

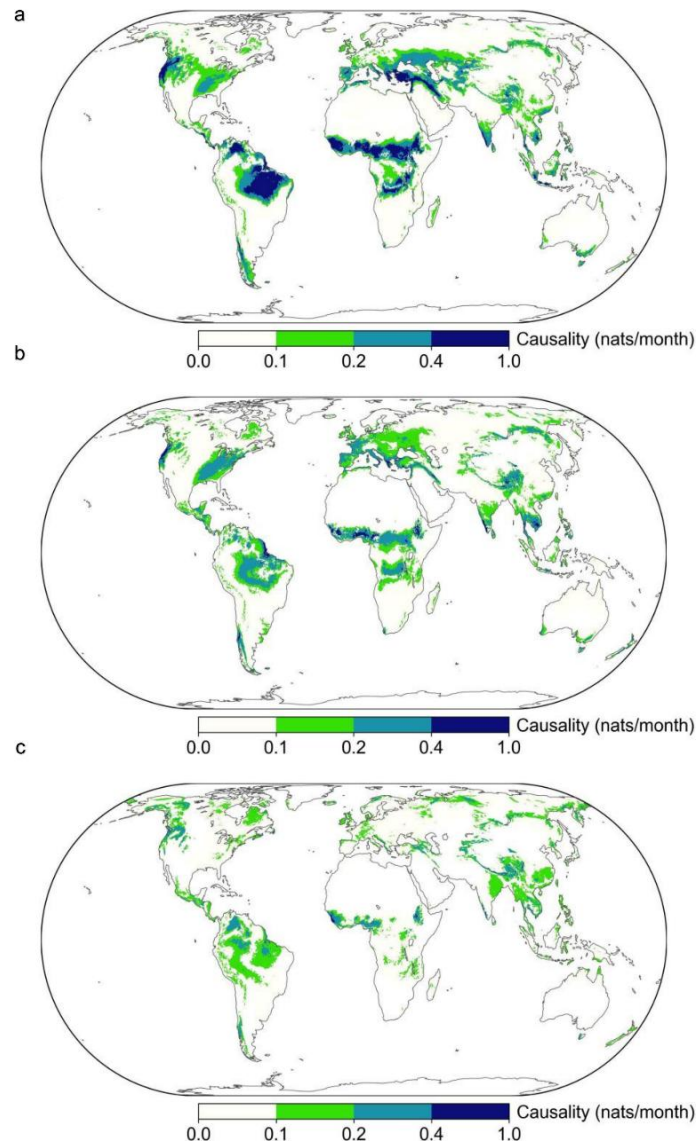
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Supplementary Information

Global patterns of directed soil moisture influence on air temperature

Fig. S1-S11

Table S1



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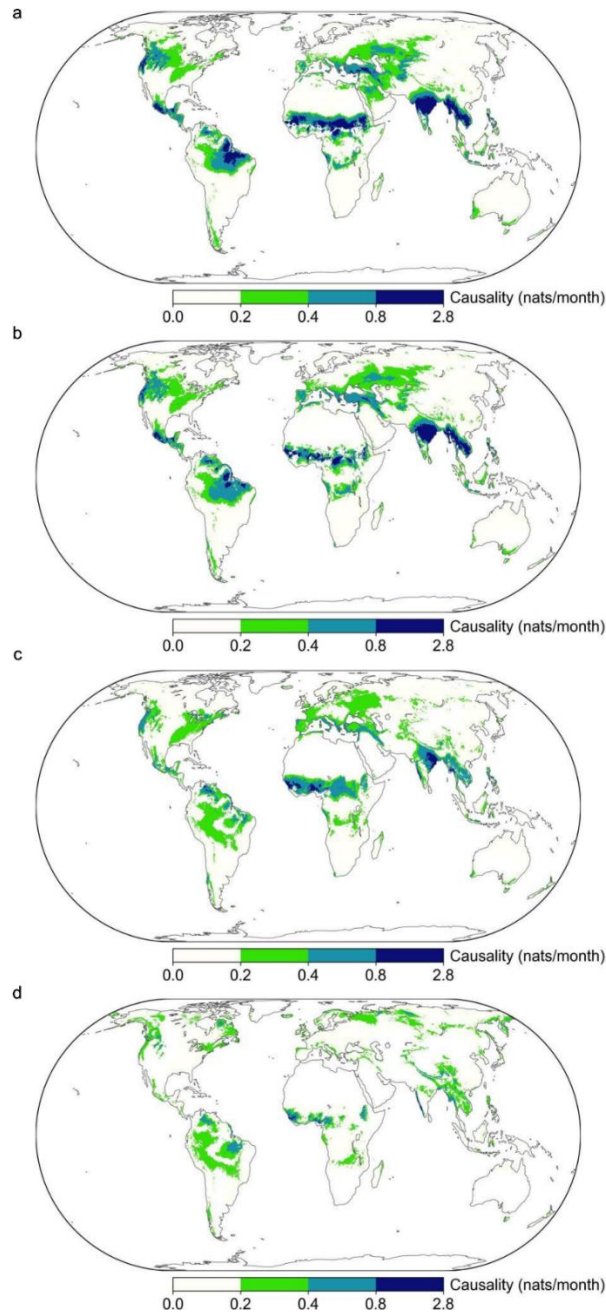
10 **Fig. S1 | Causal effects of soil moisture in different layers on air temperature.**

