Supporting Information for
"Local and non-local land surface influence in European heatwave initial condition ensembles"

A. L. Merrifield[1], I. R. Simpson[2], K. A. McKinnon[3], S. Sippel[1], S.-P. Xie[4], C. Deser[2]

[1]ETH Zurich, Zurich, Switzerland
[2]National Center for Atmospheric Research, Boulder, CO, USA
[3]University of California Los Angeles, Los Angeles, CA USA
[4]Scripps Institution of Oceanography, University of California San Diego, La Jolla, CA USA

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Text S1. Methodological Choices

The constrained circulation ensembles (CCEs) were constructed from 44 selected control (CTL) years: Years 2, 7, 12, 17, 22, 27, 32, 37, 42, 47, 52-84, 90. Each year between Year 52 and Year 84 were selected to obtain May and June soil moisture output from the CTL restart files as land surface variables from Years 52 and 54-75 from the CTL were unavailable. For this reason, fewer CTL years (287 years) were averaged to obtain the soil moisture (SM) climatology than CTL years averaged for atmospheric fields (306 years). The CTL simulation is run with prescribed climatological sea surface temperature and sea ice, with climatologies calculated as the average of years 401-1399 of the CESM Large Ensemble preindustrial control simulation [*Kay et al.*, 2015]. Within this idealized model framework, the only interactive component of the climate system that is coupled with the atmosphere and is varying in time is the land surface.

Sensitivity analyses were performed to (1) inform the decision to constrain circulation above approximately 300 hPa in the CCE_{top} and (2) determine a suitable num-

Corresponding author: Anna L. Merrifield, anna.merrifield@env.ethz.ch

Table 1. Description of CESM1 simulation experiments used in this study.

Experiment	Abbreviation	Description
Control Simulation	CTL	306 year preindustrial control simulation, with prescribed climatological sea surface temperature and sea ice from years 401 - 1399 of the CESM1 Large Ensemble preindustial control simulation.
Heatwave Case	Year 200	Year selected from CTL as a representative seasonally persistent European heatwave.
Constrained Circulation Ensemble, Upper Atmosphere	CCE_{top}	Ensemble of 44 CTL years, branched from June 1 and with Year 200 atmospheric circulation imposed above 322 hPa.
Constrained Circulation Ensemble, Full Atmosphere	CCE_{full}	Ensemble of 44 CTL years, branched from June 1 and with Year 200 atmospheric circulation imposed over the full atmospheric column.

ber of CCE members. For the first methodological choice, constraint above approximately 700 and 500 hPa were also considered. The approximately 300 hPa constraint was chosen because it allowed for both the heatwave pattern to be imposed and the atmosphere below the constraint to evolve in response to the SM anomalies present. For the second methodological choice, ensembles of 23, 44, and 102 members were considered. Spread in the CCE_{full} did not considerably increase between 44 and 102 members, so we considered 44 members sufficient to represent the heatwave intensity range.

Text S2. Hierarchical Partitioning

Hierarchical partitioning is a method of determining the independent and conjoint contributions of predictors to goodness of fit models and is useful in that it quantifies the relative contributions of correlated predictors [*Hatt et al.*, 2004]. The idea is to identify these contributions through a systematic set of hierarchical regression models, where

