# Resilience to extreme weather

## Climate and exposure mapping methodology

THE ROYAL SOCIETY

# Climate and exposure mapping methodology

## Climate projections

The metrics of climate extremes and exposure in this report are based on the climate change projections available in the Coupled Model Intercomparison Project Phase 5 (CMIP5) archive[1]. Each of the metrics described below were calculated for each separate climate model in the CMIP5 archive. Multi-model means were calculated with equal weighting for each model. Where a modelling group submitted more than one simulation for the scenario in question, only the first simulation was included in the multi-model mean to avoid over-emphasising the models which submitted multiple runs. In some cases, a given modelling group did not submit all variables to the archive, as a result the various metrics presented are based on the mean of differing numbers of models. For example, the exposure to warming metric (Figure 9, full report) is based on the mean near surface temperature projections from 40 models; the heatwave diagnostic (Figure 5, full report) is based on the daily minimum near surface temperatures in 33 models; and the labour productivity diagnostic (Figure 10, full report) is based-on the near surface humidity, temperature and surface pressure from 31 models.

## Representative Concentration Pathways

For the projections shown in this report Representative Concentration Pathways (RCPs) were used as the input for future greenhouse gas emissions. There are four RCPs, each representing a different emissions pathway and subsequent radiative forcing, which aim to show the range of temperature increases above pre-industrial levels in 2100 that are found in the scientific literature (see figure 7 in main text, Chapter 2).

Of the four RCPs the highest temperature change pathway – RCP 8.5 – is used for the maps in this report. This allows consideration of the upper range of risk, which is essential when conducting risk management exercises. The RCP 8.5 pathway is projected to lead to an increase in global mean surface temperatures of 2.6°C to 4.8°C for 2081–2100 relative to 1986–2005[2]. Although RCP8.5 is the highest emission scenario considered in the Intergovernmental Panel on Climate Change Fifth Assessment Report, current emissions trends are closest to this scenario[3].

More details on the RCPs can be found in the latest Intergovernmental Panel on Climate Change report from Working Group I[4].

1. CMIP5 model output data available from http://cmip-pcmdi.llnl.gov/cmip5/ following registration
2. IPCC 2013 *The physical science basis. Contribution of working group 1 to the fifth assessment report of the Intergovernmental Panel on Climate Change* ((ed.) Stocker, T F, Qin, D, Plattner, G-K, Tignor, M, Allen, S-K, Boschung, J, Nauels, A, Xia, Y, Bex, V & Midgley, P M). Cambridge and New York: Cambridge University Press.
3. Friedlingstein, P, Houghton, R A, Marland, G, Hackler, J, Boden, T A, Conway, T J, Canadell, J G, Raupach, M R, Ciais, P & Le Quéré, C 2010 Update on CO2 emissions. *Nature Geoscience*, **3**, 811–812 (DOI:10.1038/ngeo1022)
4. *Op. cit.*, note 2.

## Population projections

For the population scenarios data the Shared Socioeconomic Pathways (SSPs) were used. There are a total of five SSP scenarios which are compatible with different RCP scenarios (note: each SSP may be compatible with more than one RCP). The SSPs are a set of scenarios, or storylines, that were developed at an expert workshop in 2011 to be used in climate modelling exercises. Each storyline provides a narrative of the main characteristics of the future development path (see table 1 for a summary of these characteristics). The report uses the SSP that represents a central scenario (SSP2). In brief the 'storyline' for the scenario is:

### SSP2 middle of the road or current trends continue

Trends typical of recent decades continue, with some progress towards achieving development goals. Educational investments are not high enough to rapidly slow population growth, particularly in low-income countries. This pathway assumes an extension of current trends in urbanization in all parts of the world, along with similar middle of the road assumptions about population growth and economic growth. High income countries continue their practices in urban development; developing countries generally follow the historical urbanization experiences of the more developed countries.

