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Soil moisture and the water cycle in the UK Climate Projections

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Department for Business, Energy & Industrial Strategy

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Environment Agency

Working together on
UK Climate Projections

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Introduction

- Soil moisture is a key variable for plant growth
- Water available for uptake by plants

Low soil moisture:

- Constrains plant growth,
- Reduces the quality of crops,
- Increases the need for irrigation.

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Research questions

1. How well do the models in the UK Climate Projections [UKCP] represent soil moisture in current climate?
2. How is soil moisture projected to change in future over the UK?

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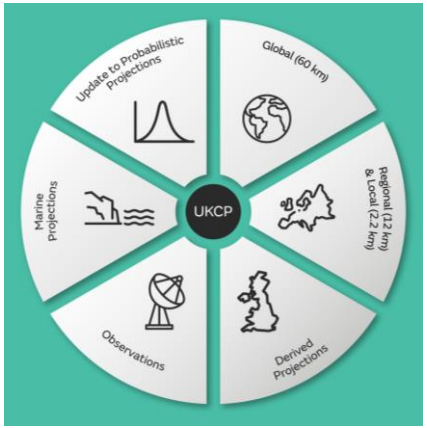
Data

- Climate model data from the UK Climate Projections [UKCP] 2018:
  - Global [resolution of 60km]: 12-member perturbed-parameter ensemble.
  - Regional [12km]: 12-member perturbed-parameter ensemble, which covers Europe with boundary conditions from the Global [60km].
  - Both use RCP8.5, to identify climate change signal.
  - Both climate models are coupled to a land-surface model: JULES
- To assess model performance:
  - Soil moisture, use JULES forced by meteorological observations from WATCH [WFDEI] to give 'proxy observations' – labelled WFDEI-JULES
  - Use NCIC observations of rainfall, the main driver of soil moisture bias and future change. Forthcoming paper will discuss evaporation and runoff.



JULES
Joint UK Land Environment Simulator

WATCH
Water and Global Change

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Soil moisture: Beta [β]

- Compares the soil moisture content to that needed for plants to grow optimally.
- θ is the soil moisture available [m^3 water per m^3 soil]
- θ_{crit} and θ_{wilt} are the critical and wilting points.
- Between θ_{crit} and θ_{wilt} (β between 1 and 0), a plant can recover from the moisture deficit but growth will be constrained by lack of moisture. Below θ_{wilt}, the plant has wilted and will not recover.

$$\beta = \begin{cases} 1 & for\ \theta > \theta_{crit} \\ \dfrac{\theta - \theta_{wilt}}{\theta_{crit} - \theta_{wilt}} & for\ \theta_{wilt} \leq \theta \leq \theta_{crit} \\ 0 & for\ \theta < \theta_{wilt} \end{cases}$$

Seneviratne, S. I., et al, 2010: URL https://doi.org/10.1016/j. earscirev.2010.02.004

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1. Soil moisture in current climate

How well do the models in the UK Climate Projections [UKCP] represent soil moisture in current climate?

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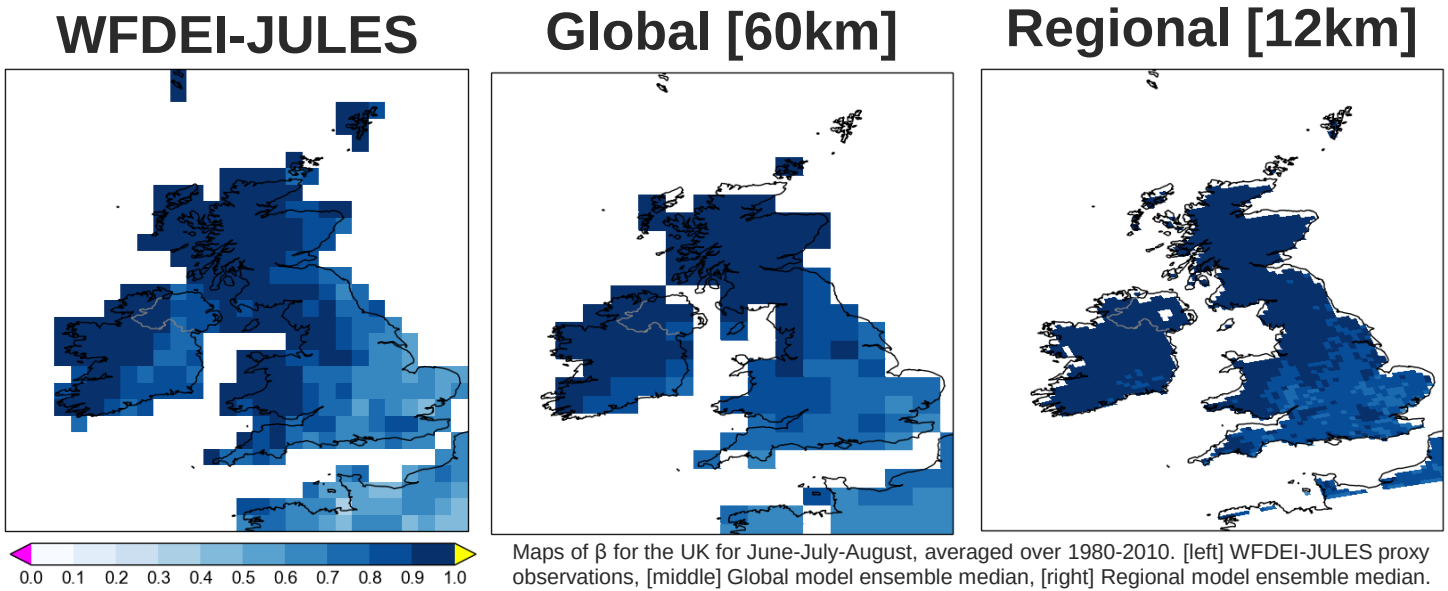
Soil moisture [β] in current climate

