THE LANCET
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Supplementary appendix

This appendix formed part of the original submission and has been peer reviewed. We post it as supplied by the authors.

Supplement to: Dasgupta S, van Maanen N, Gosling SN, Piontek F, Otto C, Schleussner C-F. Effects of climate change on combined labour productivity and supply: an empirical, multi-model study. *Lancet Planet Health* 2021; **5:** e455–65.

SUPPLEMENTARY INFORMATION

1 Method for assessing labour supply

1.1 Global impacts using WBGT

We also estimate a global exposure-response function on the impact of WBGT on labour supply. The results from Equation 1 suggest that labour supply is non-linear and concave in WBGT, with labour supply for outdoor in full sunlight being maximized at 15.8°C, while the optimal WBGT for indoor or outdoor in the shade is higher at 18.2°C (Figure 1). As expected, the optimal temperature maximizing labour supply is lower for outdoor in full sunlight (workers are more exposed to the elements) compared to indoor or outdoor in the shade.

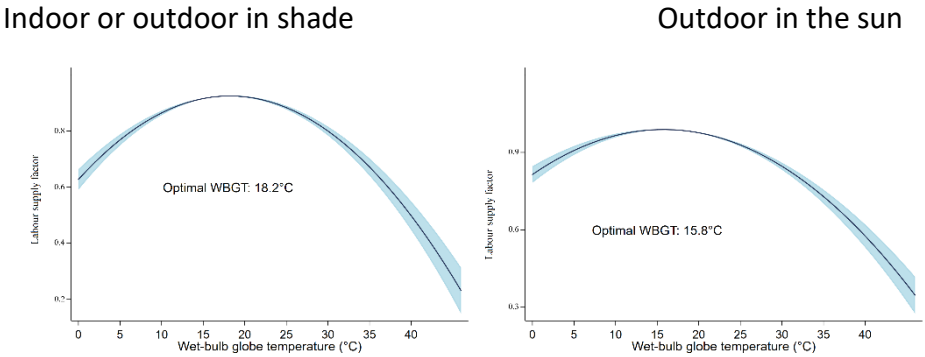
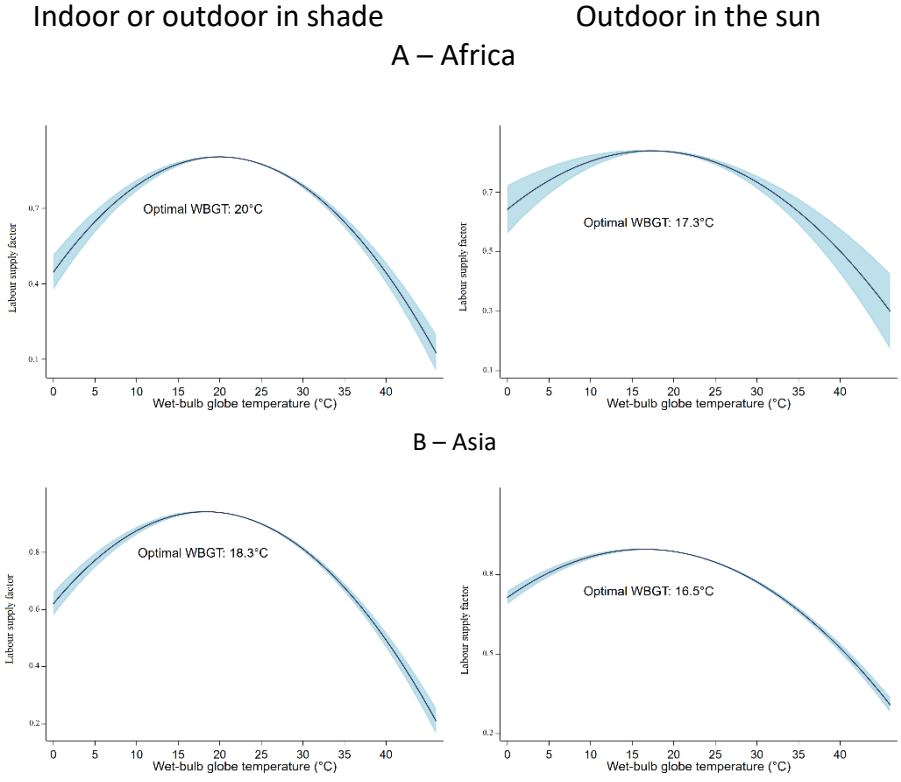


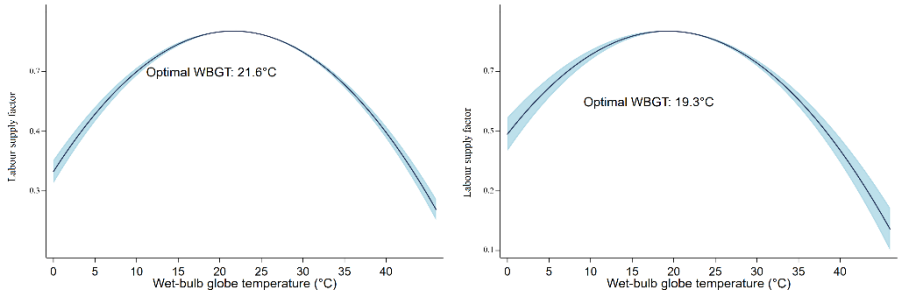
Figure 1: Non-linear relationship between WBGT and labour supply (dark navy line) with 95% confidence interval (blue shaded area) for outdoor in full sunlight (left-panel) and indoor or outdoor in the.

1.2 Regional impacts using WBGT

We find a ∩-shaped relationship between WBGT and indoor or outdoor in the shade labour supply (Figure 2), as well as for labour outdoor in full sunlight. Importantly, the relationship between WBGT and labour supply is heterogenous across the world's regions, with significant differences in optimal conditions that maximise labour supply; the optimal WBGT ranges from 13.1°C in Europe to 21.6°C in the Americas.



C – Americas



D – Europe

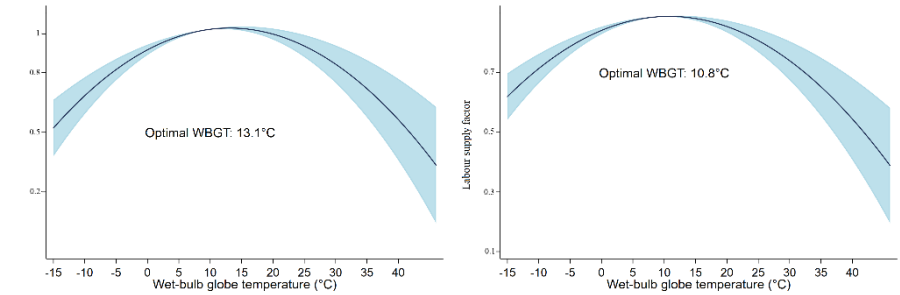


Figure 2: Non-linear relationship between WBGT and labour supply (dark navy line) with 95% confidence interval (light blue area). Specification controls for temperature, region and survey year fixed-effects. Standard-errors are clustered at the country-level.

1.3 Regression results

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Log of labour supply									
	High-exposure					Low-exposure				
	Global	Africa	Asia	Americas	Europe	Global	Africa	Asia	Americas	Europe
T	0.157***	0.079***	0.092***	0.060***	0.042***	0.079***	2.242**	0.054**	0.387***	0.028***
	(0.000)	(0.002)	(0.000)	(0.000)	(0.002)	(0.000)	(0.020)	(0.049)	(0.000)	(0.002)
T^2	-0.005***	-0.002***	-0.002***	-0.001***	-0.002***	-0.002***	-0.044**	-0.001**	-0.008***	-0.001***
	(0.011)	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)	(0.017)	(0.035)	(0.001)	(0.006)
Observations	365,245	137,412	126,751	115,245	2,125	302,147	115,875	126,751	99,511	2,125
	p-values in parentheses									
	*** p<0.01, ** p<0.05, * p<0.10, + p<0.15									

Table 1: Regression results using mean temperature.
T: mean temperature; T^2: mean temperature-squared

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Log of labour supply									
	Low-exposure working conditions					High-exposure working conditions				
	Global	Africa	Asia	Americas	Europe	Global	Africa	Asia	Americas	Europe
WBGT	3.689***	2.274***	3.685***	3.586***	0.087**	3.271***	3.059***	3.504***	4.360***	0.056**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.020)	(0.000)	(0.000)	(0.000)	(0.000)	(0.018)
$WBGT^2$	-0.117***	-0.066***	-0.112***	-0.093***	0.004**	-0.090***	-0.077***	-0.096***	-0101***	0.002*
	(0.000)	(0.000)	(0.000)	(0.000)	(0.048)	(0.000)	(0.000)	(0.000)	(0.000)	(0.055)
Observations	365,245	137,412	126,751	115,245	2,125	354,054	120,877	119,631	115,245	1,870
	p-values in parentheses									
	*** p<0.01, ** p<0.05, * p<0.10, + p<0.15									

Table 2: Regression results using WBGT.
WBGT: Wet-bulb globe temperature; T^2: Wet-bulb globe temperature-squared

