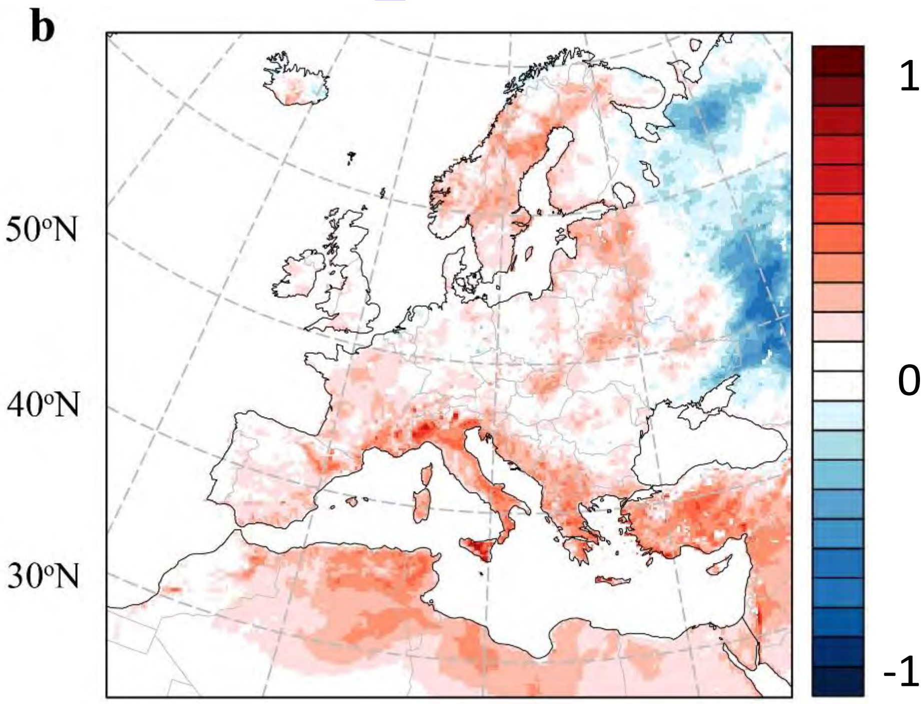


- an annual average temperature change of −0.12 ± 0.20 °C (mean ± standard deviation), with −0.42 and +0.22 °C as the 5th and 95th percentile
- At a continental level, the average difference in T_E from the recent LCCs is −0.10 ± 0.37 °C, with −0.58/+0.57 °C as the 5th and 95th percentile