11 (a) Global distribution of the causal effects of Layer 2 soil moisture (7–28 cm) on air temperature

12 during 1984–2014 based on ERA5-Land. Causal effects are quantified by information flow, and

13 only statistically significant regions are shown.

14 (b,c) Same as in (a), but for Layer 3 (28–100 cm) and Layer 4 (100–289 cm), respectively.

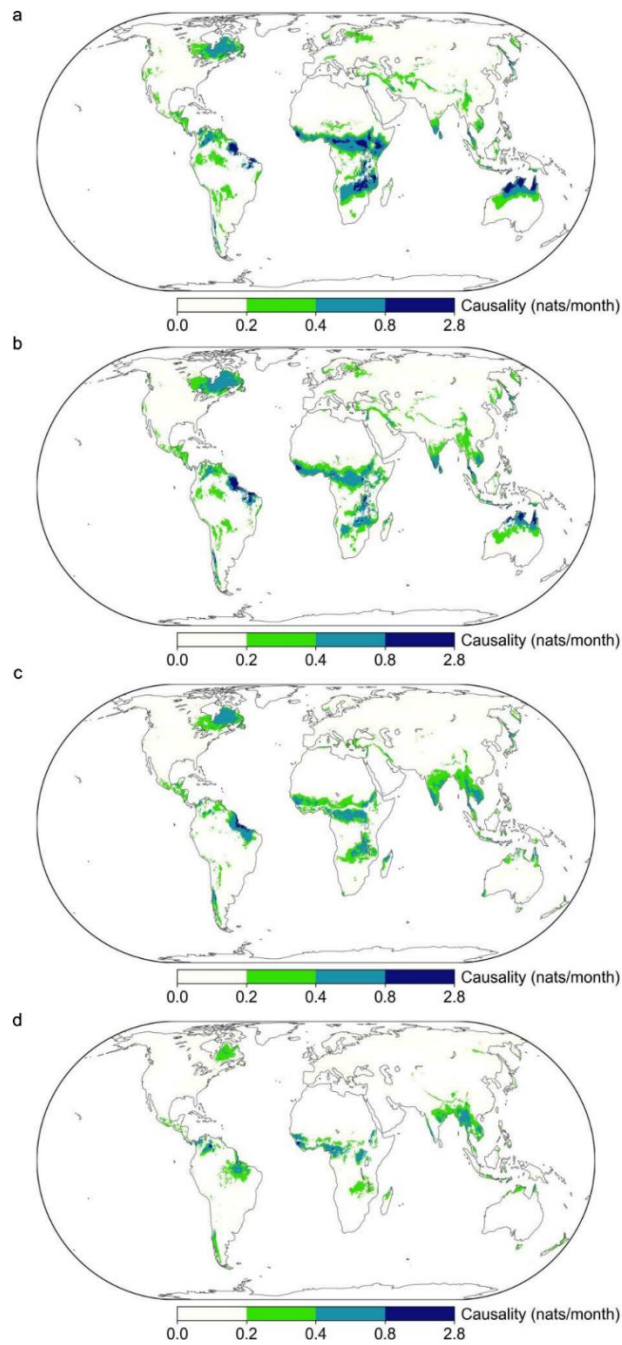


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16 **Fig. S2 | Causal effects of soil moisture at different depths during the boreal warm season.**

