E32

High Speed Rail (West Midlands - Crewe)

Environmental Statement

Volume 5: Technical appendices

Climate

Climate data and information (CL-001-000)

July 2017

ES 3.5.0.8.1

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Department for Transport

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High Speed Two (HS2) Limited,
Two Snowhill
Snow Hill Queensway
Birmingham B4 6GA

Telephone: 08081 434 434

General email enquiries: HS2enquiries@hs2.org.uk

Website: www.gov.uk/hs2

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1 Introduction

1.1.1 The climate change Appendices comprise of three documents:

- Appendix CL-001-000 – Climate data and information;
- Appendix CL-002-000 – Results of climate change assessments; and
- Appendix CL-003-000 – Summary greenhouse gas calculation outputs.

1.1.2 This Appendix provides details of the climate data and information used to inform the in-combination climate change impact assessment and the climate change resilience assessment and should be read alongside the High Speed Rail (West Midlands - Crewe) Environmental Statement (ES): Volume 3, Route-wide effects.

2 Climate data and information

2.1 Current climate baseline data

2.1.1 This section presents data for the current climate and extreme weather events experienced in and around the West Midlands and Crewe region. A summary of this information can be found in Volume 3, Section 4.

Historic climate data

2.1.2 Table 1 presents historic climate data which serves as the current climate baseline data for the West Midlands and Crewe region for comparison with the future climate baseline data. The current baseline for average climate variables has been obtained from the Met Office gridded observational data made available as part of United Kingdom Climate Projections 2009 (UKCP09) at a spatial resolution of 5km for the time period 1961 - 1990[1].

2.1.3 Simulated baseline data for extreme weather events has been obtained from the UKCP09 Weather Generator[2]. The UKCP09 Weather Generator implements a statistical method based on simulated baseline data for creating projections of future daily climate that are consistent with climate change projections. In line with UKCP09 good practice[3], a validation assessment was carried out to compare the simulated baseline data used in the UKCP09 Weather Generator with observed data. The results of this assessment are summarised in Section 2.3.

2.1.4 Four grid points centred on either end of the route have been selected for each data set. The use of different data sets for different metrics allows more consistent comparisons to be made with the future climate projections.

Table 1: Historic climate data for West Midlands and Crewe (1961 to 1990)

Parameter		West Midlands	Crewe
Temperature	Mean winter daily temperature [°C]	3.96	3.92
	Mean summer daily temperature [°C]	15.56	15.14
	Mean daily summer maximum temperature [°C]	20.48	18.13
	Mean daily summer minimum temperature [°C]	10.64	10.37
	Mean daily winter maximum temperature [°C]	6.86	5.52
	Mean daily winter minimum temperature [°C]	1.06	0.77

[1] UKCP09, *Gridded observation data sets*, http://www.metoffice.gov.uk/climatechange/science/monitoring/ukcp09/
[2] UKCP09, *Weather Generator*, http://ukclimateprojections.metoffice.gov.uk/23261
[3] UKCP09, *Validation of Weather Generator outputs*, http://ukclimateprojections.metoffice.gov.uk/media.jsp?mediaid=87941&filetype=pdf

Parameter		West Midlands	Crewe
Precipitation	Annual mean daily precipitation [mm/day]	1.84	1.96
	Winter mean daily precipitation [mm/day]	1.94	1.92
	Summer mean daily precipitation [mm/day]	1.83	1.95
Cloud	Annual cloud cover [%] (obtained from Midlands climate summary[4])	84% (1,380 sunshine hours per year)	84% (1,380 sunshine hours per year)
Extreme weather events from UKCP09 Weather Generator	Annual number of days when daily mean temperature is >25°C	0.02	0.01
	Annual number of frost days (when daily mean temperature is 0°C or lower)[5]	6.24	5.76
	Annual number of day per year when precipitation is greater than 25mm per day (Met Office definition of 'heavy rain')	1.06	0.79
	Annual number of dry spells (10+ days with no precipitation)	3.7	2.71

Local climate impacts profiles

2.1.5 Local Climate Impacts Profiles (LCLIPs) were developed by Birmingham City Council (2008)[6] and Cheshire East Council (2010)[7] to gain an understanding of the nature of extreme weather events and the impact they have on the community, environment and economy. These two LCLIPs provide a list of the past extreme weather events which have had an impact in the region.