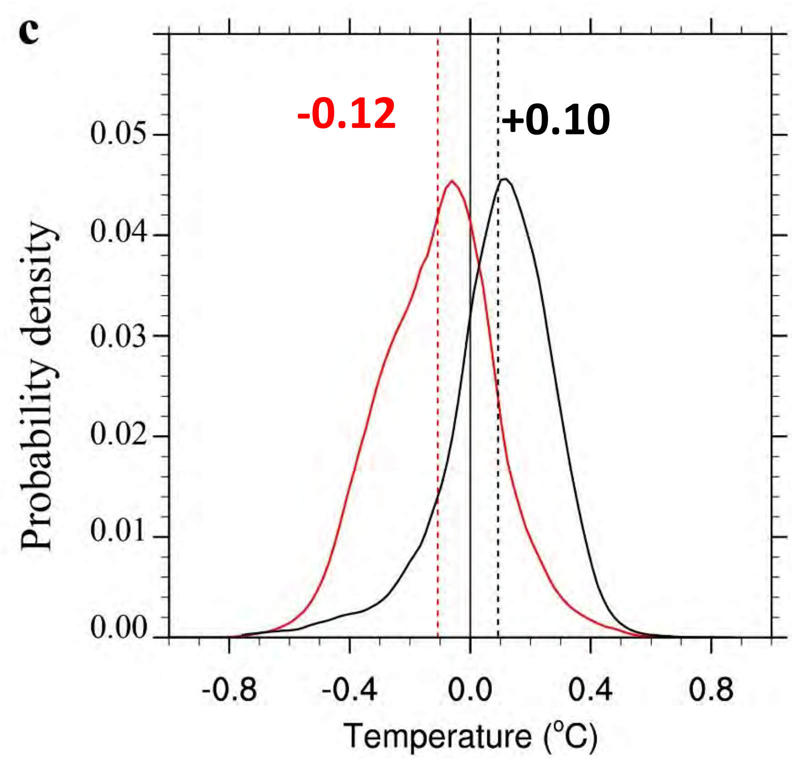
Huang et al, 2020 *Nat Commun*

Effect of agriculture abandonment

NoCROP_AB – LC2015



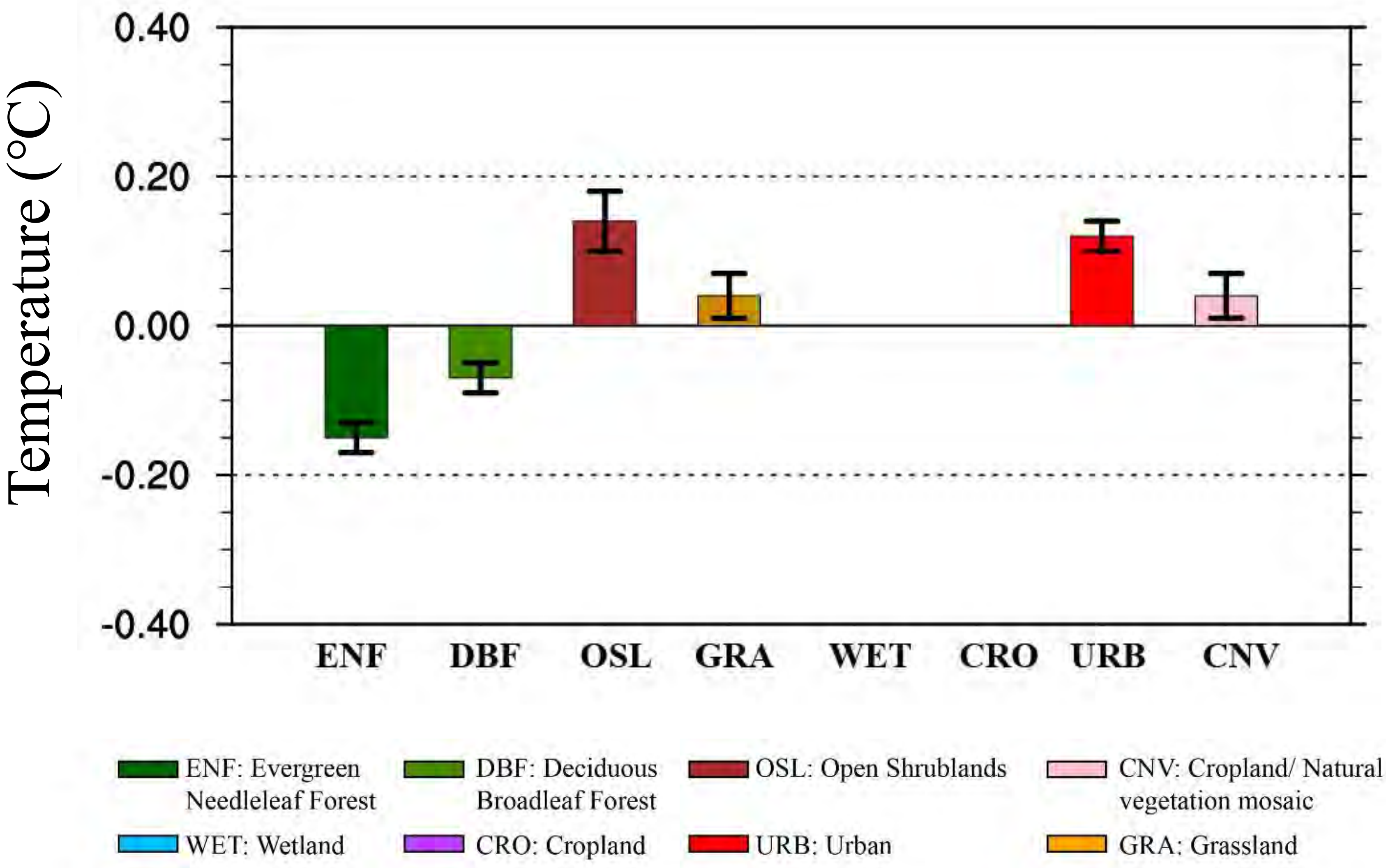
Abandonment **No Abandonment**