The SSP scenarios split countries into three groups:

- High Fertility Countries: Countries with current level of fertility less than 2.9 children per woman (2005-2010).
- Low Fertility Countries: Countries with current level of fertility less than or equal to 2.9 not belonging to Rich OECD countries
- High Income-OECD Countries: As per the definition of World Bank which, for the 2014 fiscal year, is 'high-income economies are those with a GNI per capita of $12,616 or more'[5].

For more information about the SSP storylines, see O'Neill *et al*. (2012)[6].

5. http://data.worldbank.org/about/country-and-lending-groups#OECD_members
6. O'Neill, B, Carter, T R, Ebi, K L, Edmonds, J, Hallegatte, S, Mearns, L & Riahi, K 2012 *Workshop on the nature and use of new socioeconomic pathways for climate change research*. Boulder: National Center for Atmospheric Research (See https://www2.cgd.ucar.edu/sites/default/files/iconics/Boulder-Workshop-Report.pdf, accessed 13.10.2014)

Table 1

Table 1: Main assumptions for the SSP population projections (taken from the supplementary note for the SSP data sets[7]).

The SSP scenarios include gridded population data (0.5o resolution in longitude and latitude) at yearly intervals, as well as data on the GDP, urban population share, education and demography at 5 or 10 year levels at the country level. For the SSP population data to be compatible with the CMIP5 climate data it was re-gridded by aggregating the population up to 2.5o resolution in longitude and latitude. When population was stratified (by urban/rural share or demography etc.) the stratification was applied to the 0.5o population data before re-gridding. In the absence of sub-national data, information on GDP/urban share/demography was assumed to be constant for all locations within a country.

| | SSP 1 | | | SSP 2 | | | SSP 3 | | | SSP 4 | | | SSP 5 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Country Groupings | | | | | | | | | | | | | | |
| SSP Element | *HiFert* | *LoFert* | *Rich-OECD* | *HiFert* | *LoFert* | *Rich-OECD* | *HiFert* | *LoFert* | *Rich-OECD* | *HiFert* | *LoFert* | *Rich-OECD* | *HiFert* | *LoFert* | *Rich-OECD* |
| ***Demographics*** | | | | | | | | | | | | | | | |
| *Population* | | | | | | | | | | | | | | | |
| Fertility | Low | Low | Med | Med | Med | Med | High | High | Low | High | Low | Low | Low | Low | High |
| Mortality | Low | Low | Low | Med | Med | Med | High | High | High | High | Med | Med | Low | Low | Low |
| Migration | Med | Med | Med | Med | Med | Med | Low | Low | Low | Med | Med | Med | High | High | High |
| ***Education*** | High (FT) | High (FT) | High (FT) | Med (GET) | Med (GET) | Med (GET) | Low (CER) | Low (CER) | Low (CER) | V.Low (CEN) | Low (CER) | Med (GET) | High (FT) | High (FT) | High (FT) |

## Sea level rise

The flood projections used in the report were produced using global-mean sea-level rise estimates for an RCP8.5 sea level pattern (high SLR) weighted by coastal length, rather than area, expected number of people flooded per year  and by the total population in the low elevation coastal zone below 10 m. This is done following the DIVA data model, which divides the world's coasts into about 12,000 linear segments. Full details of the sea-level scenarios and DIVA are given in Hinkel *et al.*[8].

## Climate extremes

The report addresses floods, droughts and heatwaves. It also looks at the effect of rising temperatures on outdoor labour productivity. The indicators used for each of these climate extremes and impacts are detailed in table 2 and described in Box 2 (chapter 2).

7. Available at: https://secure.iiasa.ac.at/web-apps/ene/SspDb/static/download/ssp_suplementary%20text.pdf, accessed 8 October 2014.

8. Hinkel, J, Lincke, D, Vafeidis, A T, Perrette, M, Nicholls, R J, Tol, R S J, Marzeion, B, Fettweis, X, Ionescu, C & Levermann, A. 2014 *Coastal flood damage and adaptation costs under 21st century sea-level rise*. Proceedings of the National Academy of Sciences (DOI:10.1073/pnas.1222469111).