2.1.6 The types of weather impacts, although localised, could potentially occur anywhere along the route.

2.1.7 Table 2 summarises the primary weather events currently affecting the region and provides a high level overview of the types of impacts experienced.

[4] Met Office, *Birmingham Climate*, http://www.metoffice.gov.uk/public/weather/climate/gcqdt4b2x
[5] The definition of a frost day which we have used to inform the current and future climate baseline data and Weather Generator validation is when the daily *average* air temperature is below 0°C. We have used this definition as an indication of trends in cold weather days, as distinct from an indication of specific air frost events. The Met Office definition of an air frost day is when the daily *minimum* air temperature is below 0°C, http://www.metoffice.gov.uk/climatechange/science/monitoring/ukcp09/available/monthly.html. It is also possible for frost to occur when the air temperature is above 0°C as a result of radiative cooling
[6] Kotecha, Thrones and Chapman (2008), *Birmingham's Local Climate Impacts Profile (LCLIP),* http://www.bebirmingham.org.uk/uploads/LCLIP.pdf
[7] Cheshire East Council (2010), *Cheshire East Council Local Climate Impacts Profile,* http://www.cheshireeast.gov.uk/pdf/Cheshire%20East%20LCLIP%20updated.pdf

Table 2: Summary of weather events and associated impacts experienced in and around the proposed route area

Weather event	Impacts on community and local services
Heavy rain/flash floods	• Raised river levels, flooded drains, collapsed culverts • Road closures • Disruption to train services (e.g. trains cancelled or non-stopping at certain stations) • Contaminated water • Events cancelled
High winds/tornado	• Damage to houses and other buildings • Power cuts • Fallen trees • Road closures • Disruption to train services
Heat wave	• Health impacts from breathing problems and sunstroke • Impact to biodiversity (e.g. loss of fish) • Grass and forest fires • Structural damage (e.g. rail lines buckle in heat)
Lightning	• Structural damage • Power surge and tripping electricity breakers • Fires • Health impacts from direct strikes • Events cancelled • Rail transport disrupted due to strike on cables
Snow and Ice	• Dangerous driving conditions • Damage to roads • Disruption to train services • Health impacts from slipping on ice and chest illnesses • Events cancelled
Fog	• Delayed flights at Birmingham International Airport • Dangerous driving conditions • Events cancelled

2.2 Future climate baseline data

2.2.1 This section presents the projected climate conditions and extreme weather events for the area encompassing Fradley and Crewe for the 2020s and the 2080s. An overview of the main climate change trends for Fradley and Crewe is presented in Volume 3, Section 4.

2.2.2 Using the historic baseline data, two methods were implemented to assess future climate baseline data. The changes in average climate conditions were obtained from the UKCP09 probabilistic projections of climate change[8]. The changes in extreme weather events were obtained using the UKCP09 Weather Generator[9].

Fradley, West Midlands

2.2.3 Climate change projections for a range of meteorological parameters are presented for different probability levels and emission scenarios for the 2020s and 2080s.

2.2.4 Table 3 presents expected gradual changes in mean climate conditions, such as mean temperature and precipitation and Table 4 presents changes in extreme weather events such as number of heavy rain days.

[8] UKCP09, *Climate change projections*, http://ukclimateprojections.metoffice.gov.uk/21684
[9] UKCP09, *Weather Generator*, http://ukclimateprojections.metoffice.gov.uk/22540

2.2.5 As in the rest of the UK, temperatures in the West Midlands are anticipated to increase both in winter and summer. The largest increase in temperature is estimated to be in the mean daily maximum temperature in summer, which is expected to increase from 19.9°C to 24.6°C in the 2080s (medium emissions scenario and 50% level). A higher increase in temperature is projected for the 2080s than for the 2020s.

2.2.6 Annual precipitation in the West Midlands is anticipated to decrease slightly both for the 2020s and 2080s, but the range of projected changes varies from a decrease to an increase in precipitation. The projected changes in mean precipitation vary for winter and summer. Mean winter precipitation is expected to remain similar to current mean precipitation for the 2020s and increase slightly in the 2080s, while it is expected to decrease in summer. Annual cloud cover over the West Midlands is also anticipated to decrease.