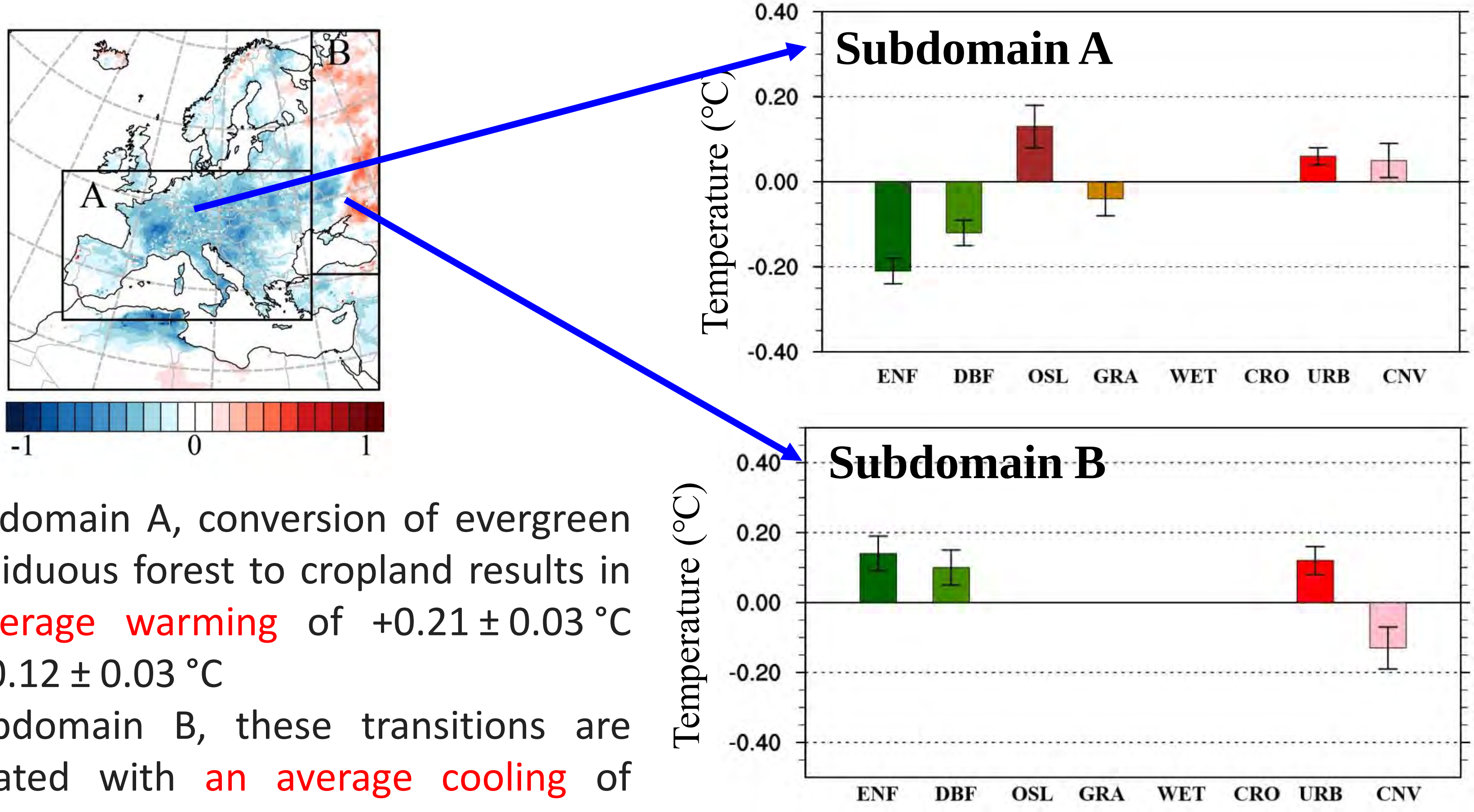
- When the transitions from cropland to other land classes are excluded, an annual average temperature change of +0.10 ± 0.19 °C, with −0.23 and +0.33 °C as the 5th and 95th percentile