17 (a) Global distribution of the boreal warm-season causal effects of surface soil moisture (0–7 cm)
 18 on air temperature during 1984–2014 based on ERA5-Land. Causal effects are quantified by
 19 information flow, and only statistically significant regions are shown.

20 (b–d) Same as in (a), but for Layer 2 (7–28 cm), Layer 3 (28–100 cm), and Layer 4 (100–289 cm),
 21 respectively.



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23 **Fig. S3 | Causal effects of soil moisture at different depths during the boreal cold season.**

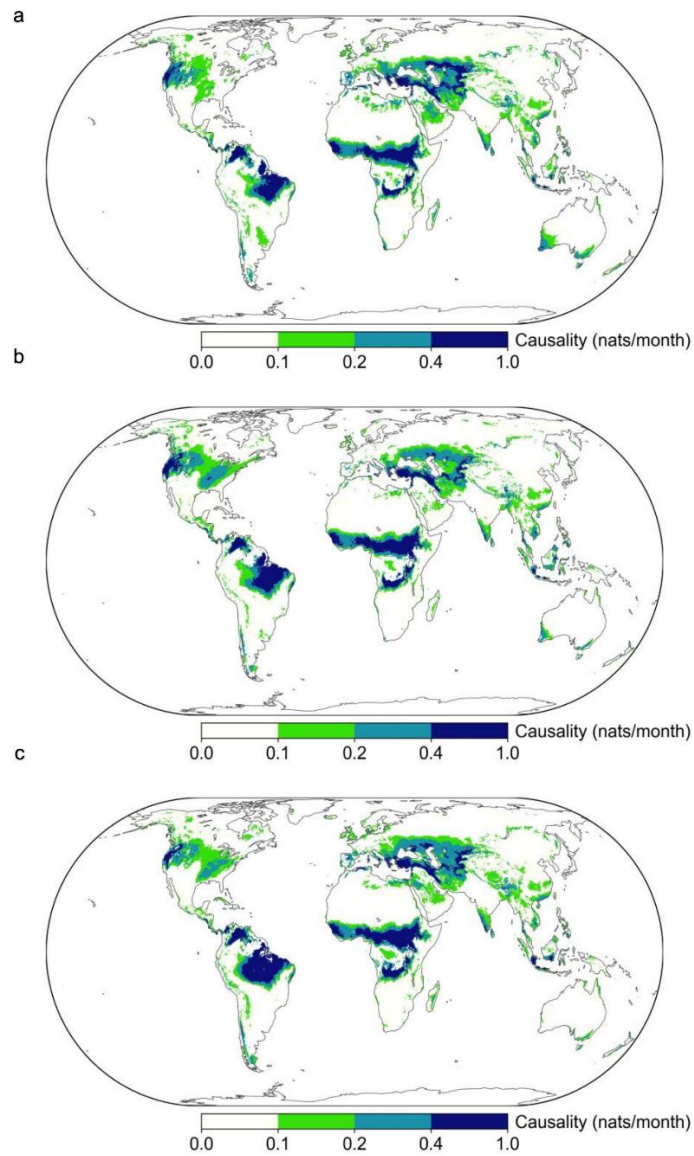
24 (a) Global distribution of the boreal cold-season causal effects of surface soil moisture (0–7 cm)

25 on air temperature during 1984–2014 based on ERA5-Land. Causal effects are quantified by

26 information flow, and only statistically significant regions are shown.

27 (b–d) Same as in (a), but for Layer 2 (7–28 cm), Layer 3 (28–100 cm), and Layer 4 (100–289 cm),

28 respectively.