1.4 Robustness tests for labour supply functions

To validate the choice of our quadradic specification, we utilize a binned temperature regression and another set of regressions using population-weighted annual mean temperature. These results support those obtained in section 2 of the main paper.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Low-exposure working conditions					High-exposure working conditions				
	Global	Africa	Asia	Americas	Europe	Global	Africa	Asia	Americas	Europe
<5°C	0.114**	0.152***	0.105***	0.094***	0.115**	0.161**	0.167***	0.105***	0.083***	0.084**
	(0.048)	(0.007)	(0.000)	(0.000)	(0.044)	(0.030)	(0.001)	(0.000)	(0.002)	(0.041)
5°C to 10°C	0.204***	0.119**	0.138***	0.147***	0.128**	0.119***	0.129**	0.138***	0.159***	0.111**
	(0.012)	(0.028)	(0.005)	(0.009)	(0.032)	(0.005)	(0.037)	(0.005)	(0.001)	(0.029)
10°C to 15°C	0.216**	0.227***	0.177***	0.213***		0.207***	0.301***	0.177***	0.274***	
	(0.032)	(0.000)	(0.000)	(0.001)		(0.003)	(0.008)	(0.000)	(0.008)	
15°C to 20°C		0.324***	0.226***	0.355***	-0.074*		0.301***	0.226***	0.302***	-0.099*
		(0.010)	(0.000)	(0.002)	(0.041)		(0.000)	(0.000)	(0.004)	(0.033)
20°C to 25°C	-0.104***				-0.071	-0.085**				-0.088
	(0.005)				(0.215)	(0.029)				(0.222)
25°C to 30°C	-0.113***	-0.217***	-0.225***	-0.331***	-0.021	-0.097***	-0.296***	-0.225***	-0.302***	-0.144
	(0.000)	(0.000)	(0.004)	(0.006)	(0.117)	(0.002)	(0.000)	(0.004)	(0.000)	(0.174)
> 30°C	-0.125*	-0.328***	-0.458***	-0.541***	-0.001	-0.139	-0.411***	-0.458***	-0.407***	-0.002
	(0.063)	(0.001)	(0.009)	(0.002)	(0.269)	(0.159)	(0.002)	(0.009)	(0.001)	(0.211)
Observations	365,245	137,412	126,751	115,245	2,125	354,054	120,877	119,631	115,245	1,870

p-values in parentheses

*** p<0.01, ** p<0.05, * p<0.10, + p<0.15

Table 3: Non-linear relationship between temperature and labour supply for outdoor full sunlight (high-exposure) and indoor or outdoor in the shade (low-exposure) working conditions. Grey boxes indicate reference bins.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Log of labour supply									
	High-exposure					Low-exposure				
	Global	Africa	Asia	Americas	Europe	Global	Africa	Asia	Americas	Europe
T	0.120***	0.136***	0.084***	0.361***	0.171***	0.175***	1.655***	0.275***	0.448***	0.131**
	(0.000)	(0.009)	(0.006)	(0.000)	(0.004)	(0.002)	(0.002)	(0.004)	(0.000)	(0.034)
T^2	-0.004***	-0.003***	-0.002***	-0.008***	-0.008***	-0.005***	-0.031**	-0.006***	-0.009***	-0.005*
	(0.007)	(0.000)	(0.004)	(0.007)	(0.000)	(0.006)	(0.017)	(0.003)	(0.003)	(0.041)
Observations	365,245	137,412	126,751	115,245	2,125	302,147	115,875	126,751	99,511	2,125

p-values in parentheses

*** p<0.01, ** p<0.05, * p<0.10, + p<0.15

Table 4: Non-linear relationship between population-weighted temperature and labour supply for outdoor full sunlight (high-exposure) and indoor or outdoor in the shade (low-exposure) working conditions.

	(1)	(2)	(3)	(4)
	Log of labour supply			
	High-exposure		Low-exposure	
T	0.0014***		0.0013***	
	(0.009)		(0.002)	
T^2	-0.00005**		-0.00004**	
	(0.014)		(0.019)	
WBGT		0.0014***		0.0014***
		(0.007)		(0.009)
$WBGT^2$		-0.00006***		-0.00005**
		(0.003)		(0.011)
Observations	76,091	75,830	76,091	75,830

p-values in parentheses

*** p<0.01, ** p<0.05, * p<0.10, + p<0.15

Table 5: Non-linear relationship between temperature/WBGT and labour supply for outdoor full sunlight (high-exposure) and indoor or outdoor in the shade (low-exposure) working conditions in the USA.

2 Impacts outdoor full sunlight

In the main paper, we only discussed the impacts of climate change on labour productivity, labour supply, and effective labour considering working conditions indoor or outdoor in the shade. The reason for this decision has been addressed in chapter 2.2 (exposure response functions for labour productivity). However, for completeness, we analysed future impacts of climate change on the work being done outdoor and in full sunlight.

2.1 Present day maps for outdoor full sunlight: labour productivity, labour supply and effective labour

As can be seen from figure 3, the effect of present-day climate (1986-2005) on the labour productivity factor (A), labour supply factor (B) and labour effectiveness factor (C) are already extremely high. Especially for labour supply, South-East Asia and the Middle East already reach 0, which is not in line with assessments from previous scientific literature. As 1986-2005 serve as the baseline period, future reductions will look minimal due to the fact that a saturation point has already been reached in the baseline period.

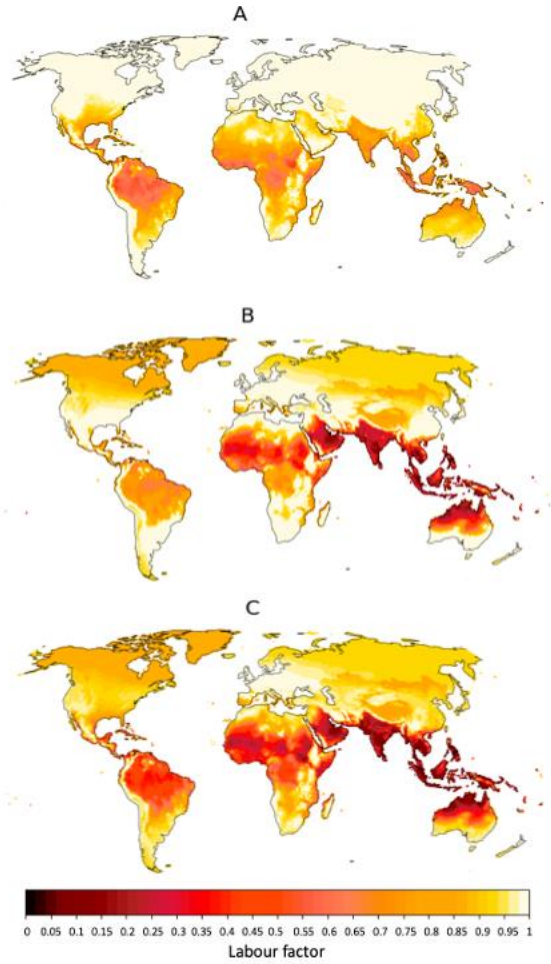


Figure 3: Effect of present day (1986-2005) climate on (A) the labour productivity factor (B) the labour supply factor and (C) the labour effectiveness factor (as a combination of A and B).

2.2 Projection maps for outdoor full sunlight: labour productivity, labour supply and effective labour

Figure 4 shows the relative reductions in labour productivity (A), labour supply (B) and effective labour (C) for working conditions outdoor in full sunlight at 1.5, 2 and 3°C of global warming. The displayed reductions are relative to the absolute reductions in Figure 3. The highest impacts are recorded at 3°C, with a large regional heterogeneity. Labour supply is calculated using mean annual temperature estimates.

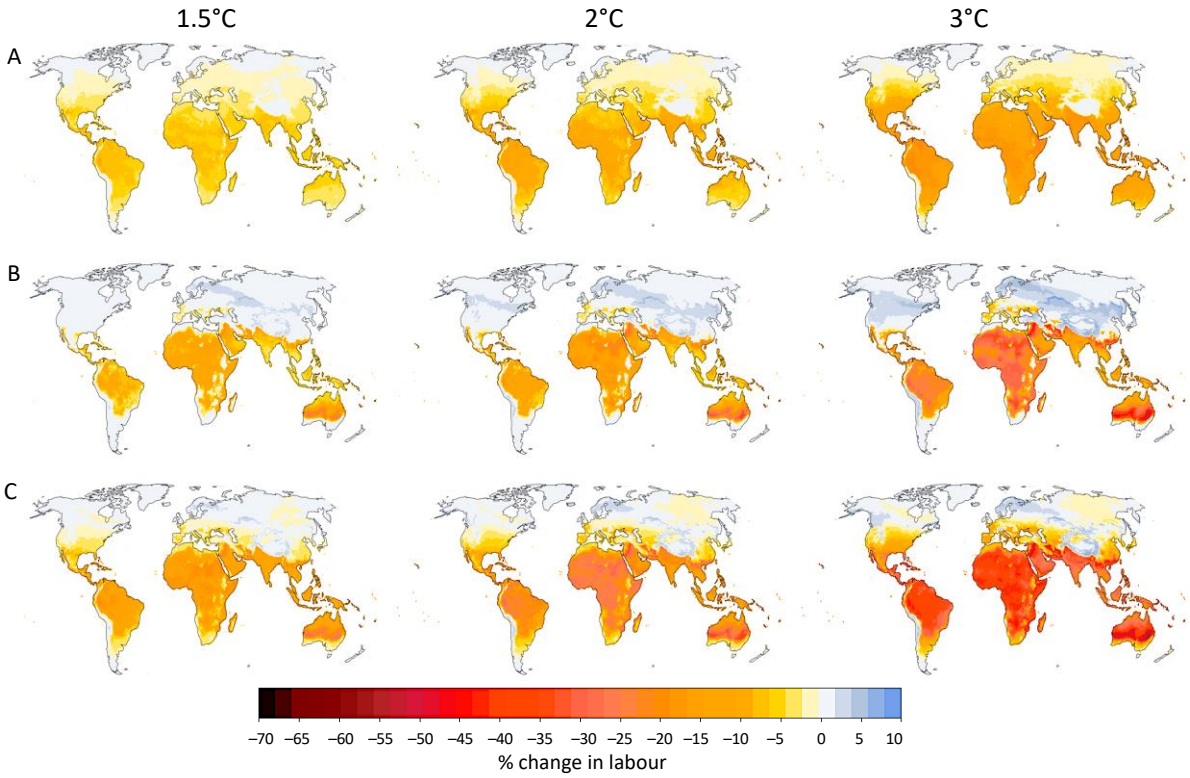


Figure 4: Relative impacts of climate change on labour productivity (A), labour supply (B) and effective labour (C) for outdoor working conditions outdoor in full sunlight for global warming levels 1.5, 2 and 3°C compared to the baseline period (1986-2005).

2.3 Boxplots changes in global and regional effective labour (outdoor full sunlight)

The boxplots from Figure 5 show the population-weighted impacts on effective labour both globally and regionally at 1.5, 2 and 3°C of global warming. The SSP2 end of century population scenario was used to assess the regional impacts. The boxplot shows that Africa will be the most impacted region, whereas for Europe the impacts will be comparably small.