Huang et al, 2020 *Nat Commun*

Temperature change with cropland transition



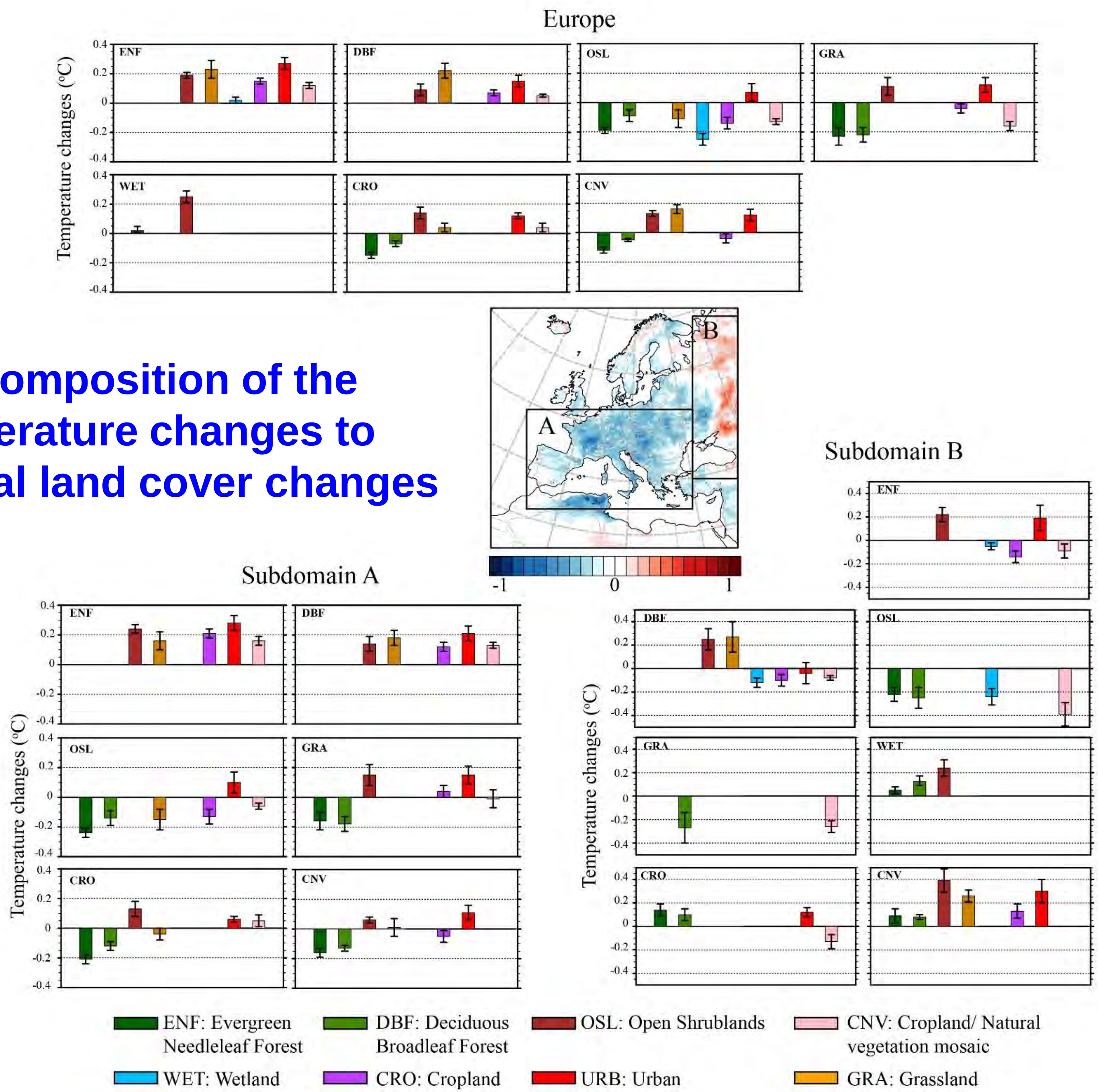
Different climate change response to cropland transition in East and West-Central Europe