Table 2

Table 2: Indicators and definitions used for the different climate hazards.

| Indicator | Definition |
|---|---|
| Temperature change | Summer mean temperature anomaly (from 1986-2005) |
| Labour capacity | Maximum labour capacity determined from the WBGT |
| Heatwave | 5 consecutive days $5°C$ above the summer mean $T_{min}$. |
| Drought | Maximum number of consecutive dry days (pr $<$1mm) |
| Flood | Maximum 5 day precipitation total |

### Heatwave

Heatwaves are defined here using the index proposed in Jacob *et al.* (2013)[9] (but using daily minimum temperature data instead of maximum), as any period of more than 3 consecutive days exceeding the 99th percentile of the daily minimum temperature of all DJF/JJA seasons for the recent past (1986-2005). The change in heatwave frequency is the difference between the projected number of heatwaves and the number of heatwaves in the recent historic period (1986-2005). The number of exposure events is calculated by multiplying by the population density of people over 65 years old.

### Wet bulb temperature

To investigate the impact of climate change on labour productivity the wet-bulb globe temperature (WBGT) is chosen as the most relevant climate metric; the WBGT has been validated for environmental heat stress occupational thresholds for industrial and United States military labour standards. The WBGT and labour capacity are calculated as in Dunne *et al.* (2013)[10], except here the summer mean values (NH JJA/SH DJF) are used instead of the annual maximum/minimum. For WBGT, 25°C is the upper threshold for heavy labour to be conducted at 100% capacity, and for increasing WBGT labour capacity drops until 33°C at which point even light labour can only be conducted at 25% capacity. The labour capacity function developed in Dunne *et al.*[11] is used here.

9. Jacob, D, Petersen, J, Eggert, B, Alias, A, Bøssing, O, Laurens C, Bouwer, M, Braun, A, Colette, A, Déqué, M, Georgievski, G, Georgopoulou, E, Gobiet, A, Menut, L, Nikulin, G, Haensler, A, Hempelmann, N, Jones, C, Keuler, K, Kovats, S, Kröner, N, Kotlarski, S, Kriegsmann, A, Martin, E, van Meijgaard, E, Moseley, C, Pfeifer, S, Preuschmann, S, Radermacher, C, Radtke, K, Rechid, D, Rounsevell, M, Samuelsson, P, Somot, S, Soussana, J-F, Teichmann, C, Valentini, R, Vautard, R, Weber, B & Yiou, P 2013 *EURO-CORDEX: new high-resolution climate change projections for European impact research*. Regional Environmental Change, **14**(2), 563-578 (DOI: 10.1007/s10113-013-0499-2).

10. Dunne J P, Stouffer, R J & John, J G 2013 *Reductions in labour capacity from heat stress under climate warming*. Nature Climate Change, **3**, 563–566 (DOI:10.1038/nclimate1827)

11. *Op. cit.*, note 10.

The total labour capacity lost is calculated by multiplying by the local rural population (under the assumption that most outdoor jobs are in rural areas).

## Drought and Flood Indices

Modelling the incidence and impacts of floods and droughts requires complex modelling of surface hydrology, including evapotranspiration, runoff generation, and the hydraulics of rivers. In order to get a first indication of changing exposure to floods and droughts for this report, indices were defined based purely on climate projections in the CMIP5 archive. Changes in the length of the longest dry period in each year (where a dry day is assumed to be one with less than 1mm of rainfall), and changes in the highest rainfall total over a 5 day period in each year, were used to indicate the changing incidence of the low and high rainfall periods associated with flood and droughts. The relevance of the latter measure to flood generation is of course dependent on basin scale, but we select a 5 day accumulation period as it is relevant to a range of medium sized catchments.

## Calculating Exposure

The vulnerability to climate change is a function of the climate hazard (eg number of floods, droughts, heatwaves) and the number of vulnerable people exposed. A first order measure of exposure is therefore defined here as:

$$E(x,t) = \Delta T(x,t)P(x,t)$$

where ΔT(x,t) is the climate hazard and P(x,t) is the density of the vulnerable section of the population (in people per $km^2$), both of which are in general dependent on both space (x) and time (t). The definition of the vulnerable population depends on the climate hazard (outlined above).