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30 **Fig. S4 | Comparison of significant causal effects of global surface soil moisture on air**

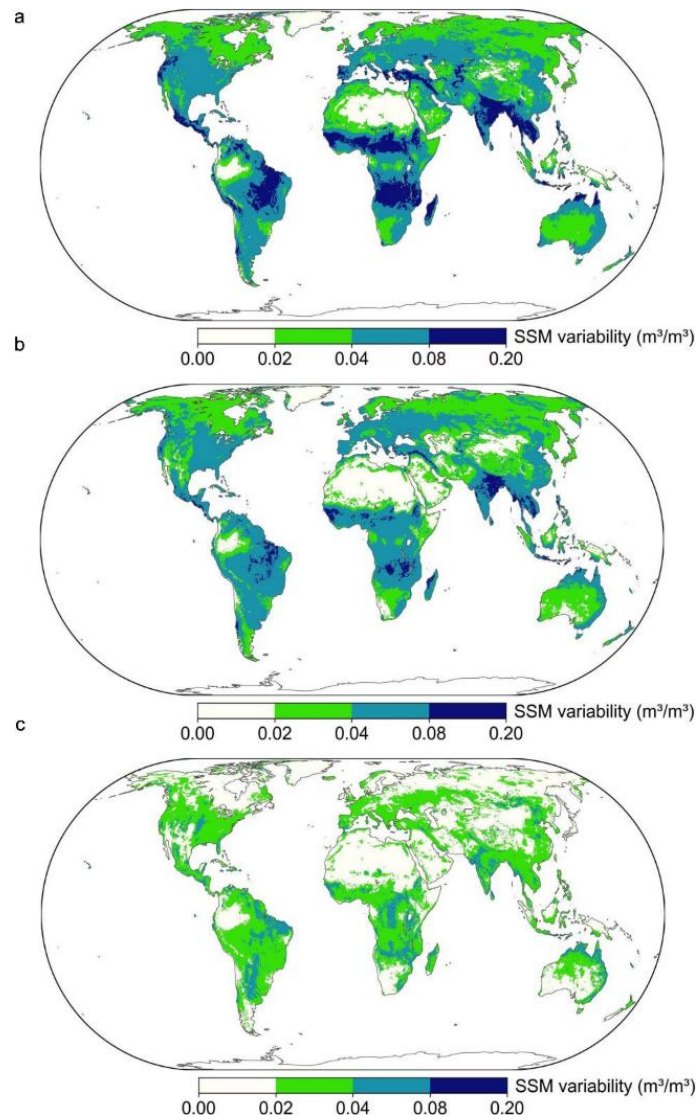
31 **temperature across different decades.**

32 (a) Global distribution of the causal effects of surface soil moisture on air temperature during

33 1984–1993 based on ERA5-Land. Causal effects are quantified by information flow, and only

34 statistically significant regions are shown.

35 (b,c) Same as in (a), but for 1994–2003 and 2004–2014, respectively.



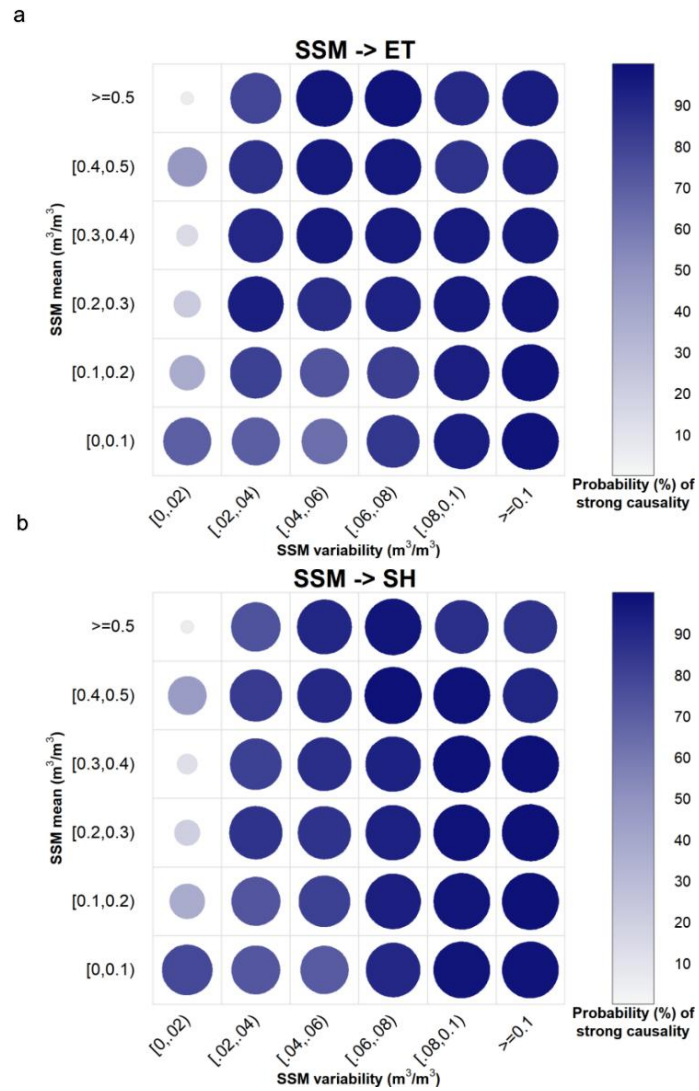
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37 **Fig. S5 | Spatial distribution of soil moisture variability at different depths.**