2.2.7 As in the case of mean temperature, the number of days with high temperature (mean temperature above 25°C) is anticipated to increase by up to 3.2 days per year in the 2080s for the high emission scenario. Similarly, the number of frost days is expected to decrease. In the case of extreme precipitation, the number of days with heavy rain (precipitation greater than 25 mm/day) is also expected to increase as well as the number of dry spells. This points to an increase in the variability of rainfall patterns in the West Midlands.

2.2.8 The projected changes from current to future conditions are higher overall for the 2080s than for the 2020s and for the high emission scenario.

Table 3: UKCP09 climate change projections for gradual meteorological changes for Fradley, West Midlands

Parameter and baseline (in brackets, 1961-1990)		2020s (2010-2039)			2080s (2070-2099)		
		Medium emissions scenario (50% level)	High emissions scenario (50% level)	Range[10]	Medium emissions scenario (50% level)	High emissions scenario (50% level)	Range
Temperature	Mean winter daily temperature [°C] (3.96°C)	4.69	4.66	3.90 – 5.50	6.30	6.90	4.79 – 8.74
	Mean summer daily temperature [°C] (15.56°C)	16.26	16.21	15.47 – 17.28	18.45	19.40	16.06 – 22.23
	Mean daily summer maximum temperature [°C] (20.48°C)	21.37	21.32	20.22 – 22.75	24.17	25.46	20.73 – 29.68
	Mean daily summer minimum temperature [°C] (10.64°C)	11.50	11.51	10.77 – 12.53	13.71	14.76	11.27 – 17.85
	Mean daily winter maximum temperature [°C] (6.86°C)	7.44	7.42	6.61 – 8.34	8.86	9.46	7.17 – 12.01
	Mean daily winter minimum temperature [°C] (1.06°C)	1.98	2.00	1.08 – 2.94	3.81	4.51	1.75 – 7.14
Precipitation	Annual mean daily precipitation (1.84 mm/day)	1.96	1.96	1.88 – 2.07	1.96	1.97	1.89 – 2.14
	Winter mean daily precipitation (1.94 mm/ day)	2.17	2.19	2.00 – 2.39	2.45	2.58	2.12 – 3.20
	Summer mean daily precipitation (1.83 mm/day)	1.79	1.84	1.51 – 2.21	1.51	1.41	1.23 – 2.03
Wind	Change in winter mean daily wind speed	-	-	-	-	-	-
	Change in summer mean daily wind speed	-	-	-	-	-	-

[10] Range from 10% level low emissions – 90% level high emissions

Parameter and baseline (in brackets, 1961-1990)		2020s (2010-2039)			2080s (2070-2099)		
		Medium emissions scenario (50% level)	High emissions scenario (50% level)	Range[10]	Medium emissions scenario (50% level)	High emissions scenario (50% level)	Range
Relative humidity	Annual relative humidity	80.94	80.97	79.76 – 82.13	79.56	78.87	78.04 – 81.51
Cloud cover	Annual cloud cover [%] (84%)	69	69	67 - 71	67	66	65 – 70

Table 4: UKCP09 Weather Generator values for extreme weather events for Fradley, West Midlands

Parameter and baseline (in brackets, 1961-1990)		2020s (2010-2039)			2080s (2070-2099)		
		Medium emissions scenario	High emissions scenario	Range[11]	Medium emissions scenario	High emissions scenario	Range
Temperature	Annual number of days when daily mean temperature is >25°C (0.02)	0.23	0.26	0.31 – 0.26	1.80	3.23	1.25 – 3.23
	Annual number of frost days (when daily mean temperature is 0°C or lower)[12] (6.24)	3.49	3.36	3.44 – 3.36	1.55	1.23	1.82 – 1.23
Precipitation	Annual number of days per year when precipitation is greater than 25mm per day (Met Office definition of 'heavy rain') (1.06)	1.31	1.35	1.35 – 1.35	1.71	1.84	1.62 – 1.84
	Annual number of dry spells (10+ day with no precipitation) (3.7)	4.69	4.56	4.55 – 4.56	5.75	5.81	5.40 – 5.81

[11] Range from 10% level low emissions – 90% level high emissions

[12] The definition of a frost day which we have used to inform the current and future climate baseline data and Weather Generator validation is when the daily *average* air temperature is below 0°C. We have used this definition as an indication of trends in cold weather days, as distinct from an indication of specific air frost events. The Met Office definition of an air frost day is when the daily *minimum* air temperature is below 0°C, http://www.metoffice.gov.uk/climatechange/science/monitoring/ukcp09/available/monthly.html. It is also possible for frost to occur when the air temperature is above 0°C as a result of radiative cooling

Crewe

2.2.9 Climate change projections for a range of meteorological parameters are presented for different probability levels and emission scenarios for the 2020s and 2080s.