- Spatial patterns broadly captured
- Wetter soils in northwest, drier in southeast
- Both Global and Regional show wet biases
- Regional's bias larger than Global



Maps of β for the UK for June-July-August, averaged over 1980-2010. [left] WFDEI-JULES proxy observations, [middle] Global model ensemble median, [right] Regional model ensemble median.

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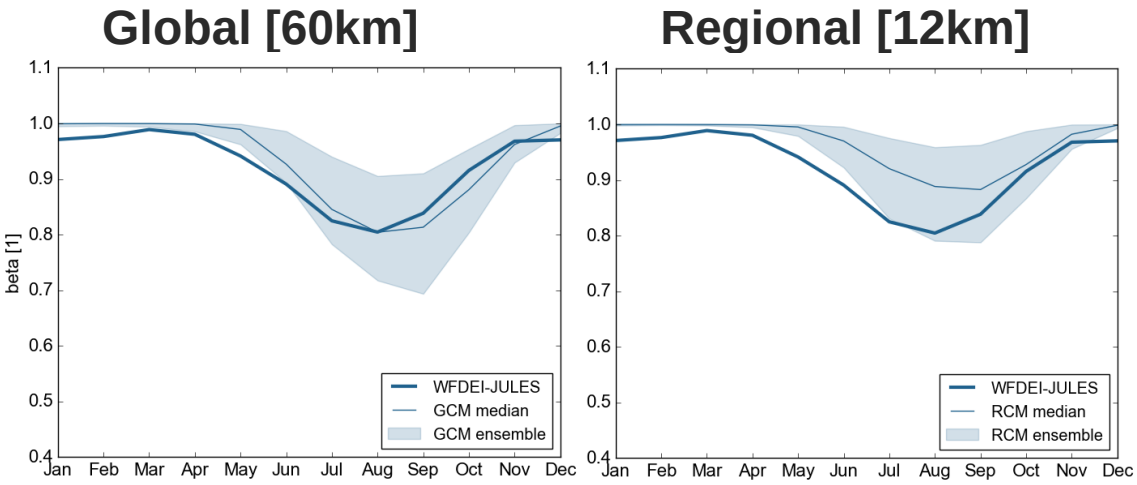
Soil moisture [β] in current climate

- Annual cycle broadly captured, with drier soil in summer and wetter in winter
- Proxy observations from WFDEI-JULES minimum in August. Models' minima in September.
- Otherwise, Global models capture proxy observations well. Regional models typically wetter throughout than proxy observations



Annual cycle of β in UKCP Global [60km horizontal resolution] and Regional [12km] model ensembles, averaged over the UK for 1980-2010. Thin line represents ensemble median and shaded area the model ensemble spread. Thick line represents WFDEI-JULES proxy observations, so it is the same for both Global and Regional plots.