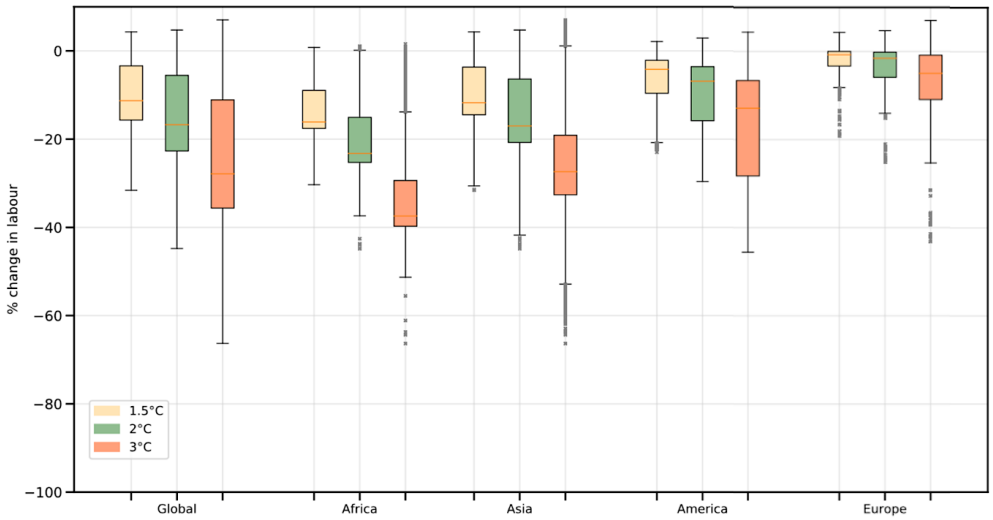


Figure 5: Population weighted (SSP2) changes (%) in global and regional (Africa, Asia, America, Europe) effective labour under 1.5, 2 and 3°C of global warming compared to the baseline period (1986-2005) for outdoor in full sunlight. The boxes show the quartiles and the horizontal line in the box shows the median, the whiskers are the most extreme non-outlier data points, and the fliers are the points representing data that extend beyond the whiskers.

3 Tables

Table 6 displays the numbers used in the main paper to assess the global and regional impacts of climate change on labour productivity, labour supply and effective labour for working conditions indoor or outdoor in the shade. Even though one decimal digit is provided in the table, we suggest these results are too specific and would thus suggest rounding up/off the number value for further use. Table 7 provides the same numbers for working conditions outdoor in full sunlight.

3.1 Indoor or outdoor in the shade

Labour Productivity	°C of global warming	Mean	Median	Min	Max
Global					
	1.5°C	-4.1	-4.7	-9.8	0.0
	2°C	-7.8	-8.8	-16.3	0.0
	3°C	-11.5	-13.8	-27.5	0.2
Africa					
	1.5°C	-5.0	-5.4	-9.5	0.0
	2°C	-9.2	-9.6	-16.3	0.0
	3°C	-13.8	-14.9	-17.5	0.0
Asia					
	1.5°C	-4.4	-5.2	-8.6	0.0
	2°C	-8.2	-9.0	-12.9	0.0
	3°C	-12.3	-14.7	-20.1	0.0
America					
	1.5°C	-3.1	-2.8	-9.8	0.0
	2°C	-6.5	-6.8	-14.7	0.0
	3°C	-9.0	-8.8	-24.5	0.2
Europe					
	1.5°C	-0.5	-0.4	-6.8	0.1
	2°C	-1.9	-1.6	-10.2	0.0
	3°C	-1.7	-1.1	-17.3	0.0
Labour Supply *	**°C of global warming**	**Mean**	**Median**	**Min**	**Max**
Global					
	1.5°C	-2.7	-1.3	-17.2	3.4
	2°C	-4.3	-2.6	-23.5	4.3
	3°C	-8.2	-7.1	-36.2	6.4
Africa					
	1.5°C	-5.2	-1.9	-17.2	1.7
	2°C	-8.0	-6.3	-23.5	1.7
	3°C	-14.5	-16.8	-36.2	2.7
Asia					
	1.5°C	-2.4	-3.2	-7.6	3.4
	2°C	-3.8	-5.0	-10.4	4.3
	3°C	-7.5	-9.9	-21.0	6.4
America					
	1.5°C	-0.5	0.1	-7.4	1.3
	2°C	-0.7	0.2	-9.8	1.8
	3°C	-1.7	0.3	-16.8	2.6
Europe					
	1.5°C	0.4	0.3	-7.4	3.4
	2°C	0.5	0.4	-9.8	4.3
	3°C	0.7	0.6	-13.6	6.3
Effective labour *	**°C of global warming**	**Mean**	**Median**	**Min**	**Max**
Global					
	1.5°C	-6.7	-6.4	-23.1	3.1
	2°C	-10.3	-10.6	-32.6	3.6
	3°C	-18.3	-20.3	-48.8	5.3
Africa					
	1.5°C	-9.9	-8.8	-23.1	1.2
	2°C	-14.9	-14.4	-32.6	1.7
	3°C	-25.9	-30.0	-48.8	2.7
Asia					
	1.5°C	-6.7	-8.5	-14.7	3.1
	2°C	-10.4	-13.1	-21.2	3.6
	3°C	-18.6	-23.5	-33.6	5.3
America					
	1.5°C	-3.5	-2.7	-14.9	1.3
	2°C	-5.6	-4.5	-20.6	1.8

	3°C	-10.4	-8.4	-35.0	2.6
Europe					
	1.5°C	-0.1	0.0	-13.6	3.1
	2°C	-0.3	0.0	-18.2	3.6
	3°C	-1.0	-0.2	-28.5	5.3

Table 6: Relative global and regional impacts of climate change (1.5, 2 and 3°C of global warming) on labour productivity, labour supply and effective labour for working conditions indoor or outdoor in the shade. The results are population weighted by SSP2.

* Using mean temperature (for labour supply calculations)

3.2 Outdoor in full sunlight

Labour Productivity	°C of global warming	Mean	Median	Min	Max
Global					
	1.5°C	-5.1	-5.7	-9.9	0.0
	2°C	-7.8	-8.8	-16.3	0.0
	3°C	-13.6	-15.3	-27.0	0.0
Africa					
	1.5°C	-6.2	-6.4	-9.7	0.0
	2°C	-9.2	-9.6	-16.3	0.0
	3°C	-16.0	-16.8	-27.0	0.0
Asia					
	1.5°C	-5.3	-6.0	-9.1	0.0
	2°C	-8.2	-9.0	-12.9	0.0
	3°C	-14.2	-15.4	-21.8	0.0
America					
	1.5°C	-4.2	-4.1	-9.9	0.0
	2°C	-6.5	-6.8	-14.7	0.0
	3°C	-11.6	-12.1	-24.5	0.0
Europe					
	1.5°C	-1.2	-1.1	-6.9	0.0
	2°C	-1.9	-1.6	-10.2	0.0
	3°C	-3.4	-2.9	-17.4	0.0
Labour Supply *	**°C of global warming**	**Mean**	**Median**	**Min**	**Max**
Global					
	1.5°C	-5.3	-4.9	-28.8	5.0
	2°C	-7.9	-7.4	-40.7	6.3
	3°C	-13.4	-13.0	-62.0	9.3
Africa					
	1.5°C	-7.8	-10.2	-27.4	0.8
	2°C	-11.7	-15.0	-40.7	1.1
	3°C	-20.1	-26.1	-62.0	1.9
Asia					
	1.5°C	-5.4	-5.2	-28.8	5.1
	2°C	-8.0	-7.5	-40.7	6.3
	3°C	-13.0	-12.4	-62.0	9.3
America					
	1.5°C	-1.9	0.1	-15.1	2.1
	2°C	-3.0	0.2	-19.4	2.9
	3°C	-6.1	0.3	-31.7	4.4
Europe					
	1.5°C	-0.4	0.1	-13.4	5.1
	2°C	-1.0	0.0	-16.7	6.3
	3°C	-2.5	-2.0	-31.3	9.3
Effective labour *	**°C of global warming**	**Mean**	**Median**	**Min**	**Max**
Global					
	1.5°C	-10.1	-11.3	-31.6	4.3
	2°C	-14.9	-16.2	-44.8	4.7
	3°C	-24.8	-27.8	-45.5	7.0
Africa					
	1.5°C	-13.5	-16.1	-30.3	0.8
	2°C	-19.8	-23.2	-44.8	1.1
	3°C	-32.8	-37.4	-66.3	1.6
Asia					
	1.5°C	-10.4	-11.7	-31.6	4.3
	2°C	-15.4	-17.0	-44.8	4.7
	3°C	-25.1	-27.4	-66.3	7.0
America					
	1.5°C	-5.9	-4.1	-23.0	2.1

	2°C	-9.3	-6.9	-29.6	2.9
	3°C	-16.7	-12.9	-45.5	4.4
Europe					
	1.5°C	-1.6	-0.8	-19.2	4.3
	2°C	-2.8	-1.5	-25.1	4.7
	3°C	-5.8	-5.0	-43.1	7.0

Table 7: Relative global and regional impacts of climate change (1.5, 2 and 3°C of global warming) on labour productivity, labour supply and effective labour for working conditions outdoor in full sunlight. The results are population weighted by SSP2.

* Using mean temperature (for labour supply calculations)

4 Impacts on labour supply using WBGT

In the following paragraph we provide estimates of change on labour supply using the WBGT estimates that were introduced in sections 5.1.3 and 5.1.4. As estimates of effective labour depend on both the results of labour productivity and labour supply analyses, the assessment of labour supply using WBGT instead of mean temperature will consequently impact effective labour estimates. Therefore, we repeated the previous analyses using labour supply estimates that were quantified with the WBGT method for both outdoor in full sunlight and indoor or outdoor in the shade. We provide estimates of the effects of current-day climate (1986-2005) on the labour factor (Figures 6 and 7), as well as the absolute impacts under 1.5, 2 and 3°C of global warming (Figure 8 and 9) and population-weighted boxplots (using SSP2). Compared to estimates using mean annual temperature for labour supply, we here see the sensitivity of the WBGT method, which leads to more extreme results already for present day conditions. Reaching the saturation point in multiple regions in the baseline period leads to minor reductions in the projected results.

4.1 Present day maps: labour productivity, labour supply and effective labour (using WBGT)

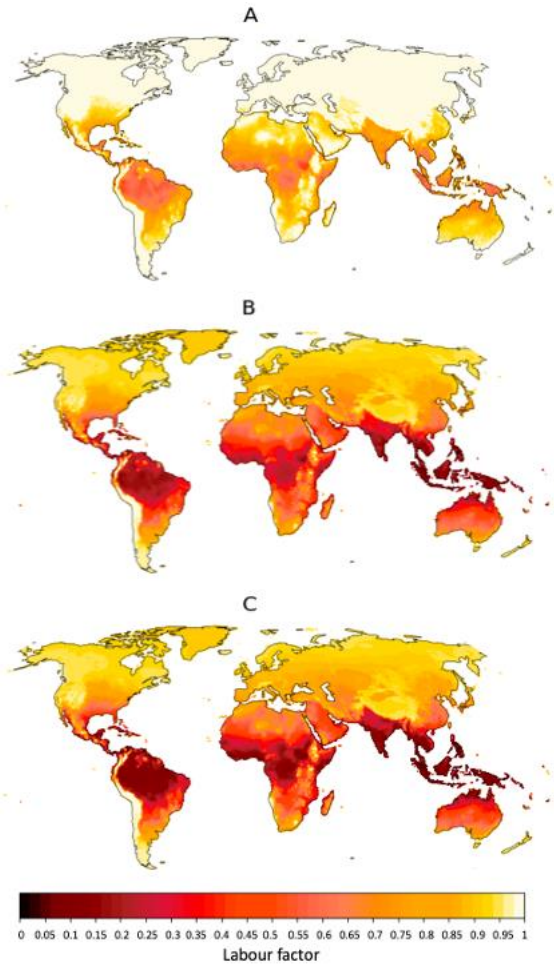


Figure 6: Effect of present day (1986-2005) climate on (A) the labour productivity factor (B) the labour supply factor (using WBGT instead of mean annual temperature) and (C) the labour effectiveness factor (as a combination of A and B) for indoor or outdoor in the shade.