2.2.10 Table 5 presents expected gradual changes in mean climate conditions such as mean temperature and precipitation and Table 6 presents changes in extreme weather events such as the number of heavy rain days.

2.2.11 The climate change projections obtained for Crewe are similar to those obtained for the West Midlands. There is projected to be an increase in temperature, a slight increase in winter precipitation, a decrease in summer precipitation and a decrease in cloud cover. The only exception is the projected increase in mean annual precipitation in Crewe, compared to no change for the West Midlands.

2.2.12 Extreme weather events for Crewe are also expected to change in a similar way as for the West Midlands. The number of days with high temperatures, heavy rainfall and dry spells are expected to increase while frost days are projected to decrease.

Table 5: UKCP09 climate change projections for gradual meteorological changes for Crewe

Parameter and baseline (in brackets, 1961-1990)		2020s (2010-2039)			2080s (2070-2099)		
		Medium emissions scenario (50% level)	**High emissions scenario (50% level)**	**Range**[13]	**Medium emissions scenario (50% level)**	**High emissions scenario (50% level)**	**Range**
Temperature	Mean winter daily temperature [°C] (3.92°C)	5.45	5.40	4.68 – 6.21	6.98	7.55	5.57 – 9.26
	Mean summer daily temperature [°C] (15.14°C)	16.39	16.32	15.65 – 17.28	18.41	19.30	16.19 – 21.8
	Mean daily summer maximum temperature [°C] (18.13°C)	20.69	20.63	19.63 – 21.94	23.23	24.37	20.09 – 28.23
	Mean daily summer minimum temperature [°C] (10.37°C)	12.46	12.44	11.72 – 13.38	14.55	15.51	12.19 – 18.39
	Mean daily winter maximum temperature [°C] (5.52 °C)	8.07	8.03	7.26 – 8.89	9.46	10.03	7.83 – 12.37
	Mean daily winter minimum temperature [°C] (0.77 °C)	2.99	2.95	2.04 – 3.90	4.80	5.49	2.73 – 8.09
Precipitation	Annual mean daily precipitation [mm/day] (1.96mm/day)	2.19	2.19	2.09 – 3.90	2.18	2.18	2.06 – 2.33
	Winter mean daily precipitation [mm/day] (1.92mm/day)	2.30	2.29	2.11 – 2.48	2.51	2.61	2.24 – 3.09
	Summer mean daily precipitation [mm/day] (1.95mm/day)	1.94	1.99	1.65 – 2.36	1.74	1.74	1.41 – 2.21
Wind	Change in winter mean daily wind speed	-	-	-	-	-	-
	Change in summer mean daily wind speed	-	-	-	-	-	-

[13] Range from 10% level low emissions – 90% level high emissions

Parameter and baseline (in brackets, 1961-1990)		2020s (2010-2039)			2080s (2070-2099)		
		Medium emissions scenario (50% level)	**High emissions scenario (50% level)**	**Range[13]**	**Medium emissions scenario (50% level)**	**High emissions scenario (50% level)**	**Range**
Relative humidity	Annual relative humidity	80.61	80.64	79.74 – 81.52	79.71	79.28	78.53 – 81.28
Cloud cover	Annual cloud cover [%] (84%)	70	70	69 – 72	69	68	67 – 71