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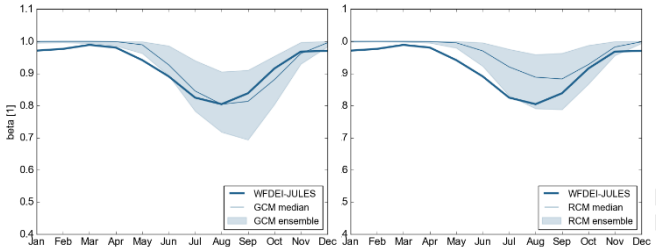
Rainfall in current climate

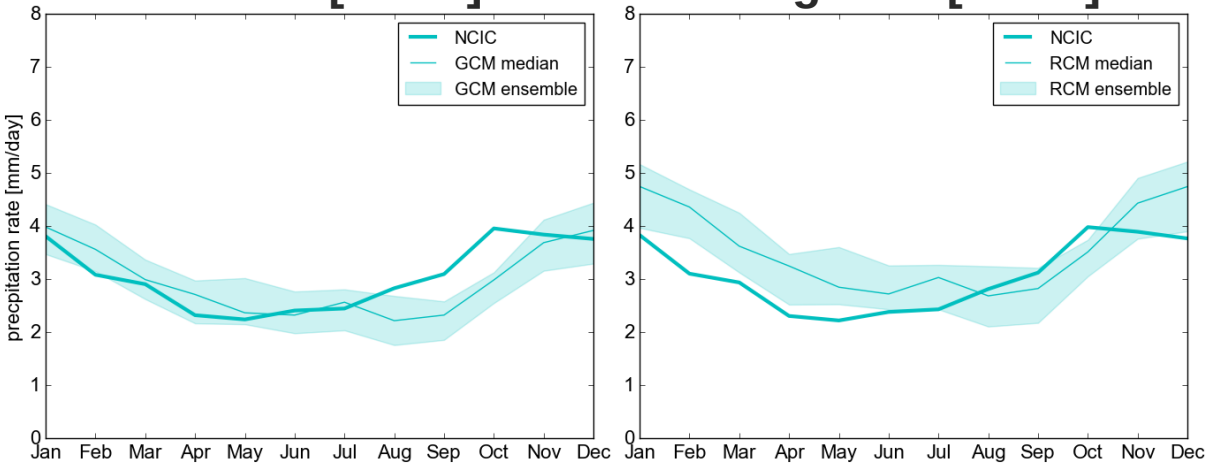
- November to July: more rainfall in model, compared to observations.
- August to October: less rainfall in model, compared to observations.
- ➢ These two factors combine to delay the minimum β in the model, compared to WFDEI-JULES proxy observations.
- Regional models have more rainfall than Global.



β plots from previous slide

Global [60km]

Regional [12km]



Annual cycle of rainfall in UKCP Global [60km] and Regional [12km], averaged over the UK for 1980-2010. Thin line represents ensemble median, and shaded area the model ensemble spread, thick line represents NCIC observations.

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Summary

Results:

- **In current climate** model has typically wetter soil and has later minimum in soil moisture.
- Mainly related to rainfall, which is higher in model than observations for much of the year but lower August to October.

Implications

- **In current climate**:
  - Differences in timing mean growth metrics that include onset or cessation dates require careful assessment of bias in current climate.

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2. Soil moisture in future climate

How is soil moisture projected to change in future over the UK?

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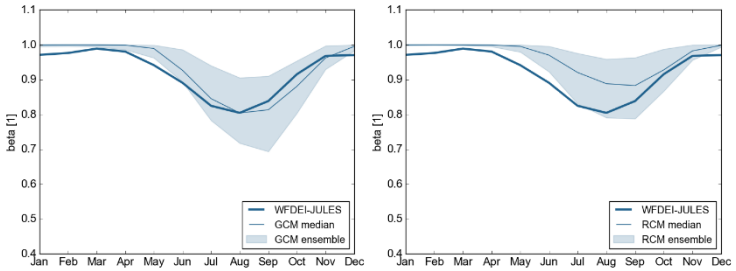
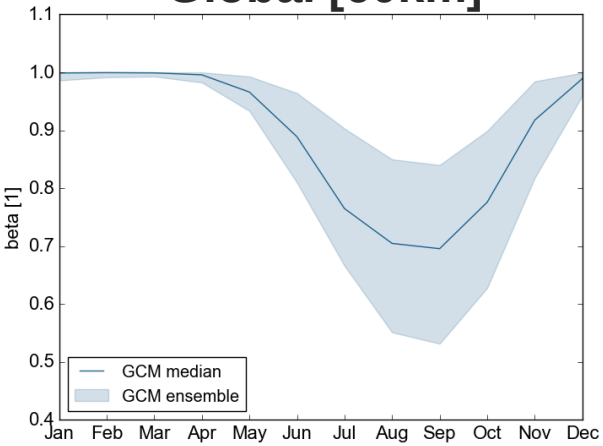
β in future climate

- Both Global and Regional projections show broader and drier summer
  - Soil becomes drier earlier; drier at minimum; takes longer to recover in autumn.
- Greatest changes in August to October
  - Compare that with the delay in model minimum beta, compared to proxy observations.