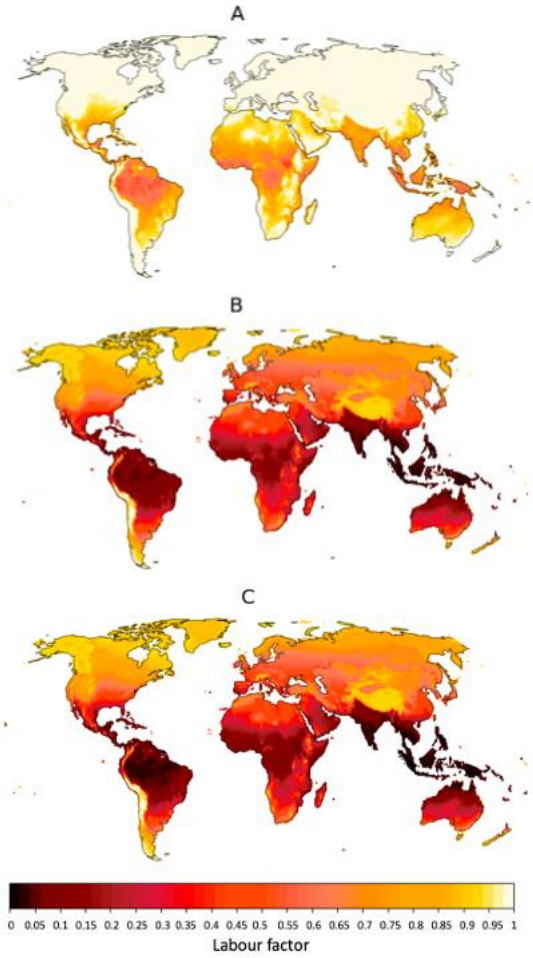


Figure 7: Effect of present day (1986-2005) climate on (A) the labour productivity factor (B) the labour supply factor (using WBGT instead of mean annual temperature) and (C) the labour effectiveness factor (as a combination of A and B) for outdoor in full sunlight.

4.2 Projection maps: labour productivity, labour supply and effective labour

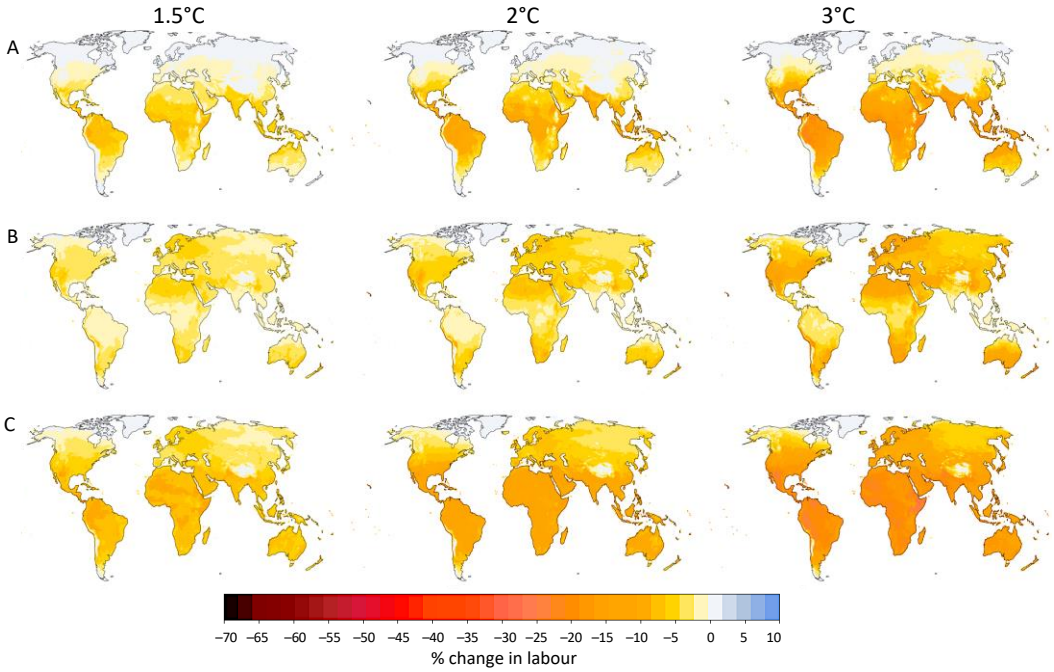


Figure 8: Relative impacts of climate change on labour productivity (A), labour supply using WBGT (B) and effective labour (C) for outdoor working conditions indoor or outdoor in the shade for global warming levels 1.5, 2 and 3°C compared to baseline period (1986-2005).

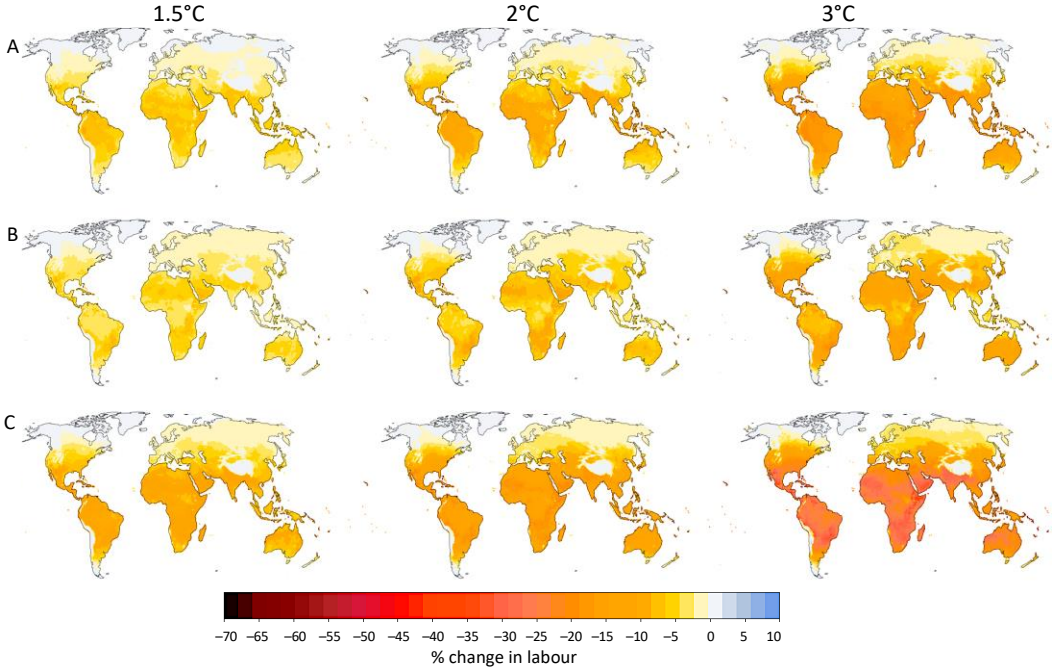


Figure 9: Relative impacts of climate change on labour productivity (A), labour supply using WBGT (B) and effective labour (C) for outdoor working conditions outdoor in full sunlight for global warming levels 1.5, 2 and 3°C compared to baseline period (1986-2005).

4.3 Boxplots changes in global and regional effective labour

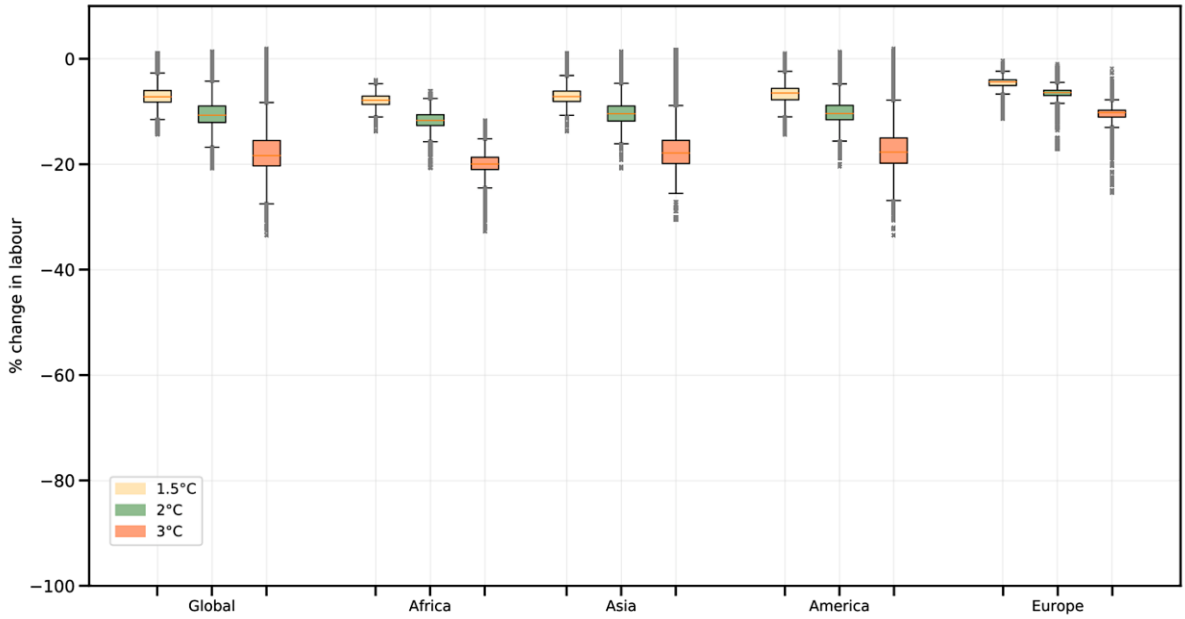


Figure 10: Population weighted (SSP2) changes (%) in global and regional (Africa, Asia, America, Europe) effective labour under 1.5, 2 and 3°C of global warming compared to the baseline period (1986-2005) for indoor or outdoor in the shade (using WBGT for labour supply calculations). The boxes show the quartiles and the horizontal line in the box shows the median, the whiskers are the most extreme non-outlier data points, and the fliers are the points representing data that extend beyond the whiskers.

