GERICS
Climate Service Center
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Briefing paper

How to read a Climate-Fact-Sheet

Instructions for reading and interpretation of the Climate-Fact-Sheets (Updated Version 2015)

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1. Background

In 2011 the Climate-Fact-Sheets have been developed jointly by the KfW Development Bank and the Climate Service Center Germany (GERICS) in order to provide an easy accessible way of providing information about future climate change information relating to individual countries/regions in a condensed manner. In general, the Climate-Fact-Sheets were designed to summarize the projected climate changes on a country level. However, in some cases, regional Climate-Fact-Sheets seemed to be more appropriate. More details on this issue can be found in Section 3.

Originally, the Climate-Fact-Sheets were developed on the basis of the climate change projections presented in the 4th Assessment Report[1] (AR4) of the Intergovernmental Panel on Climate Change (IPCC). With the release of the 5th IPCC Assessment Report[2] (IPCC AR5) in 2013/2014, it was decided to update the Climate-Fact-Sheets to the data source of IPCC AR5. Details on this can be found in Sections 4 and 5.

Due to the update of the Climate-Fact-Sheets data bases, the figures presenting the climate change information were also changed. In addition this manual on "How to read a Climate-Fact-Sheet" had to be updated as well. This manual aims to briefly describe the concept of the Climate-Fact-Sheets, the data on which the information is based on, as well as the figures used within the Climate-Fact-Sheets. Note that this manual is not intended to be a comprehensive review on the use of climate model data. Sources of data/methods are referred to in various footnotes.

2. Concept and structure of the Climate-Fact-Sheets

The Climate-Fact-Sheets have a three-part structure comprising of information on the current climate, the observed historical climate development and the projected future climate changes. The Sections relating to the current climate and the historical climate development are in the form of a concise overview only. The main focus of the Climate-Fact-Sheets is on the information relating to projected future climate developments for a specific country/region. Therefore, the main bulk of information presented in a Climate-Fact-Sheet relates to this. Additionally, a short explanation of the innovations in the updated Climate Fact Sheets as well as the descriptions of the figures used is written in the "Update of the Climate-Fact-Sheets in a nutshell" is provided within each Climate-Fact-Sheet in order to allow the user to understand the figures without reading through this extended manual.

Each Climate-Fact-Sheet delivers standard information on the following climate parameters: *annual mean*, *minimum* and *maximum temperatures*, *heat waves, cold spells, total annual* and *mean monthly precipitation, dry spells*, *intensity* and *frequency of heavy rain events*, *actual evaporation*, *climatic water balance, mean solar irradiance* and *mean wind speed*. Additionally, if appropriate, changes in *mean sea level* are included into the Climate-Fact-Sheets. A short description of all parameters and their derivations is given in the glossary (see Section 9).

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[1] Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. [Core Writing Team, Pachauri, R.K. and Reisinger, A. (Eds.)]. IPCC, Geneva, Switzerland. 104 pp.
[2] Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

3. Geographical representation

In the standard form, the Climate-Fact-Sheets deliver climate change information aggregated for individual countries, but in specific cases, other geographical representations might be more appropriate. In general, the Climate-Fact-Sheets are based on projections from global climate models, available for all regions of the world. However, the spatial resolution of these projections lies between approximately 100 and 500 kilometres (see Table 1). This means that on the basis of this data it is not possible to quantify the magnitude of future climate change for smaller regions or even local sites, but only as average over larger regions. Therefore, it is possible that individual countries might be too small to be represented by data of such coarse scale climate change projections. In order to circumvent this, smaller countries are either grouped into a regional Climate-Fact-Sheet, or a minimum area of at least 4° x 4° centred around the country of interest (or at least of a specific part of the country) is considered as representative for the given country. Examples of these are given in Figure 1 below. The respective target region of the Climate-Fact-Sheet is indicated by a yellow/orange frame/box.
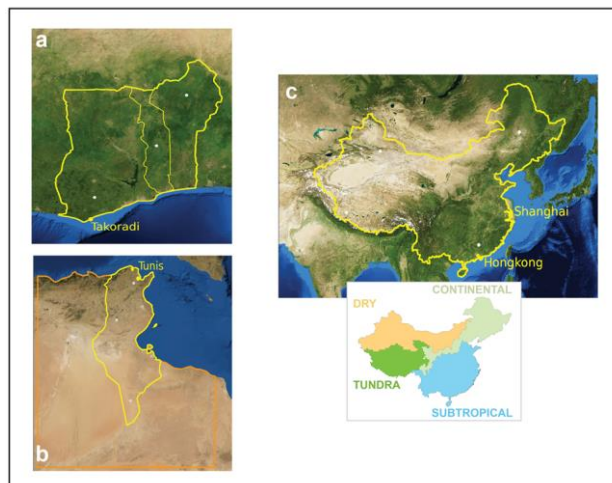

Figure 1: Examples for different types of geographical representation in the Climate-Fact-Sheets apart from the standard single country Climate-Fact-Sheet: a) Ghana, Togo and Benin grouped into a regional Climate-Fact-Sheet; b) 4° x 4° box (orange frame) centred around Tunisia, as the country area of Tunisia is too small to be solely represented by the global climate model projections; c) China is subdivided into four different climate zones of which for each a separate analysis is included into the respective Climate-Fact-Sheet.