38 (a) Global distribution of Layer 2 soil moisture variability (7–28 cm; m^3/m^3) during 1984–2014.

39 Variability is defined as the standard deviation of monthly mean soil moisture.

40 (b,c) Same as in (a), but for Layer 3 (28–100 cm) and Layer 4 (100–289 cm), respectively.



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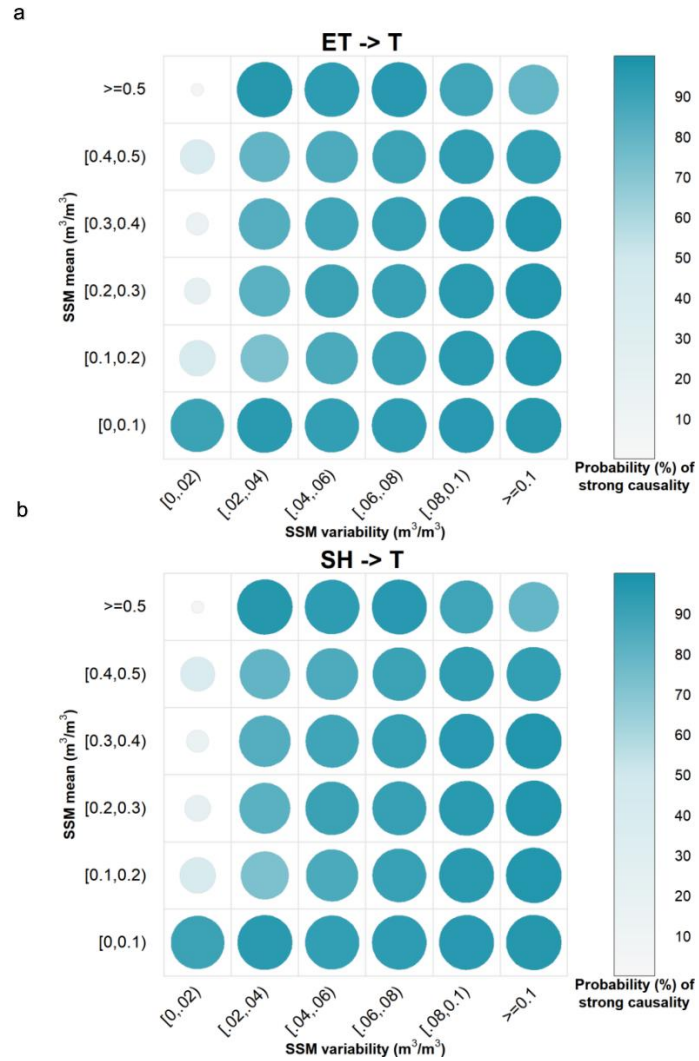
42 **Fig. S6 | Probability of significant $SSM \rightarrow ET$ and $SSM \rightarrow SH$ causality across soil moisture**
 43 **variability and mean-state bins.**

44 (a) Probability of significant $SSM \rightarrow ET$ causality across two-dimensional bins of surface SSM
 45 variability and mean state. Probability is defined as the fraction of significant grid cells relative to
 46 the total number of grid cells within each bin.

