SPECIAL PROJECT PROGRESS REPORT

All the following mandatory information needs to be provided. The length should *reflect the complexity and duration* of the project.

Reporting year	2020
Project Title:	The influence of CO_2 on an individual extreme event: the high February temperatures in the UK 2019
Computer Project Account:	spgbleac
Principal Investigator(s):	Nicholas Leach
Affiliation:	Oxford University
Name of ECMWF scientist(s) collaborating to the project (if applicable)	
Start date of the project:	16/01/2020
Expected end date:	31/12/2020

Computer resources allocated/used for the current year and the previous one

(if applicable)

Please answer for all project resources

		Previous year		Current year	
		Allocated	Used	Allocated	Used
High Performance Computing Facility	(units)	-	-	6500000	1764899.22
Data storage capacity	(Gbytes)	-	-	8000	3770

Summary of project objectives (10 lines max)

To determine the influence of increased diabatic CO_2 heating, primarily caused by anthropogenic fossil fuel emissions, on an individual extreme event. In general, this kind of "extreme event attribution" is carried out with large climate model ensembles, but we aimed to explore the novel use of a forecast model ensemble to determine the direct CO_2 component in the heatwave. This involved: characterising the heatwave in a quantitative manner using observations and reanalysis data; and determining the changes in likelihood of "the event" between the operational forecast ensemble, and a forecast ensemble in which we have reduced the CO_2 concentration back to pre-industrial levels. We additionally aim to use the forecast ensemble to determine the drivers of the event, and in particular the dynamical component, to ensure that likelihood changes between the operational and reduced CO_2 ensembles are not simply due to dynamical changes.

Summary of problems encountered (10 lines max)

The biggest difficulty in this project thus far was to find a working combination of IFS source and scripts code that would run properly after making changes to the IFS source that would reduce the CO_2 concentrations to pre-industrial levels. The changes themselves were straightforward (a single line of code in the IFS source), but then determining a combination of source and scripts branches/ tags proved a little tricky. However, after several trial forecasts with reduced members/ length, and help from Paul Dando, we now have a source/ scripts combination that runs the forecasts as desired.

Summary of plans for the continuation of the project (10 lines max)

Primarily, we plan to try and determine the dynamic and thermodynamic contributions to the heatwave. The first approach we will explore is the Constructed Analogue Technique from Deser et al (2016), used recently in O'Reilly (2020). Decomposing the heatwave into dynamic and thermodynamic components will allow us to confirm that changes in the likelihood of the event between operational and reduced CO_2 forecast ensembles are definitively attributable to diabatic CO_2 heating, as opposed to dynamical changes.

We additionally plan to investigate the impact of forecast lead time on attribution results. While we carried out the event attribution using forecasts at a lead of 10 days, we plan to use our remaining units to run several extra forecasts at different lead times and redo our attribution analysis.

List of publications/reports from the project with complete references

None accepted. One draft submitted to the BAMS special report "Explaining Extreme Events from a Climate Perspective" as:

Leach, NJ, Allen, MR, Palmer, T, Weisheimer, A. "Quantifying the direct impact of increased CO_2 on the February 2019 heatwave over Europe using an operational forecast system".

Summary of results

If submitted **during the first project year**, please summarise the results achieved during the period from the project start to June of the current year. A few paragraphs might be sufficient. If submitted **during the second project year**, this summary should be more detailed and cover the period from the project start. The length, at most 8 pages, should reflect the complexity of the project. Alternatively, it could be replaced by a short summary plus an existing scientific report on the project attached to this document. If submitted **during the third project year**, please summarise the results achieved during the period from July of the previous year to June of the current year. A few paragraphs might be sufficient.

Towards the end of February 2019, large areas of Western Europe experienced exceptionally high temperatures for the time of year, with widespread temperature anomalies of 10-15 C between the 25th and 27th. This heatwave was accompanied by several characteristic drivers: a narrow tilted ridge flow pattern, high pressure over the North Sea, low cloud cover and a persistent diurnal cycle strength of over 20 C. As a measure of how unusual these temperatures were, only 2/1980 model climatology members exceed the temperatures observed in the ERA-5 reanalysis of the event. This event was well-predicted by the ensemble prediction system at ECMWF at a lead time of around 10 days. We used this successful forecast to carry out an attribution experiment on the influence of diabatic CO2 heating on the extreme surface temperatures.

Using IFS CY45R1 in a near-identical configuration to the operational ensemble prediction system, we ran two forecasts of the event, initialised on the 17th February. The 17th was chosen as the longest range at which we are confident the model is certainly simulating the heatwave. In one experiment, we reduced CO2 concentrations to pre-industrial levels of 285 ppm, and in the other we increased them to 600 ppm. 600 ppm was chosen as the level of an equal but opposite CO2 radiative forcing effect to the difference between the operational concentration of 414 ppm and pre-industrial concentration of 285 ppm; since CO2 radiative forcing is approximately proportional to the logarithm of concentrations. Carrying out both the reduced and increased CO2 experiments allows for a more robust estimation of the direct CO2 effect on surface temperature due to an increased signal.

Comparing the three experimental ensembles (operational, reduced CO2 and increased CO2), we quantify changes to the atmospheric flow (through Z500) and surface temperatures caused by changing CO2 concentrations. We find that changes to the flow between experiments grow exponentially over the integration period, becoming significant around 8 days after initialisation. By the end of the integration, 11 days after initialisation, the average difference in Z500 over Europe between experiments but using the same initial conditions is approaching the same magnitude as the difference between ensemble members of the same experiment. This exponential error growth is also observed in mean sea level pressure and total cloud cover fields. We find that ensemble mean surface temperatures change by up to 0.5 C over land, reducing in the reduced CO2 experiment and increasing in the increased CO2 experiment. Temperatures over the ocean tend to change in the same direction as the land temperatures, but with a significantly lower magnitude.

We present attribution results in two different ways: a traditional "Fraction of attributable risk" framing, and in terms of the number of temperature records that would no longer have been broken without the diabatic CO2 heating component of the heatwave. For the heat experienced over the British Isles (used here as the event was particularly extreme, and particularly well-forecast), the fraction of risk attributable to the direct CO2 effect just over the days immediately preceding the event is 0.32 [-0.24, 0.69] (median [5%, 95%]). In terms of records broken over Europe, we find a best-estimate of between 10 and 20 % of the records broken (uncertainty here is due to the specific weather station dataset used) would not have been broken if CO2 was at a pre-industrial level.

These results demonstrate the potential value of high-resolution NWP models in attribution. Key advantages of using a forecast model for attribution of an event that it predicted are that a) the model is clearly able to simulate the event as it occurred in reality; and b) the attribution is unequivocally of the event in question, rather than of a mixture of events that share one or more characteristics. Neither of these advantages are necessarily true for attribution analyses using large climate model ensembles. We hope to further explore this avenue of research by looking into the impact of forecast lead time on attribution results.