- In subdomain A, conversion of evergreen or deciduous forest to cropland results in an average warming of +0.21 ± 0.03 °C and +0.12 ± 0.03 °C
- In subdomain B, these transitions are associated with an average cooling of −0.14 ± 0.05 °C and −0.10 ± 0.05 °C

- This is mostly due to the local conditions discussed above, such as the interplay between surface albedo changes, evapotranspiration efficiencies and soil moisture

Decomposition of the temperature changes to individual land cover changes



Comparison of climate change with land cover transition in observation data

Land Cover Transition	Europe		Subdomain A		Subdomain B	
	Our study	Ref.	Our study	Ref.	Our study	Ref.
ENF <=> OSL	0.19±0.04	0.20±0.08			0.22±0.12	0.18±0.12
ENF <=> GRA	0.23±0.12	0.11±0.06	0.16±0.12	0.24±0.06		
ENF <=> WET	0.02±0.04	-0.40±0.04			-0.05±0.06	-0.39±0.04
ENF <=> CRO	0.12±0.04	0.20±0.04	0.21±0.06	0.80±0.06	-0.14±0.10	-0.03±0.10
DBF <=> GRA	0.22±0.08	-0.16±0.14	0.18±0.10	-0.08±0.12	0.27±0.26	-0.29±0.10
DBF <=> WET					-0.12±0.08	-0.52±0.10
DBF <=> CRO	0.07±0.04	0.34±0.04	0.12±0.06	0.68±0.04	-0.10±0.10	-0.03±0.04
OSL <=> GRA	-0.11±0.12	0.10±0.14				
OSL <=> WET	-0.25±0.08	-0.18±0.10			-0.24±0.14	-0.17±0.10
OSL <=> CRO	-0.14±0.08	-0.27±0.06	-0.13±0.10	-0.12±0.14		
GRA <=> CRO	-0.04±0.06	0.43±0.04	0.04±0.08	0.67±0.04		

Mean ± 2stddev

Summary

- Around **70 Mha of land cover changes** occurred in Europe from 1992 to 2015
- An **average temperature cooling of -0.12±0.20 °C**, with seasonal and spatial variations
- At a continental level, the mean cooling is mainly driven by **agriculture abandonment** (cropland-to-forest transitions)
- A novel Bayesian regression approach decomposed the temperature change to the individual land transitions, showing **opposite responses to cropland losses and gains** between western and eastern Europe

This study combines regional climate model and statistic model to decompose climate change caused by a single land cover transition in Europe.

Huang, B., X. Hu, G.-A. Fuglstad, X. Zhou, W. Zhao, and F. Cherubini, 2020: Predominant regional biophysical cooling from recent land cover changes in Europe. *Nat Commun*, **11,** 1066.