47 (b) Same as in (a), but for the $SSM \rightarrow SH$ pathway.

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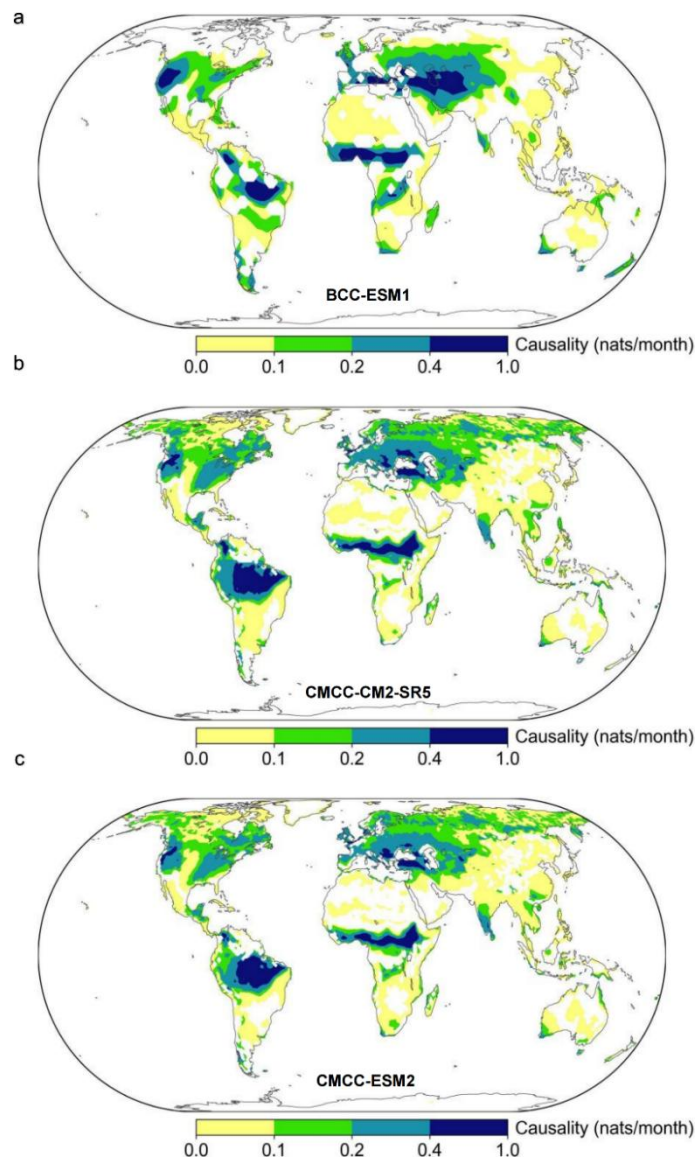
50

51 **Fig. S7 | Probability of significant $ET \rightarrow T$ and $SH \rightarrow T$ causality across soil moisture**
 52 **variability and mean-state bins.**

53 (a) Probability of significant $ET \rightarrow T$ causality across two-dimensional bins of surface soil
 54 moisture variability and mean state. Probability is defined as the fraction of significant grid cells
 55 relative to the total number of grid cells within each bin.

56 (b) Same as in (a), but for the $SH \rightarrow T$ causality.