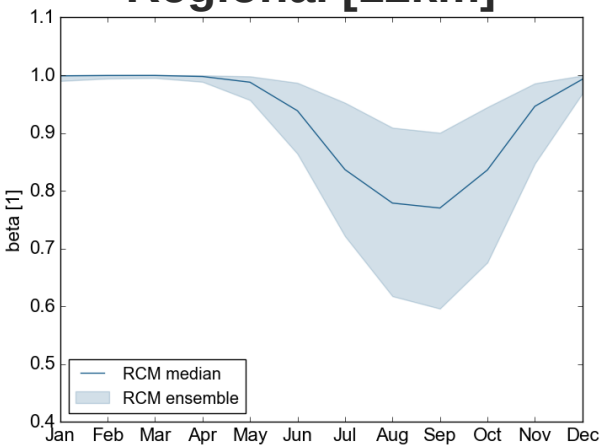


β plots from current climate

Global [60km]



Regional [12km]



Annual cycle of β in UKCP Global [60km horizontal resolution] and Regional [12km] model ensembles, averaged over the UK for 2060-2080. Thin line represents ensemble median, and shaded area the model ensemble spread.

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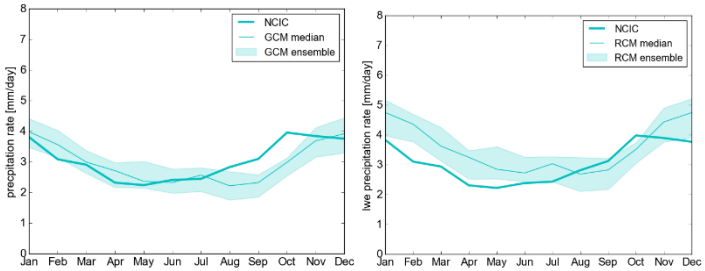
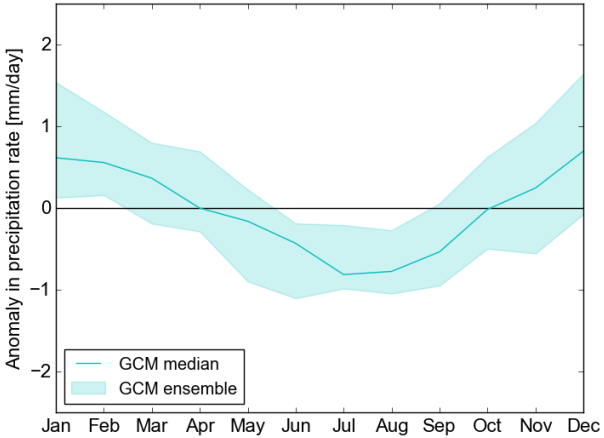
Rainfall in future climate

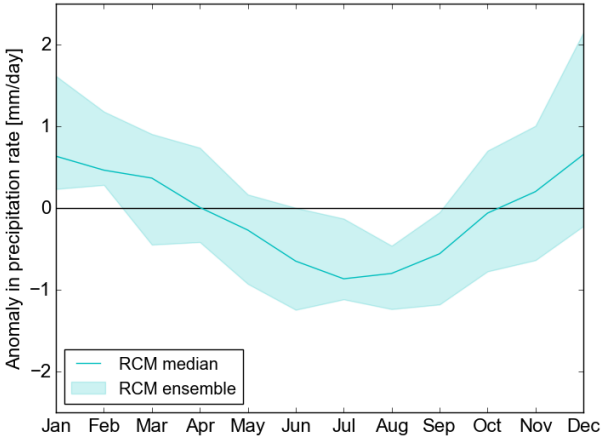
- Wetter winters; drier summers (with more heavy rainfall events – see UKCP Headline findings)
- Drier spring and summer main drivers of drier soil moisture in summer.
- Drier autumn means soil moisture takes longer to recover to winter levels.



Global [60km]



Regional [12km]



Annual cycles of rainfall in UKCP Global [60km horizontal resolution] and Regional [12km] model ensembles, averaged over the UK for future (2060-2080) minus baseline (1980-2010). Thin line represents the ensemble median, and shaded area the model ensemble spread.

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Summary

Results:

- **In current climate** model has typically wetter soil and has later minimum in soil moisture
- Mainly related to rainfall, which is higher in model than observations for much of the year but lower August to October.
- **In future climate**, a broader, deeper dry season is projected for the UK.
- Mainly driven by changes to rainfall, with wetter winters and drier summers.
- Forthcoming paper will discuss evaporation and runoff.

Implications

- **In current climate**:
  - Differences in timing mean growth metrics that include onset or cessation dates require careful assessment of bias in current climate.
- **In future climate**:
  - A deeper dry season means crops would be water stressed to a greater extent;
  - Broader means plants would be stressed for longer;
  - Increased need for irrigation.

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