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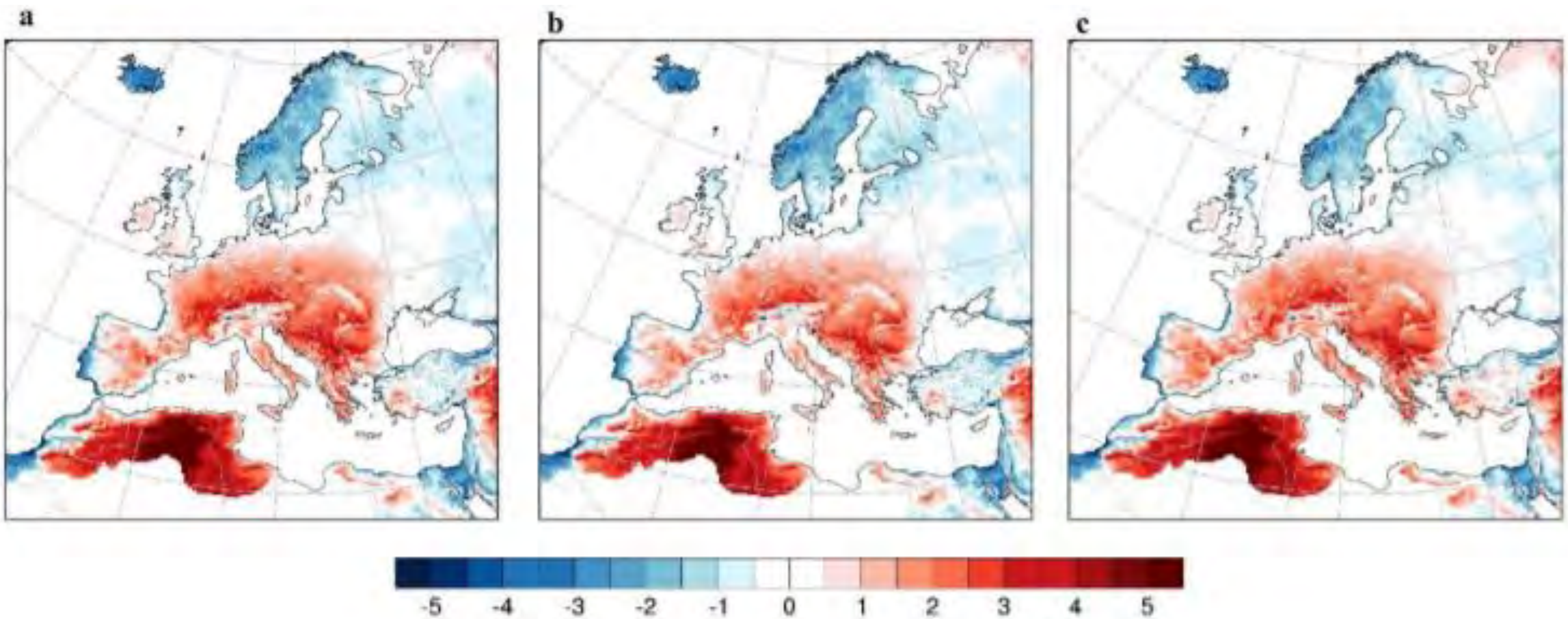
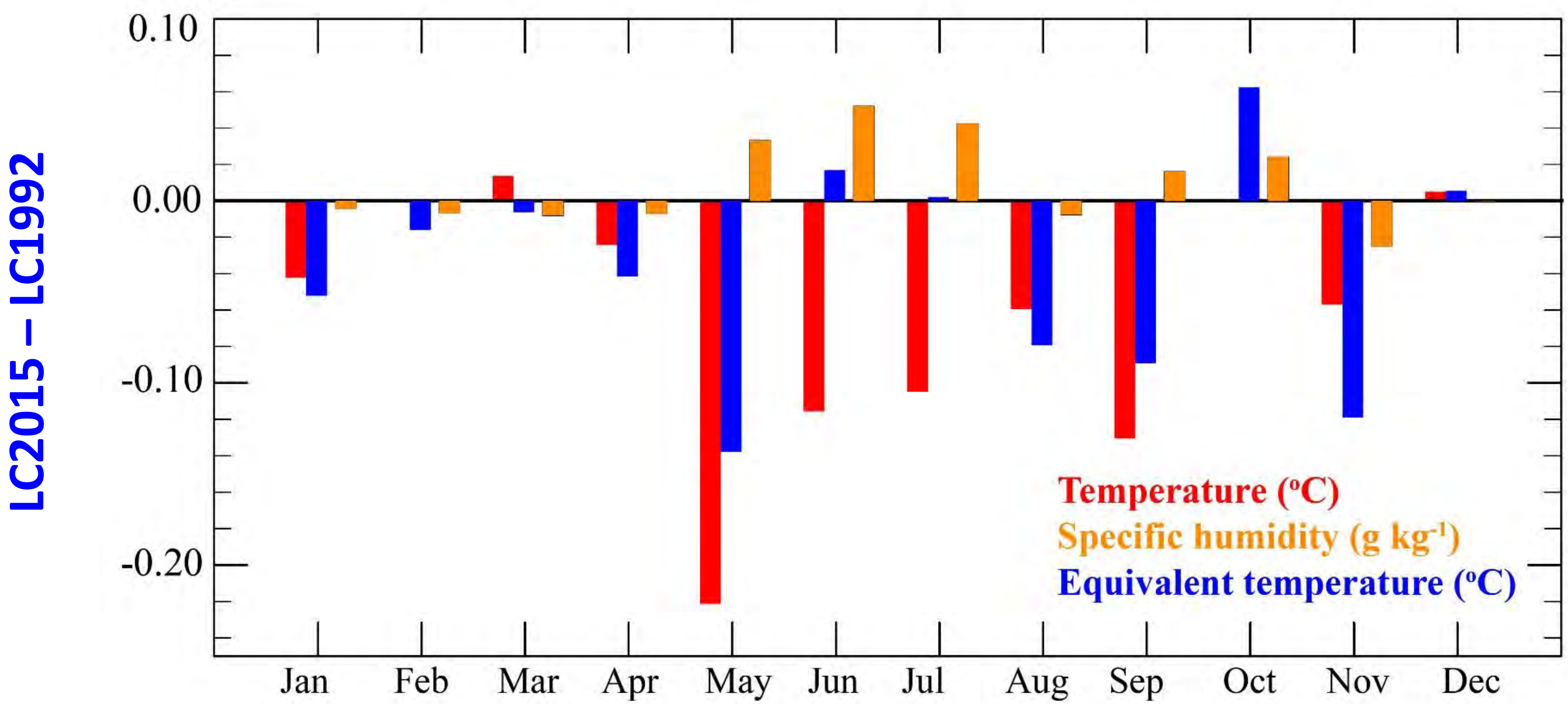
Thank You