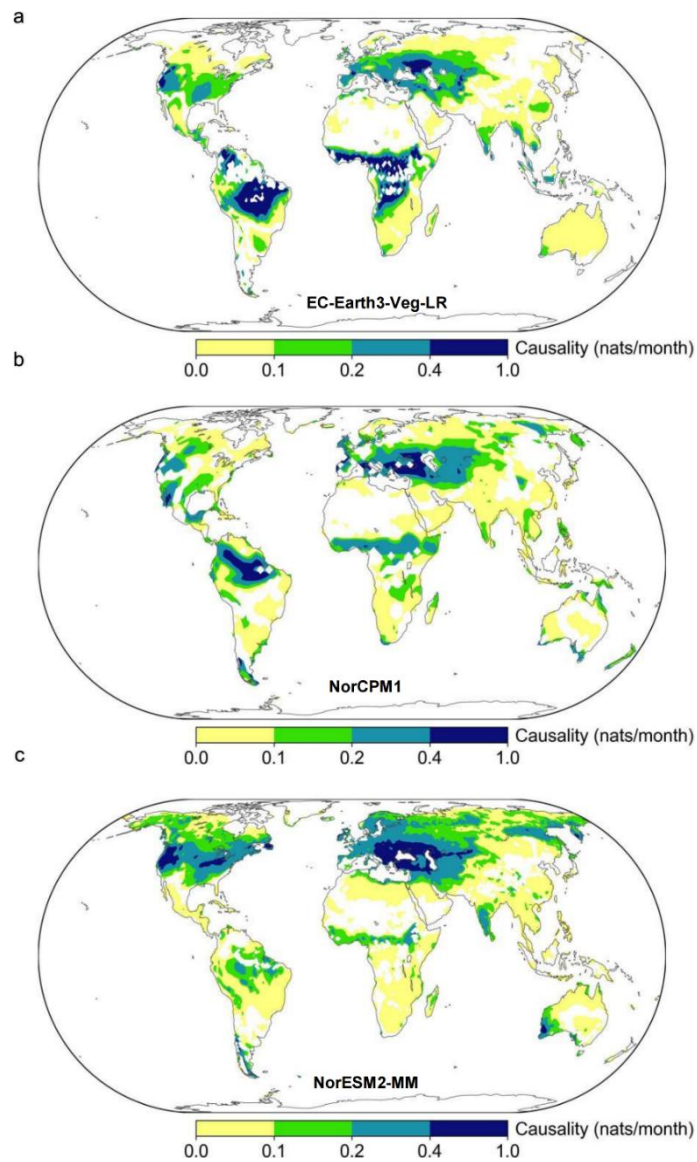
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59 **Fig. S8 | Global distribution of significant $SSM \rightarrow T$ causal effects simulated by climate**
 60 **models.**

61 (a–c) Global distribution of the causal effects of surface soil moisture on air temperature during
 62 1984–2014 based on three climate models. Causal effects are quantified by information flow, and
 63 only statistically significant regions are shown. The three models are BCC-ESM1, CMCC-CM2-
 64 SR5, and CMCC-ESM2.



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66 **Fig. S9 | Global distribution of significant $SSM \rightarrow T$ causal effects simulated by climate**

67 **models.**

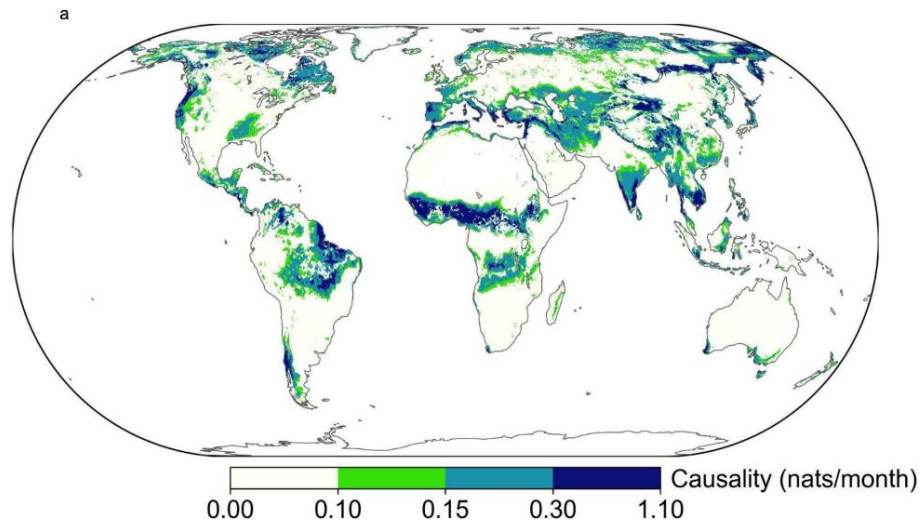
68 (a–c) Global distribution of the causal effects of surface soil moisture on air temperature during

69 1984–2014 based on three climate models. Causal effects are quantified by information flow, and