Table 6: UKCP09 Weather Generator values for extreme weather events for Crewe

Parameter and baseline (in brackets, 1961-1990)		2020s (2010-2039)			2080s (2070-2099)		
		Medium emissions scenario	**High emissions scenario**	**Range[14]**	**Medium emissions scenario**	**High emissions scenario**	**Range**
Temperature	Annual number of days when daily mean temperature is >25°C (0.01)	0.12	0.11	0.13 - 0.11	1.45	2.43	0.90 – 2.43
	Annual number of frost days (when daily mean temperature is 0°C or lower)[15] (5.76)	3.03	3.25	3.14 - 3.25	1.39	1.16	1.55 – 1.16
Precipitation	Annual number of days per year when precipitation is greater than 25mm per day (Met Office definition of 'heavy rain') (0.79)	1.08	1.12	1.17 - 1.12	1.42	1.51	1.30 – 1.51
	Annual number of dry spells (10+ day with no precipitation) (2.71)	3.53	3.41	3.49 - 3.41	4.52	4.91	4.17 – 4.91

[14] Range from 10% level low emissions – 90% level high emissions

[15] The definition of a frost day which we have used to inform the current and future climate baseline data and Weather Generator validation is when the daily *average* air temperature is below 0°C. We have used this definition as an indication of trends in cold weather days, as distinct from an indication of specific air frost events. The Met Office definition of an air frost day is when the daily *minimum* air temperature is below 0°C, http://www.metoffice.gov.uk/climatechange/science/monitoring/ukcp09/available/monthly.html. It is also possible for frost to occur when the air temperature is above 0°C as a result of radiative cooling

2.3 Validation exercise for the UKCP09 Weather Generator

2.3.1 The UKCP09 Weather Generator is subject to a number of known limitations that are described on the UKCP09 website[16] and in the UK Climate Projections science report 'Projections of future daily climate for the UK from the Weather Generator'[17]. The main limitation of the Weather Generator is its representation of extreme weather events, especially the representation of short duration (hourly) extreme rainfall and long-term events such as droughts.

2.3.2 Therefore, a validation exercise was carried out for the UKCP09 simulated baseline data to identify any discrepancies when compared against observed historic climate data and any consequent shortcomings in the projections of extreme weather events. The following section describes the definitions and sources used in the validation exercise and the subsequent results.

Metric definition

2.3.3 The results described below show agreement with simple metrics based on the observed and simulated climate data. Definitions of the metrics are provided in Table 7.

Table 7: Metric definitions for climate variables used in the UKCP09 Weather Generator validation exercise

Climate variable	Definition of metric
Annual heavy rainfall	The number of days per year with precipitation higher than 25mm/day
Annual dry spells	The number of events per year with 10 or more days without precipitation
Annual frost days	The annual number of days the mean temperature is below 0°C[18]
Annual high temperature events	The number of days with a mean temperature higher than 25°C

Data sources

2.3.4 The data sources used to inform the exercise are presented in Table 8. The water resources and flood risk topic have used Environment Agency data as the rainfall input data to their models for Phase 2a. Despite these data being superseded by flow rate observations, they are used here for consistency. The Environment Agency does not provide information on temperature. Therefore, World Meteorological Organisation (WMO) data was used to obtain temperature data for sites located near Fradley and Crewe that have a long observation time history. The climate projection data used for the two climate change assessments were based upon an average of the data for eight grid points covering Crewe and the West Midlands region (four grid points centred around each end of the route). However, in order to minimise the effects of spatial variation in the UKCP09 Weather Generator validation exercise, individual grid points were used for the UKCP09 Weather Generator simulated baseline data. Therefore,

[16] UKCP09 (2014), *Limitations of Weather Generator 2.0* (2014), http://ukclimateprojections.metoffice.gov.uk/22653
[17] UKCP09 (2009),*Projections of future daily climate for the UK from the Weather Generator* http://ukclimateprojections.metoffice.gov.uk/media.jsp?mediaid=87848&filetype=pdf
[18] The definition of a frost day which we have used to inform the current and future climate baseline data and Weather Generator validation is when the daily *average* air temperature is below 0°C. We have used this definition as an indication of trends in cold weather days, as distinct from an indication of specific air frost events. The Met Office definition of an air frost day is when the daily *minimum* air temperature is below 0°C, http://www.metoffice.gov.uk/climatechange/science/monitoring/ukcp09/available/monthly.html. It is also possible for frost to occur when the air temperature is above 0°C as a result of radiative cooling

absolute values presented in the validation exercise and the assessments respectively may vary slightly.