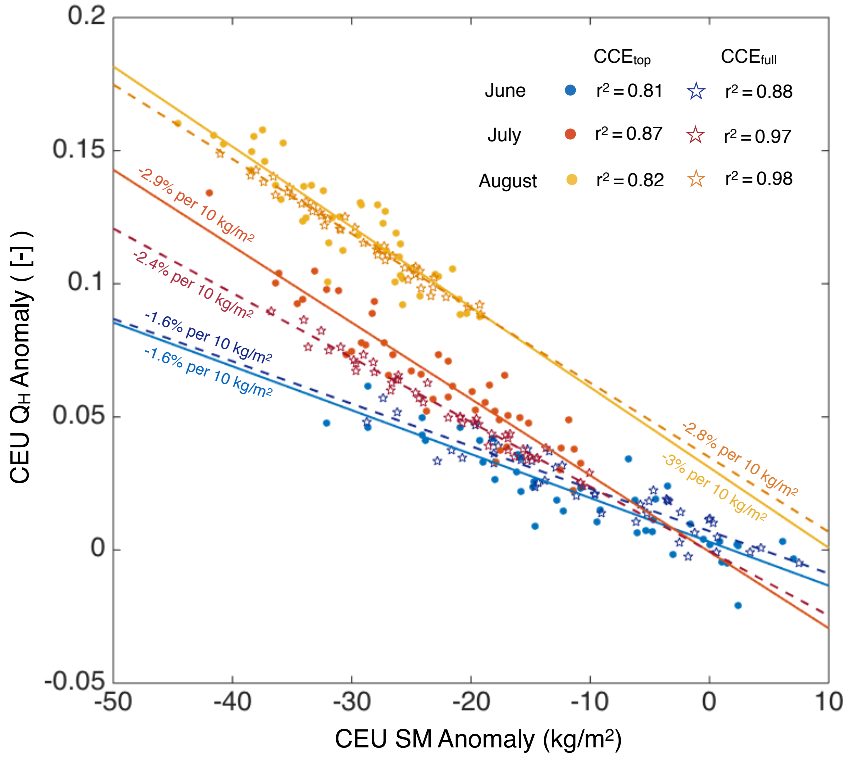

Figure 1. Relationships between CEU Soil Moisture and Sensible Heat Flux Fraction, indicative of the terrestrial segment of the land surface feedback on SAT [*Dirmeyer*, 2011], for June (blue), July (red), and August (yellow) in the CCE_{top} (dots) and CCE_{full} (stars). R^2 values for each month and ensemble combination are given in the legend in the upper right. Least-squares regression coefficients accompany lines of best fit.

individual predictors are assigned high independent contribution if they explain variability in the target variable independently from the other predictors. Conversely, joint variability is the fraction of variability that can be explained by several variables, and thus that part of explained variability cannot be assigned to an individual variable. Hierarchical partitioning systematically uses all hierarchies of variables and results in an exact linear partitioning. Joint effects are split among the respective contributing variables and added proportionately.

Text S3. Observational Consistency

We also consider observational estimates of root zone soil moisture from the Global Land Evaporation Amsterdam Model version 3.2a (GLEAM v3.2a [*Martens et al.*, 2017]).

A histogram of GLEAM May soil moisture (OBS; CEU-averaged and normalized with respect to 1980-2017 climatology) is shown in Fig. S3, superposed on normalized CESM1 May CEU soil moisture used as initial conditions for the CCEs. For the CCE, a distribution of the 44 members is shown. For OBS, 38 years of observational estimates are used. Both the CCE and OBS soil moisture distributions have a longer dry than wet side tail. Central European soils were approximately 1.2 σ drier than average prior to the 2003 European heatwave.