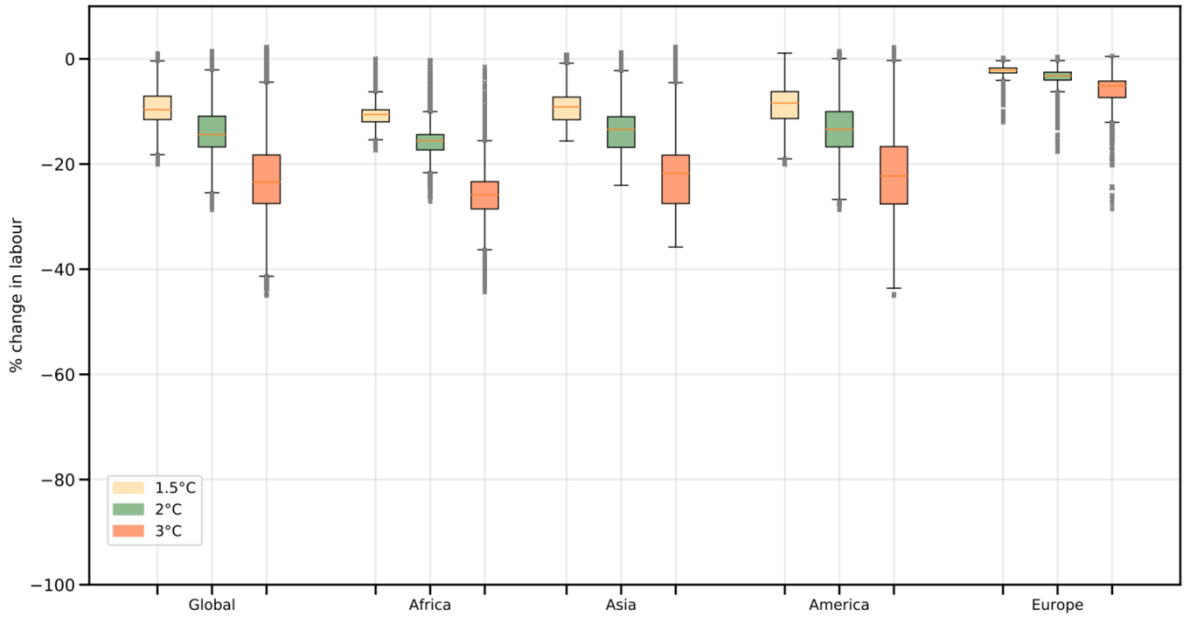


Figure 11: Population weighted (SSP2) changes (%) in global and regional (Africa, Asia, America, Europe) effective labour under 1.5, 2 and 3°C of global warming compared to the baseline period (1986-2005) for outdoor in full sunlight (using WBGT for labour supply calculations). The boxes show the quartiles and the horizontal line in the box shows the median, the whiskers are the most extreme non-outlier data points, and the fliers are the points representing data that extend beyond the whiskers.

5 Regions

The following regions were used to assess region-specific exposure response functions for labour supply and used to assess the region-specific impacts of labour productivity, labour supply and effective labour.

5.1 Africa

Figure 12: Regional area summarized as Africa

5.2 Asia

Figure 13: Regional area summarized as Asia (including Australia)

5.3 America

Figure 14: Regional area summarized as America (South America, North America and Greenland)

5.4 Europe

Figure 15: Regional area summarized as Europe (including Russia)

6 Impacts on labour productivity for impact models separately

The main paper extensively discusses the uncertainty arising from existing impact models. We use five impact models following a study by Gosling et al. (2018) out of which we derive an augmented mean response function to assess the relationship between WBGT and labour productivity. We have assessed the separate current and future impacts of the five underlying impact models separately. In the following we have analysed the effect of present-day climate (1986-2005) on the labour productivity, labour supply and labour effectiveness factors, the absolute effects at 1.5, 2 and 3°C and the relative effects at 1.5, 2 and 3°C compared to the baseline period. We have quantified the impacts for both indoor or outdoor in the shade and outdoor in full sunlight.

The five impact models are 1) a meta-analysis of ergonomics studies (Pilcher et al, 2002); 2) the National Institute for Occupational Safety and Health (NIOSH) standards where light, moderate and heavy labour are combined into a single metric (Dunne et al, 2013); 3) an ISO standard for heavy intensity work (Kjellstrom et al, 2014); empirical evidence of how high heat exposure affects agricultural tasks (Sahu et al, 2013); and 5) empirical evidence of declines in re-bar working (heavy labour) with increasing temperatures (Li et al, 2016).

As can be seen from all figures, there are extreme differences between the expected impacts of WBGT on labour productivity. Whereas Impact 2 already reaches saturation in many areas across the globe, the is only a minimal effect in both Impact 1 and Impact 5. Due to the extreme impacts at present day conditions (baseline), the projected impacts for 1.5, 2 and 3°C of global warming are minimal (or even positive). This analysis encourages our effort to build an augmented mean response function, which can be found in the main paper.

6.1 Present day climate effects on labour productivity factor

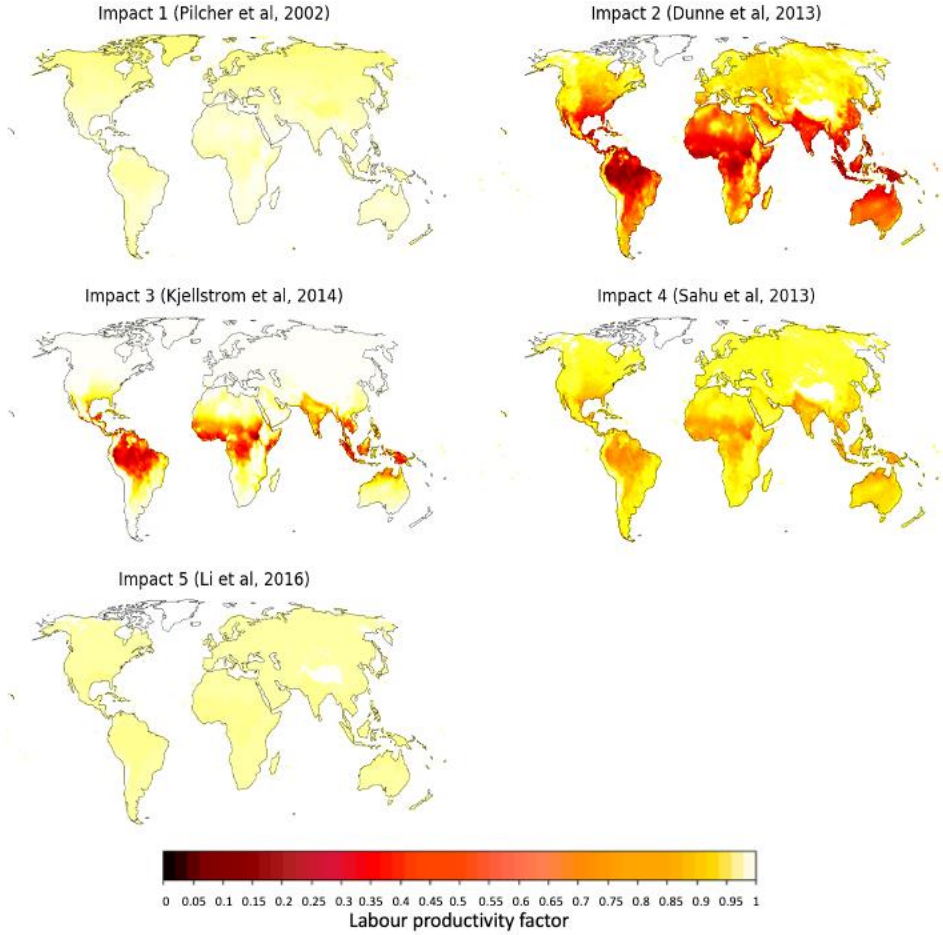


Figure 16: Effect of present-day climate (1986-2005) on the labour productivity factor for indoor or outdoor in the shade

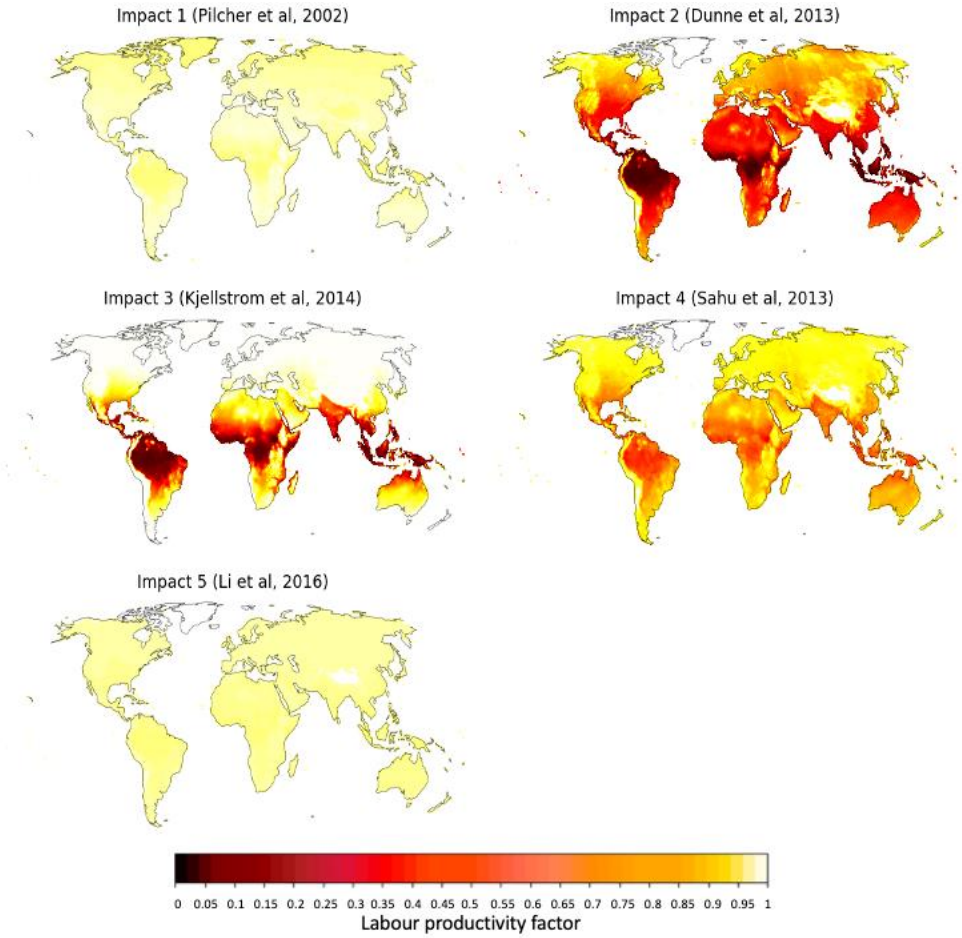


Figure 17: Effect of present-day climate (1986-2005) on the labour productivity factor for outdoor in full sunlight