WRF3.9-CLM4 performance



Simulation	PCC	Bias (°C)	RMSE (°C)
a) LC1992 - EOBS	0.98	0.35	1.87
b) LC2015 - EOBS	0.98	0.24	1.77
c) IGBP - EOBS	0.98	0.47	1.89

Monthly climate change



- *T* and T_E generally exhibit similar seasonal patterns, but T_E values are larger
- During winter and early spring, humidity is low and differences between the two variables are small
- As humidity increases from late spring to early fall, differences become larger

Supplementary Table 3 Cross-walking table provided by the ESA-CCI to convert the UNLCCS classes to the standard IPCC classes[2]. This cross-walking table is only used for simplification and visualization purposes of the land cover changes shown in Figure 1 of the main paper.

	CCI-LC		IPCC classification									
	code	description	Agriculture	Forest	Grassland	Wetland	Settlement	Shrubland	Lichens and mosses	Sparse vegetation	Bare area	Water
1	0	no_data										
2	10	cropland_rainfed	X	-	-	-	-	-	-	-	-	-
3	11	cropland_rainfed_herbaceous_cover	X	-	-	-	-	-	-	-	-	-
4	12	cropland_rainfed_tree_or_shrub_cover	X	-	-	-	-	-	-	-	-	-
5	20	cropland_irrigated	X	-	-	-	-	-	-	-	-	-
6	30	mosaic_cropland	X	-	-	-	-	-	-	-	-	-
7	40	mosaic_natural_vegetation	X	-	-	-	-	-	-	-	-	-
8	50	tree_broadleaved_evergreen_closed_to_open	-	X	-	-	-	-	-	-	-	-
9	60	tree_broadleaved_deciduous_closed_to_open	-	X	-	-	-	-	-	-	-	-
10	61	tree_broadleaved_deciduous_closed	-	X	-	-	-	-	-	-	-	-
11	62	tree_broadleaved_deciduous_open	-	X	-	-	-	-	-	-	-	-
12	70	tree_needleleaved_evergreen_closed_to_open	-	X	-	-	-	-	-	-	-	-
13	71	tree_needleleaved_evergreen_closed	-	X	-	-	-	-	-	-	-	-
14	72	tree_needleleaved_evergreen_open	-	X	-	-	-	-	-	-	-	-
15	80	tree_needleleaved_deciduous_closed_to_open	-	X	-	-	-	-	-	-	-	-
16	81	tree_needleleaved_deciduous_closed	-	X	-	-	-	-	-	-	-	-
17	82	tree_needleleaved_deciduous_open	-	X	-	-	-	-	-	-	-	-
18	90	tree_mixed	-	X	-	-	-	-	-	-	-	-
19	100	mosaic_tree_and_shrub	-	X	-	-	-	-	-	-	-	-
20	110	mosaic_herbaceous	-	-	X	-	-	-	-	-	-	-
21	120	shrubland	-	-	-	-	-	X	-	-	-	-
22	121	shrubland_evergreen	-	-	-	-	-	X	-	-	-	-
23	122	shrubland_deciduous	-	-	-	-	-	X	-	-	-	-
24	130	grassland	-	-	X	-	-	-	-	-	-	-
25	140	lichens_and_mosses	-	-	-	-	-	-	X	-	-	-
26	150	sparse_vegetation	-	-	-	-	-	-	-	X	-	-
27	152	sparse_shrub	-	-	-	-	-	-	-	X	-	-
28	153	sparse_herbaceous	-	-	-	-	-	-	-	X	-	-
29	160	tree_cover_flooded_fresh_or_brakish_water	-	X	-	-	-	-	-	-	-	-
30	170	tree_cover_flooded_saline_water	-	X	-	-	-	-	-	-	-	-
31	180	shrub_or_herbaceous_cover_flooded	-	-	-	X	-	-	-	-	-	-
32	190	urban	-	-	-	-	X	-	-	-	-	-
33	200	bare_areas	-	-	-	-	-	-	-	-	X	-
34	201	bare_areas_consolidated	-	-	-	-	-	-	-	-	X	-
35	202	bare_areas_unconsolidated	-	-	-	-	-	-	-	-	X	-
36	210	water	-	-	-	-	-	-	-	-	-	X
37	220	snow_and_ice	-	-	-	-	-	-	-	-	-	-