70 only statistically significant regions are shown. The three models are EC-Earth3-Veg-LR,

71 NorCPM1, and NorESM2-MM.

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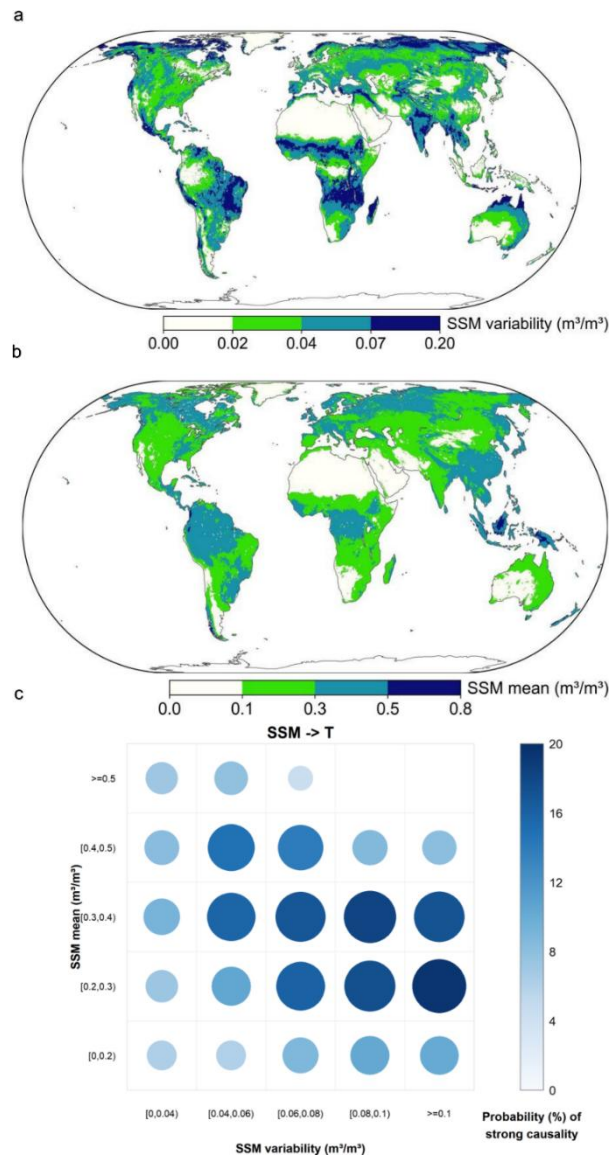
74 **Fig. S10 | Significant causal effects of global surface soil moisture on air temperature based on**

75 **GLEAM.**

76 Global distribution of the causal effects of surface soil moisture on air temperature during 1984–

77 2014 based on GLEAM. Causal effects are quantified by information flow, and only statistically

78 significant regions are shown.



79

80 **Fig. S11 | Relationship between global surface soil moisture characteristics and the probability**

81 **of significant $SSM \rightarrow T$ causality based on GLEAM.**

82 (a) Spatial distribution of surface SSM variability during 1984–2014 based on GLEAM. Variability

83 is defined as the standard deviation of monthly mean SSM.

84 (b) Spatial distribution of mean surface SSM during 1984–2014 based on GLEAM.

85 (c) Probability of significant $SSM \rightarrow T$ causality across two-dimensional bins of SSM variability

86 and mean state. Probability is defined as the fraction of significant grid cells relative to the total

87 number of grid cells within each bin.

Table S1 | CMIP6 models used in this study.

CMIP6 models	Grid points (lon × lat)	Variables
AWI-ESM-1-1-LR	192×96	mrsos, tas
BCC-ESM1	128×64	mrsos, tas
CMCC-CM2-HR4	288×192	mrsos, tas
CMCC-CM2-SR5	288×192	mrsos, tas
CMCC-ESM2	288×192	mrsos, tas
EC-Earth3-Veg-LR	320×160	mrsos, tas
MPI-ESM1-2-HR	384×192	mrsos, tas
MPI-ESM1-2-LR	192×96	mrsos, tas
NorCPM1	144×96	mrsos, tas
NorESM2-MM	288×192	mrsos, tas