In another form, it could also be the case that a country is very large and spans over a series of different climates. In order to represent these variations the territory of the country is divided into separate climate zones. For each of the climate zones, a separate analysis of the development of the future climate is conducted and depicted in the Climate-Fact-Sheet (see Figure 1c). However, information on the current climate or on historical climate development applies for the country as a whole i.e., across the borders of any existent climate zones.

It is important to note that due to the brevity of the Climate-Fact-Sheets and due to the availability of comparable climate model projections for regions throughout the globe; it is unfortunately not possible to arrive at more detailed conclusions on geographic variability. Therefore, in addition to the information provided in the Climate-Fact-Sheets, more detailed studies need to be conducted to provide information for the planning process on a subnational/subregional or even local scale.

4. Data underlying the Climate-Fact-Sheets

As mentioned before, the Climate-Fact-Sheets provide a brief overview of the current climate in a target country as well as climatic developments in the past and a detailed synopsis of projected climatic change. Various sources of datasets have been referred to as follows:

i). Current Climate and past climate trends: In order to present the **current climate** conditions, globally available observational datasets from the Climate Research Unit of the University of East Anglia in Norwich, UK (also known as CRU[3]), the ERA-40[4] reanalysis product from ECMWF, and the WATCH forcing data[5] have been used. These datasets are frequently used as reference datasets in climate research and are well-known and widely accepted. We also used these datasets for the evaluation of the single model simulations quality for today's conditions as part of the expert judgment (see Section 8.2.2.). For the **historical trends** also the CRU data has been used to quantify changes in the annual mean temperature and annual total precipitation, both for the period from 1901 to 2013. Here, the same thresholds and assumptions to categorize the observed changes into a small, medium-large or large trend have been used as for the projected changes (see Table 3; small refers to weak, medium-large to medium-strong and large to strong, respectively). In addition to the data estimates of these globally available dataset, data from country/region specific literature sources on past trends and extreme events have also been included into the Climate-Fact-Sheets.

ii). Climate change projections: An estimation of the possible magnitude of future climate change is made on the basis of multiple projections of global climate models. A so-called multi-model multi-scenario ensemble from a variety of different global climate models and projections for different greenhouse gas emission scenarios forms the basis of this. The intention to use this large ensemble of different projections is to increase the robustness of projections regarding future climatic change, since one can generally assume that conclusions suggested by any single model, given the necessary simplification of naturally occurring processes within that model, are only conditionally applicable. As these simplifying methods are employed differently in the case of each model, one can assume that when considering several models (i.e. a multi-model ensemble), that the robustness of the results will rise. The same holds true for the different greenhouse gas emission pathways. From today's perspective, it is not possible to identify an emission pathway which is more likely to be followed throughout the course of the 21st century. Therefore different emission scenarios are included into the data analysis. Details on the multi-model multi-scenario ensemble are given in Section 5.

In the Climate-Fact-Sheets climate change projections are presented for the whole 21st century. But only projected future changes with respect to the mean situation over the reference period from 1971 to 2000 are shown. This averaging over thirty years ensures that short term climate variability, (e.g. annual or decadal fluctuations) does not adulterate the long-term climate change signal. Therefore the projection diagrams in the Climate-Fact-Sheets (for details see Section 7) are also showing 30-year moving averages and therefore only cover the period from 2006 to 2085 (as the year 2085 is the centre of a 30yr moving average from 2071 to 2100).