6.2 Absolute effects at 1.5°C

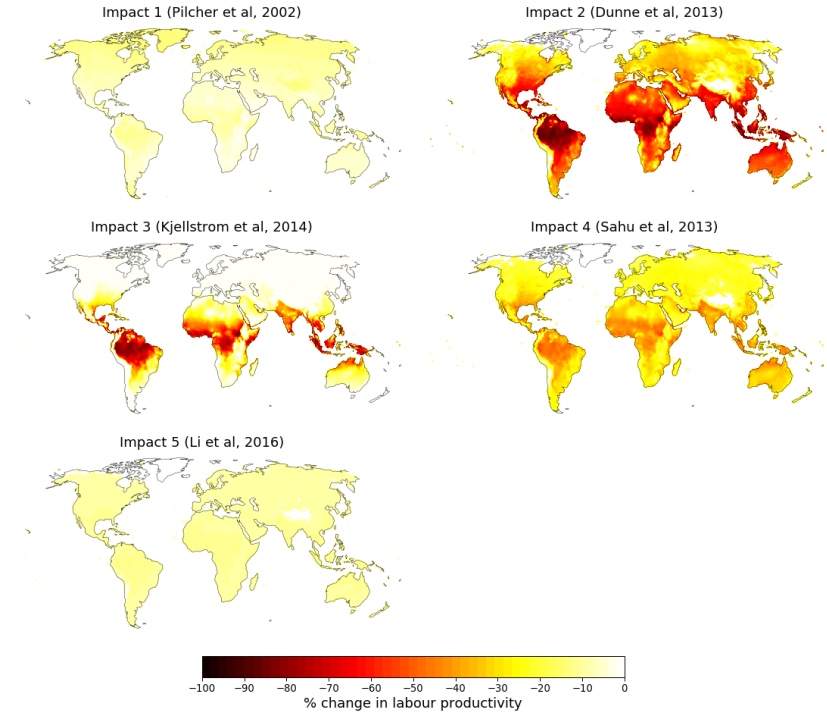


Figure 18: Absolute effects at 1.5°C (indoor or outdoor in the shade)

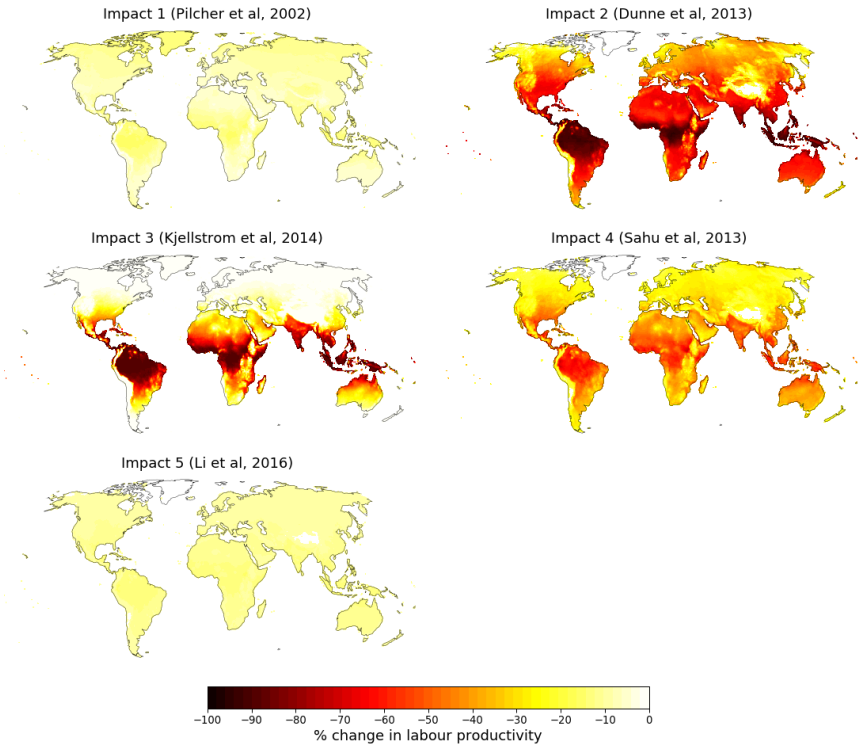


Figure 19: Absolute effects at 1.5°C (outdoor full sunlight)

6.3 Absolute effects at 2°C

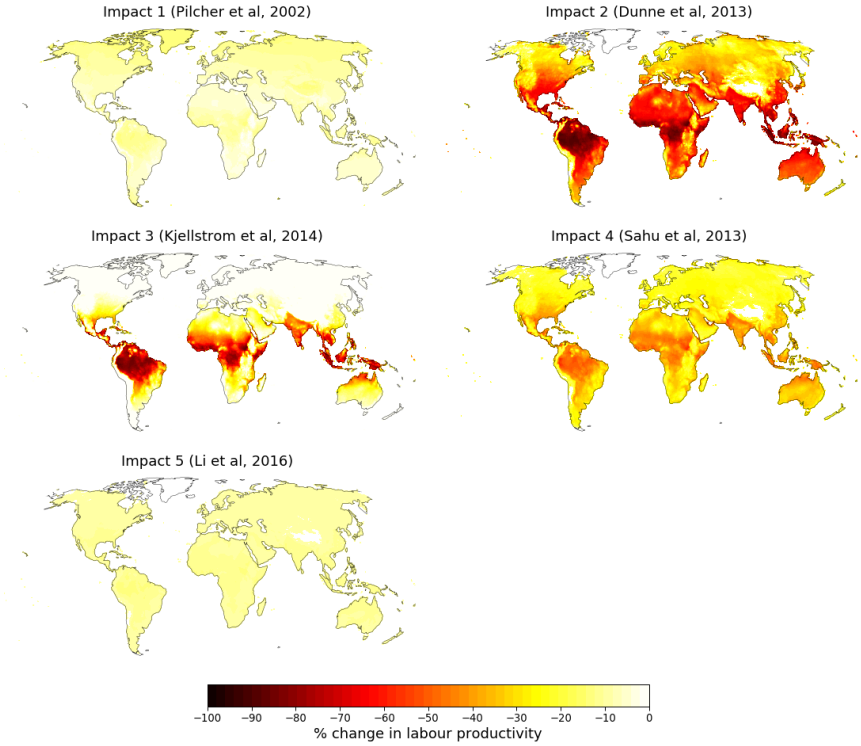


Figure 20: Absolute effects at 2°C (indoor or outdoor in shade)

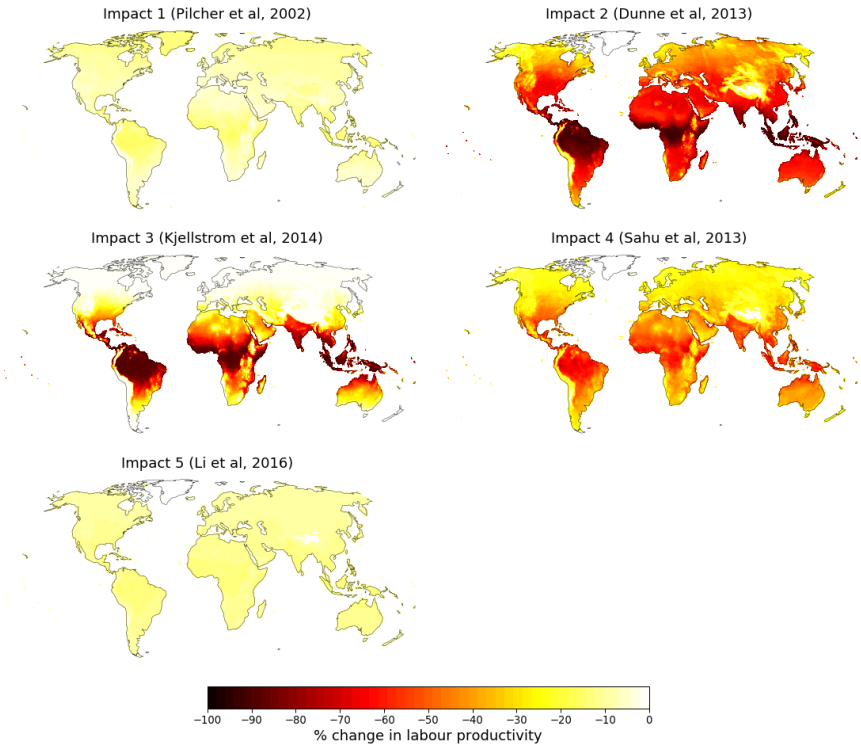


Figure 21: Absolute effect at 2°C (outdoor full sunlight)

6.4 Absolute effects at 3°C

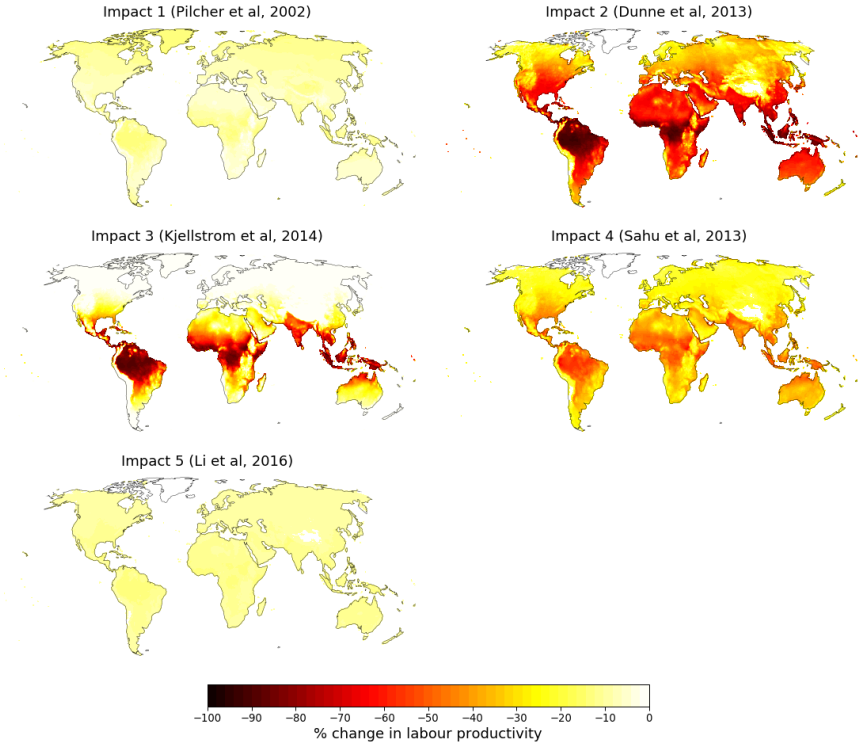


Figure 22: Absolute effects 3°C (indoor or outdoor in shade)

