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Causes and uncertainty of future summer drying over Europe

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Previous studies have shown that the continuing rise in anthropogenic emissions is likely to cause continental European summers to become substantially drier over the coming century. Since this predicted decline in rainfall and soil moisture (SM) would bring significant stress to society and ecosystems, it is essential that its reliability or otherwise is properly assessed. One approach is to gain a better understanding of the model's mechanisms of regional climate change and integrate this with knowledge of the model's strengths and weaknesses. Here we propose a methodology that partitions the mechanisms of regional climate change, and apply it to the problem of summer drying over continental Europe.

Earlier work has suggested that the mechanisms of future mid-latitude continental summer drying are: (a) an earlier and more rapid decline in SM during spring, leading to lower SM in summer, and hence less convective rainfall ('Spring SM'); (b) a larger land–sea contrast in lower tropospheric summer warming, leading to reduced relative humidity in air advected onto the continent, and so reduced rainfall ('Warming'); (c) other large-scale atmospheric changes, including remotely forced circulation changes ('Large-Scale'); and (d) a positive feedback mechanism in summer, whereby the reduced rainfall dries the soil further, so reducing convective activity further ('Summer SM Feedback').

We attempt to isolate these mechanisms by integrating a geographic subset of the high resolution global atmospheric model HadAM3P to roughly quantify their relative importance in generating the projected European summer drying. Each mechanism is approximately represented (and so isolated) using an appropriate mix of inputs to the model, with some matching a control integration and others matching a future sce-

nario integration. These mixed inputs are: atmospheric composition (CO_2, aerosol and ozone), surface boundary data (SM and SSTs), and lateral boundary data (temperature, moisture, winds, and surface pressure). We describe this methodology and the experimental suite, and show that the separation of mechanisms is not compromised by interactions between them.

For continental and southeastern Europe, it is found that both the ‘Warming’ and ‘Spring SM’ mechanisms are the primary drivers of the projected summer drying. ‘Summer SM Feedback’ plays an important secondary role, and ‘Large-Scale’ mechanisms have least influence. Since the two dominant mechanisms depend on processes in which we have reasonable confidence, this gives us high confidence in the *sign* of the projected summer drying over continental and southeastern Europe. Nevertheless, uncertainties in model formulation and future anthropogenic emissions mean that the *magnitude* of this future rainfall anomaly remains unclear. Over Great Britain and southern Scandinavia, our experiments show that the rainfall anomaly is dominated by opposing effects from the ‘Warming’ and ‘Large-Scale’ mechanisms, dictating increased and decreased rainfall respectively. Given this rivalry, and also that we have low confidence in the ‘Large-Scale’ mechanism, this suggests that even the sign of the projected drying here is uncertain.