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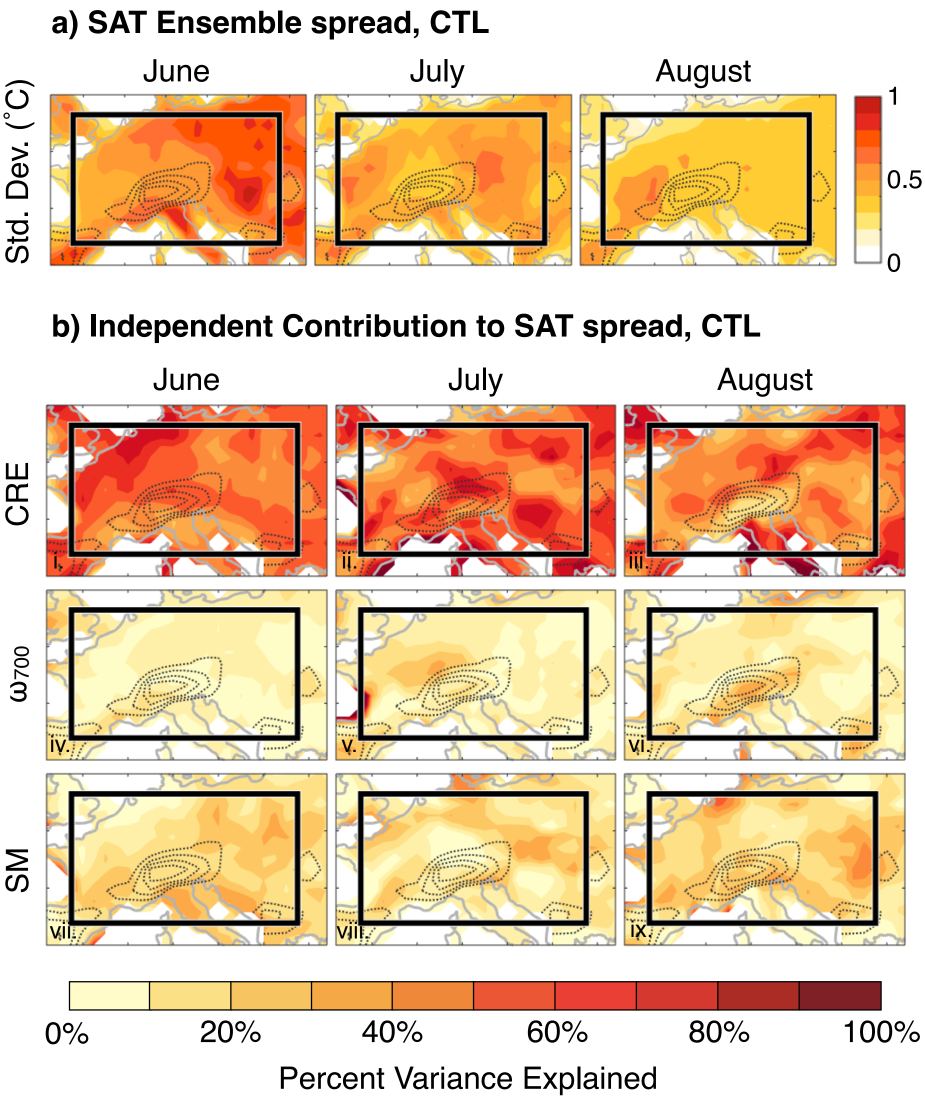

Figure 2. a) Ensemble standard deviation (i-iii) of CTL SAT (°C) in the CEU (box) for June, July, and August respectively. Dotted contours show orographic features above 600 m at 200 m intervals. b) The independent contribution to CTL SAT spread of processes related to heatwave intensity. Panels i-iii show the June through August independent contribution of radiation, represented by the cloud radiative effect (CRE). Panels iv-vi show the contribution of subsidence, represented by vertical velocity at 700 hPa (ω_{700}), and panels vii-ix show the contribution of the land surface feedback, represented by root zone soil moisture (SM).

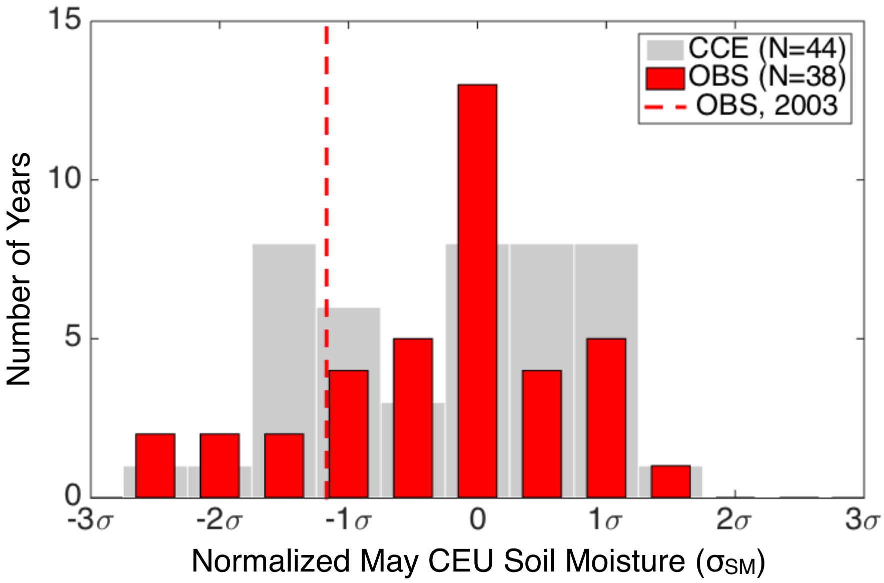

Figure 3. Normalized May CEU SM (σ_{SM}) for the CCEs (gray bars) and observational estimates (OBS; red bars). The OBS value in 2003, prior to the European heatwave, is shown as a dashed red line.