Table 8: Summary of data sources used for the UKCP09 Weather Generator validation exercise

Data source	Information available	Locations available
UKCP09 gridded observation data sets[19]	Time series of daily maximum temperature Time series of daily minimum temperature Time series of daily mean temperature Time series of daily precipitation Number of high precipitation events per year (>25mm/day) Number of dry spells per year (>10 days with no precipitation) Number of hot days (mean temperature >25°C) Number of frost days (mean temperature <0°C)	UK 5km gridded data
WMO weather station data[20]	Time series of daily mean temperature Time series of daily maximum temperature Time series of daily minimum temperature	Crewe Chester Coleshill
Environment Agency data[21]	Time series of daily precipitation No temperature data	Audlem Alsager Kidsgrove Worleston Barton Under Needwood Elford Hanch Hixon Stafford

[19] UKCP09, *Gridded observation data sets*, http://www.metoffice.gov.uk/climatechange/science/monitoring/ukcp09/, UKCP09, *Weather Generator*, http://ukclimateprojections.metoffice.gov.uk/23261, and UKCP09, *Validation of Weather Generator outputs*, http://ukclimateprojections.metoffice.gov.uk/media.jsp?mediaid=87941&filetype=pdf

[20] World Meteorological Organization, *Observations,* https://public.wmo.int/en/our-mandate/what-we-do/observations

[21] Environment Agency, *Quality Controlled Daily and Monthly Rain gauge Data from Environment Agency Gauges*, https://data.gov.uk/dataset/quality-controlled-daily-and-monthly-raingauge-data-from-environment-agency-gauges-afa148

Validation of climate metrics

2.3.5 A validation of the UKCP09 Weather Generator simulated baseline data against the observed historical data for selected metrics of climate variables is provided in Figure 1 for both the West Midlands and Crewe.

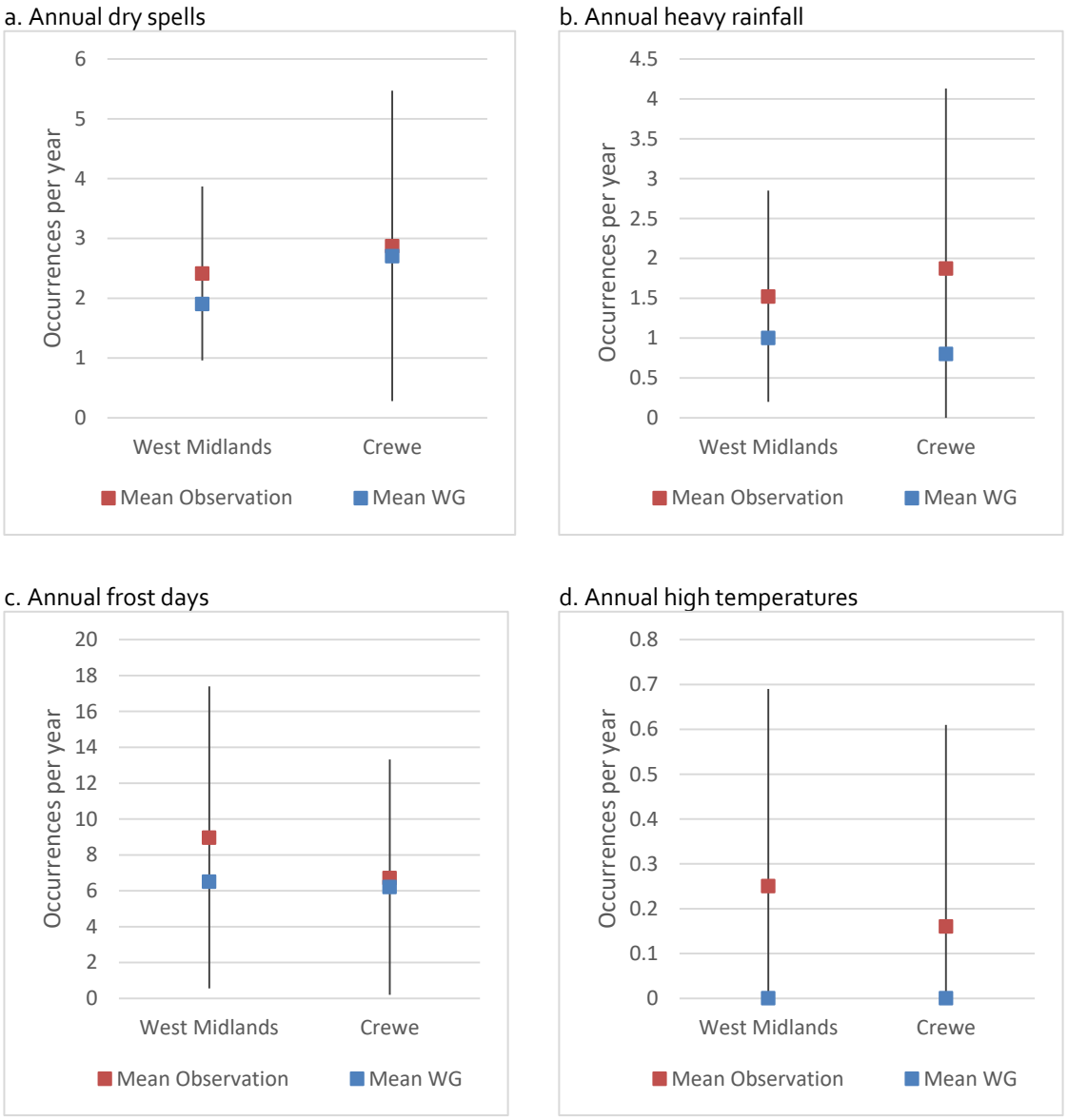
2.3.6 For both locations the UKCP09 Weather Generator simulated baseline data appears to reflect the number of observed annual dry spells and annual frost days with reasonable accuracy, and is well within the standard deviation (see Figure 1a and Figure 1c). The values for observed annual frost days presented in Figure 1c are slightly lower than the number of observed annual frost days in the region around Phase 2a (summarised in Table 5 in Volume 3, Section 4). This is due to the fact that the two sources of observed data obtained for different purposes (to provide the existing baseline data for the assessments and for the UKCP09 Weather Generator validation exercise respectively) use different definitions of a frost day. The most common definition is when the daily minimum air temperature is below 0°C, but it is also possible for frost to occur when the air temperature is above 0°C as a result of radiative cooling[22].