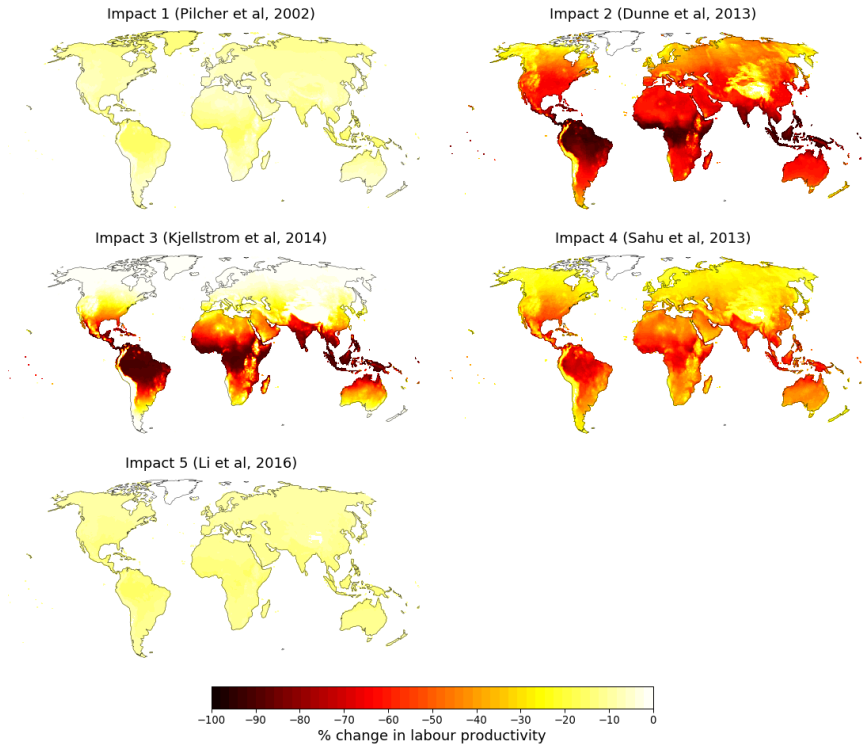


Figure 23: Absolute effects 3°C (outdoor full sunlight)

6.5 Relative effects at 1.5°C

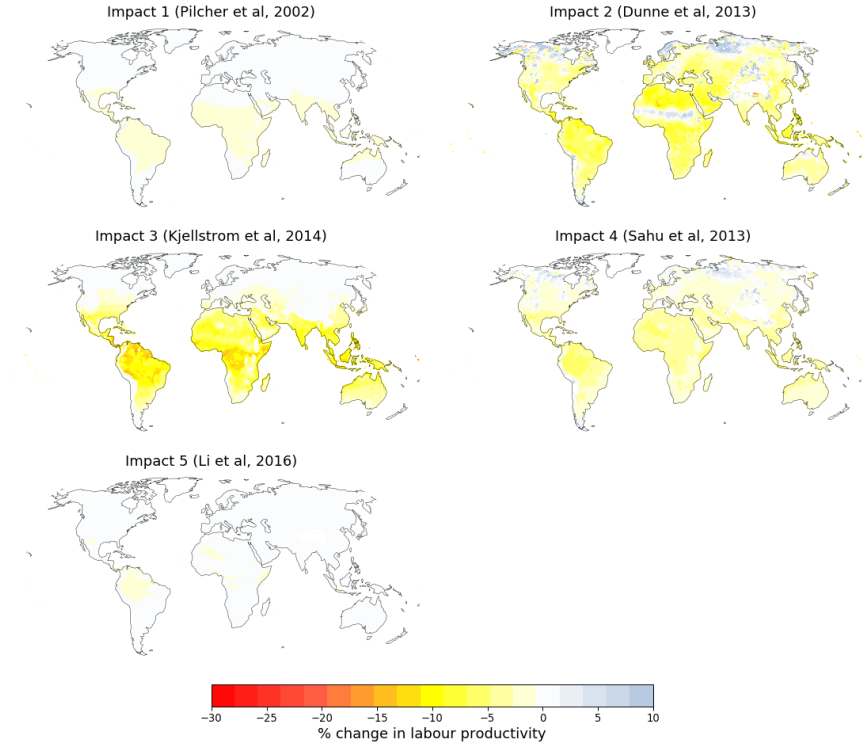


Figure 24: Relative effects at 1.5°C (indoor or outdoor in shade)

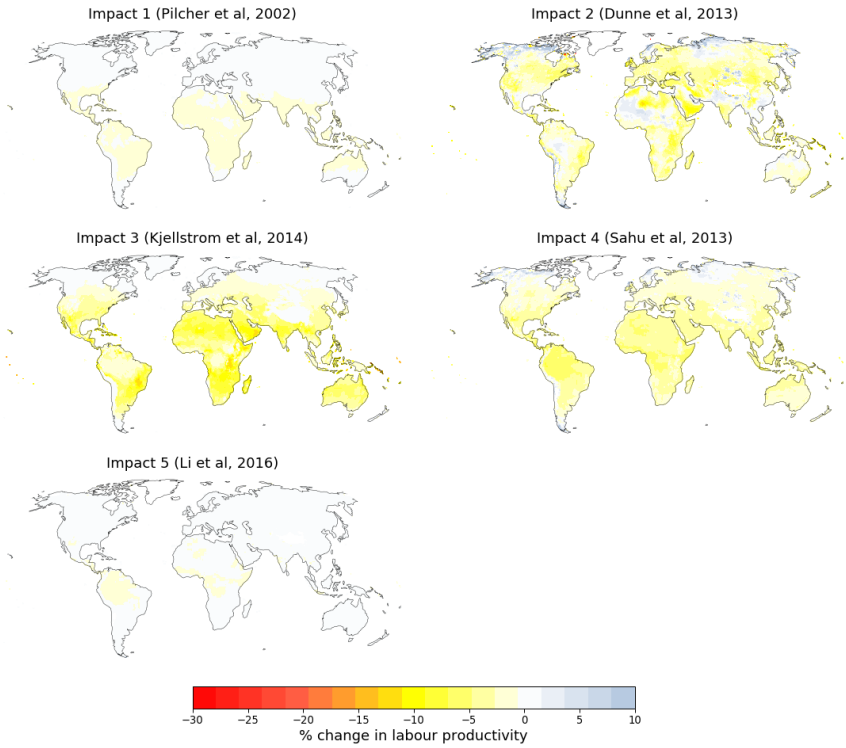


Figure 25: Relative effects at 1.5°C (outdoor full sunlight)

6.6 Relative effects at 2°C

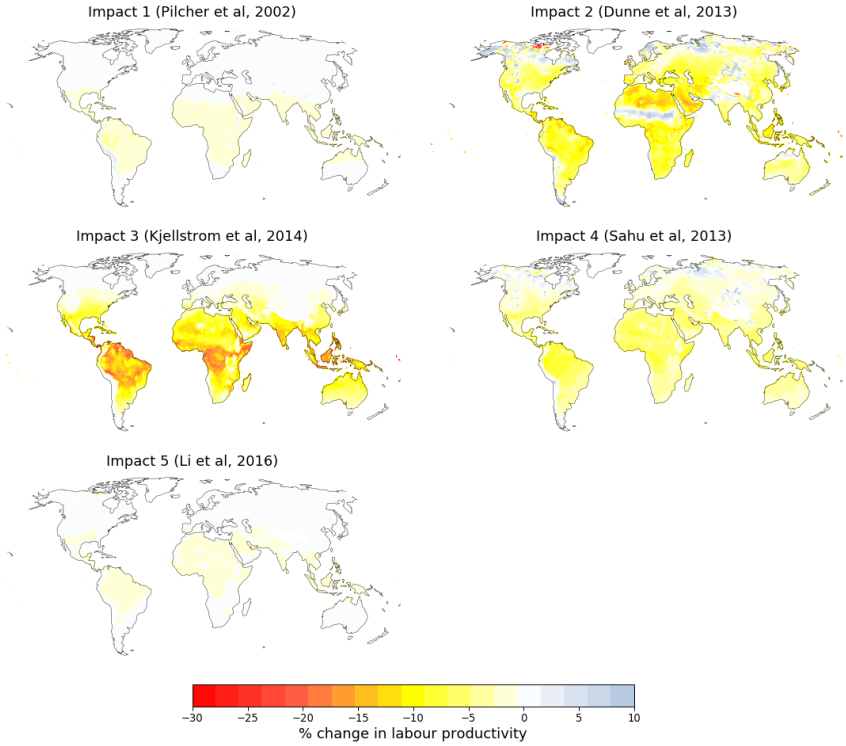


Figure 26: Relative effects at 2°C (indoor or outdoor in shade)