https://static-content.springer.com/esm/art%3A10.1038%2Fs41467-020-14890-0/MediaObjects/41467_2020_14890_MOESM1_ESM.pdf

Supplementary Table 4 Cross-walking table used to convert the CCI land cover classes to the IGBP land cover classes used as input to WRF (adapted from other references[1,3,4]).

	CCI-LC	IGBP																				
		1 Evergreen Needleleaf forest	2 Evergreen Broadleaf forest	3 Deciduous Needleleaf forest	4 Deciduous Broadleaf forest	5 Mixed forest	6 Closed shrubland	7 Open shrublands	8 Woody savannas	9 Savannas	10 Grasslands	11 Permanent wetlands	12 Croplands	13 Urban and built-up	14 Cropland/Natural vegetation mosaic	15 Snow and ice	16 Barren or sparsely vegetated	17 Water	18 Wooded Tundra	19 Mixed Tundra	20 Barren Tundra	21 Lake
0	no_data																					
10	cropland_rainfed												X									
11	cropland_rainfed_herbaceous_cover												X									
12	cropland_rainfed_tree_or_shrub_cover												X									
20	cropland_irrigated												X									
30	mosaic_cropland														X							
40	mosaic_natural_vegetation														X							
50	tree_broadleaved_evergreen_closed_to_open		X																			
60	tree_broadleaved_deciduous_closed_to_open				X																	
61	tree_broadleaved_deciduous_closed				X																	
62	tree_broadleaved_deciduous_open				X																	
70	tree_needleleaved_evergreen_closed_to_open	X																				
71	tree_needleleaved_evergreen_closed	X																				
72	tree_needleleaved_evergreen_open	X																				
80	tree_needleleaved_deciduous_closed_to_open			X																		
81	tree_needleleaved_deciduous_closed			X																		
82	tree_needleleaved_deciduous_open			X																		
90	tree_mixed					X																
100	mosaic_tree_and_shrub							X														
110	mosaic_herbaceous							X														
120	shrubland							X														
121	shrubland_evergreen						X															
122	shrubland_deciduous						X															
130	grassland										X											
140	lichens_and_mosses																X					
150	sparse_vegetation																X					
152	sparse_shrub																X					
153	sparse_herbaceous																X					
160	tree_cover_flooded_fresh_or_brakish_water											X										
170	tree_cover_flooded_saline_water											X										
180	shrub_or_herbaceous_cover_flooded											X										
190	urban													X								
200	bare_areas																X					
201	bare_areas_consolidated																X					
202	bare_areas_unconsolidated																X					
210	water																	X				
220	snow_and_ice															X						

https://static-content.springer.com/esm/art%3A10.1038%2Fs41467-020-14890-0/MediaObjects/41467_2020_14890_MOESM1_ESM.pdf