2.3.7 By contrast, the UKCP09 Weather Generator simulated baseline data does not appear to accurately reflect the number of observed annual heavy rainfall events or the number of observed annual high temperature events (see Figure 1b and Figure 1d). For annual heavy rainfall events this may be due to the simplified equation used to derive hourly rainfall rates[23]. As a result, simulations of future extreme precipitation events may be limited because the UKCP09 Weather Generator does not account for a potential increase in convective precipitation events. For annual high temperature events this may be due to the difficulties in representing the blocking events which can lead to heatwaves. As a result, simulations of future extreme hot weather events may be limited. These are both known limitations of the UKCP09 Weather Generator[24,25].

2.3.8 Despite the apparent limitations of the UKCP09 Weather Generator it is currently still widely considered to be a useful indicator of current and future extreme weather events and of threshold exceedances, parameters which are not provided by the standard UKCP09 output. However, Figure 1 shows there is an underestimation of the number of extreme rainfall events and extreme hot weather events. Therefore, the values presented in Table 4 and Table 6 in Section 2.2 of this document and in Table 5 of Volume 3, Section 4 may similarly be underestimated. This is considered in the in-combination climate change impacts assessment and the climate change resilience assessment.

[22] Met Office, http://www.metoffice.gov.uk/learning/frost/forecasting-frost
[23] UKCP09 (2009), *Projections of future daily climate for the UK from the Weather Generator*, http://ukclimateprojections.metoffice.gov.uk/media.jsp?mediaid=87848&filetype=pdf
[24] UKCP09 (2014), *Limitations of Weather Generator 2.0*, http://ukclimateprojections.metoffice.gov.uk/22653
[25] UKCP09 (2010), *Projections of future daily climate for the UK from the Weather Generator*, http://ukclimateprojections.metoffice.gov.uk/media.jsp?mediaid=87944&filetype=pdf

Figure 1: Comparison of the frequency of selected climate metrics from observed weather data and the UKCP09 Weather Generator simulated baseline data



Note: Bars show the standard deviation of observations a) Annual dry spells b) Annual heavy rainfall c) Annual frost days d) Annual high temperatures.

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High Speed Two (HS2) Limited
Two Snowhill
Snow Hill Queensway
Birmingham B4 6GA

08081 434 434
HS2Enquiries@hs2.org.uk

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