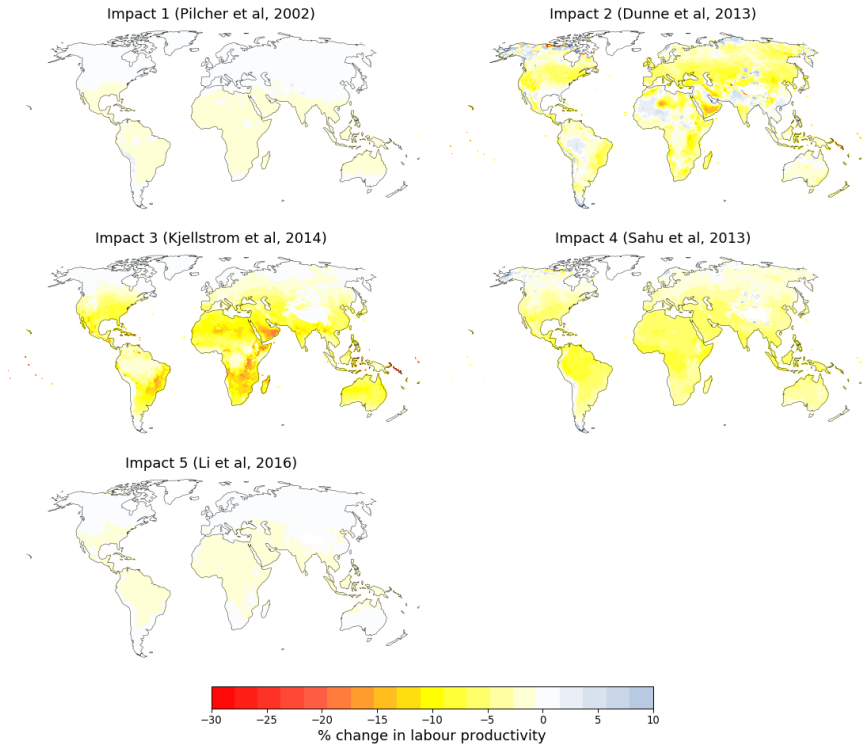


Figure 27: Relative effects at 2°C (outdoor full sunlight)

6.7 Relative effects at 3°C

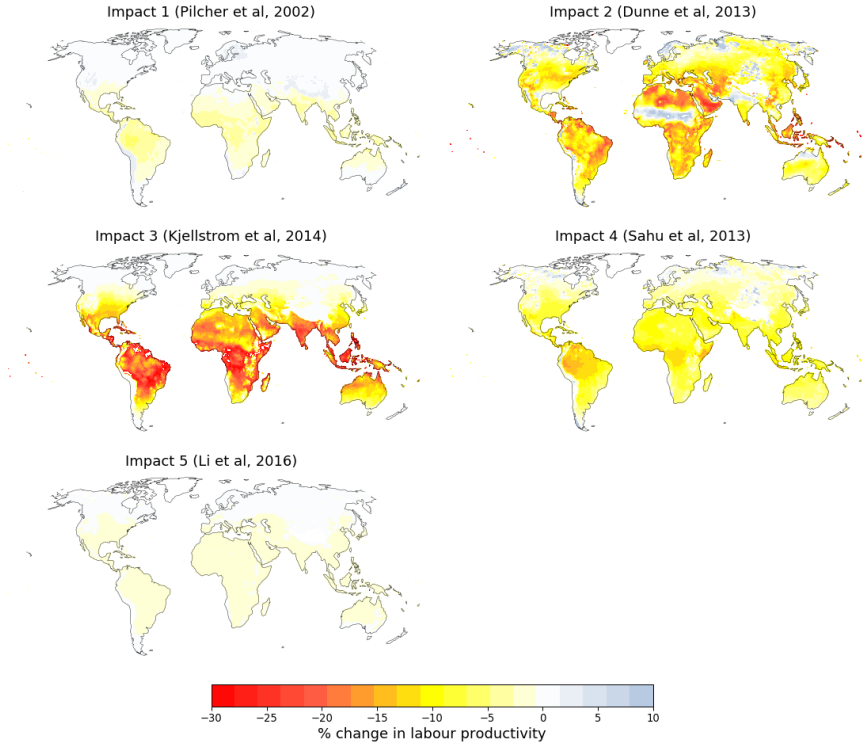


Figure 28: Relative effects 3°C (indoor or outdoor in shade)

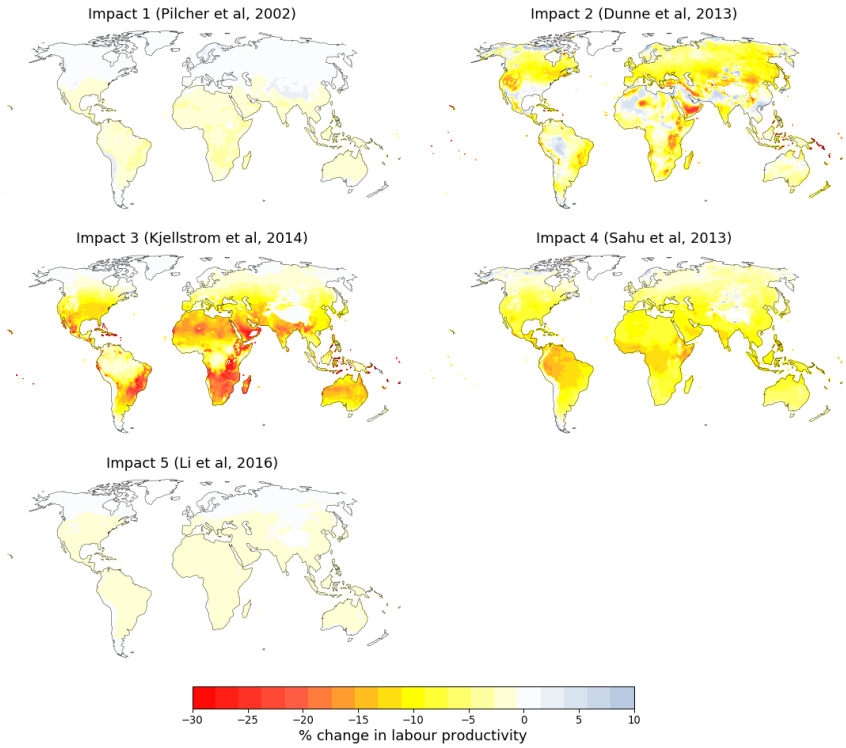


Figure 29: Relative effects 3°C (outdoor full sunlight)

7 Uncertainty decomposition and robustness tests

In a complex global analysis such as the underlying effort, it is essential to decompose the multiple sources of uncertainty that could influence our results (Figure 6). The first source of uncertainty comes from the global climate models (GCMs). We used two GCMs IPSL-CM5A-LR and GFDL-ESM2M, Figure 6A shows the mean percentage change in labour productivity (Mean LP) at 3°C warming, consisting of the average out of the two GCMs, which can be seen on the right-hand side, but separately. The uncertainty from the GCMs is comparatively small. Secondly, the uncertainty from the five different impact models used to derive the augmented mean exposure response function are shown in Figure 6B. There is a large distinction between the projected impacts of climate change on labour productivity for the five impact models compared to the augmented mean response. Particularly in comparison to Figure 6A, the uncertainty associated with the impact models is much higher than that from the climate models. Figure 6C assesses the uncertainty of the labour supply estimates, comparing the mean global labour supply impacts at 3°C of global warming compared to the reference period with the higher and lower standard deviations. Similarly, there seems to be a smaller discrepancy within the assessment of labour supply, It is clear that the main uncertainty in the estimate of effective labour comes from the impact models assessing the relationship between WBGT and labour productivity, underlining the need for more research in this area and highlighting the importance of choice when selecting the labour productivity model to employ in a climate change impact assessment.

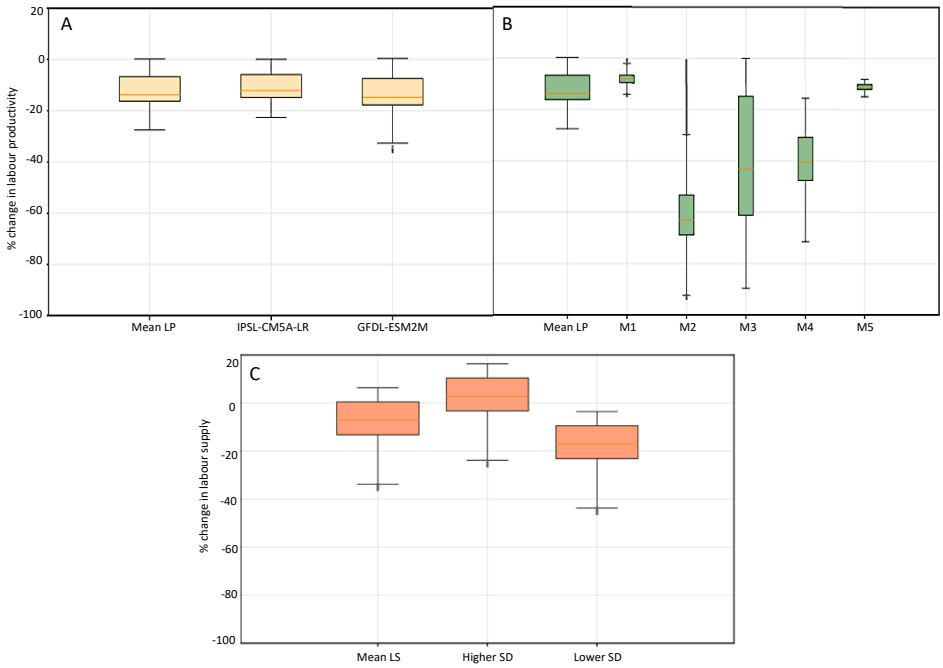


Figure 30: Uncertainty at 3°C compared to the reference period (1986-2005). (A) Mean labour productivity (mean LP) as a mean over the two GCMs and for the two GCMs (IPSL-CM5A-LR and GFDL-ESM2M) separately. (B) Mean labour productivity (mean LP) and for the five impact models M1 (Pilcher et al, 2002), M2 (Dunne et al, 2013), M3 (Kjellstrom et al, 2014), M4 (Sahu et al, 2013) and M5 (Li et al, 2016). (C) Mean labour supply (Mean LS) and the higher and lower standard deviations (SD) for labour supply. The Boxplots are population-weighted with the SSP2 population scenario. The boxes show the quartiles and the horizontal line in the box shows the median, the whiskers are the most extreme non-outlier data points, and the fliers are the points representing data that extend beyond the whiskers.

8 Uncertainty associated with WBGT

An additional source of uncertainty comes from the WBGT metric, which we use to quantify the impacts on labour productivity and is "a common method to assess the environmental contribution to heat stress as part of an occupational exposure assessment" (Bernard and Barrow, 2013). Historically, WBGT is measured using instruments such as thermometers, however, for a global analysis that seeks to assess future time trends, WBGT needs to be quantified using climate model data. The main uncertainty when quantifying $WBGT_{shade}$ comes from the differences in the measurement of temperature and relative humidity (Lemke and Kjellstrom, 2012). Relative humidity, however, is likely to be more uncertain than temperature projections (Lemke and Kjellstrom, 2012) and in our analysis we do only consider daily average values of relative humidity.