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[3] New M., Lister D., Hulme M., Makin I. (2002): A high-resolution data set of surface climate over global land areas. In: Climate Research, 21, 1, doi:10.3354/cr021001.
[4] Uppala SM, et al. (2005): The ERA-40 re-analysis. Quarterly Journal of the Royal Meteorological Society 131(612): 2961–3012.
[5] Weedon G.P., Gomes S., Viterbo P., Shuttleworth W.J., Blyth E., Osterle H., Adam J.C., Bellouin N., Boucher O., Best M. (2011): Creation of the WATCH Forcing Data and Its Use to Assess Global and Regional Reference Crop Evaporation over Land during the Twentieth Century. In: Journal of Hydrometeorology, 12, 823–848.

iii). Information on the mean sea level: Observed trends in the mean sea level have been taken from literature and the "Tides and Currents" portal from NOAA (http://tidesandcurrents.noaa.gov). However, for many of the countries considered in the Climate-Fact-Sheets no long-term mean sea level observations are available. For the future, projections of mean sea level change data are based on different coupled atmosphere-ocean general circulation model simulations, which are the basis of the IPCC AR5 chapter 13[6] on sea level change. Additionally an uncertainty measure for (90% confidence interval) is given. This uncertainty estimate include the multi-model spread as well as additional contributors to sea level change that are not included in the model simulations, such as changes in the Greenland and Antarctic ice-sheets and land water storage. For details on what components have contributed to the sea level change estimates and their respective uncertainties, please refer to http://www.climatechange2013.org/images/report/WG1AR5_Ch13SM_FINAL.pdf.

The data for this have been accessed via the Integrated Climate Data Center (ICDC; http://icdc.zmaw.de/daten/ocean/ar5-slr.html). Projected changes in sea level are presented as mean change for two 20-year-periods from 2046 to 2065 and 2081 to 2100 only to be consistent with the reference period from 1986 to 2005. The projected changes of mean sea levels are depicted for selected coastal cities, following the approach applied in IPCC AR5.

5. Description of the Climate-Fact-Sheets multi-model multi-scenario ensemble

In the updated version of the Climate-Fact-Sheets two multi-model multi-scenario ensembles of global climate change projections are considered to estimate the future climate development. The main data source is the CMIP5[7] (Coupled intercomparison Project No 5) data ensemble, which builds the data base for the global climate change projections presented in IPCC AR5 (released in 2013/2014). Additionally, the projections from the CMIP3[8] (Coupled intercomparison Project No 3) that are the data basis of the IPCC AR4 (released in 2007), and which were used in the original version of the Climate-Fact-Sheets, are included into the analysis. Both projects, CMIP3 and CMIP5 have been promoted by the World Climate Research Programme (WCRP). Although the CMIP5 ensemble is more recent than the CMIP3 ensemble, the projections of CMIP3 are still valid and are used to complement the information coming from CMIP5, than being replaced by them. Including data from both ensembles allows further to compare the ranges of projected climate change depicted in the original version to the ones of depicted in the updated version of the Climate-Fact-Sheets.

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[6] Church, J.A., P.U. Clark, A. Cazenave, J.M. Gregory, S. Jevrejeva, A. Levermann, M.A. Merrifield, G.A. Milne, R.S. Nerem, P.D. Nunn, A.J. Payne, W.T. Pfeffer, D. Stammer and A.S. Unnikrishnan, (2013): Sea Level Change Supplementary Material. In: Climate Change (2013): The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Available from www.climatechange2013.org and www.ipcc.ch

[7] Taylor, Karl E., Ronald J. Stouffer, Gerald A. Meehl (2012): An Overview of CMIP5 and the Experiment Design. Bull. Amer. Meteor. Soc., 93, 485–498.

[8] Meehl, Gerald A., Curt Covey, Karl E. Taylor, Thomas Delworth, Ronald J. Stouffer, Mojib Latif, Bryant McAvaney, and John F. B. Mitchell, (2007): THE WCRP CMIP3 Multimodel Dataset: A New Era in Climate Change Research. Bull. Amer. Meteor. Soc., 88, 1383–1394.

Table 1: Overview on the number of models and the horizontal resolution of the available climate change projections from the CMIP3 (data base of IPCC AR4) and CMIP5 (data base of IPCC AR5) multi-model multi-scenario ensembles.

	No. of Models	Horizontal Resolution* (Atmoshphere)				
		<1°	1.0° - 2.0°	2.0° - 3.0°	3.0° - 4.0°	>4.0°
CMIP3	24	0	7	9	5	3
CMIP5	30	1	15	11	3	0

* Note that 1° corresponds to about 111km at the equator. While in north-south direction this remains constant for all locations of the globe (constant distance between latitudes) the distance between different longitudes (east-west direction) is getting smaller towards the poles.

In general, two major differences exist between the multi-model multi-scenario ensembles generated from CMIP3 and CMIP5. First, the global climate models and the computing systems have developed further from the CMIP3 to the CMIP5 project, which means that for CMIP5 more comprehensive models at a slightly higher spatial resolution than in CMIP3 have been used. Details on the number of models included in each of the intercomparisons and the respective horizontal resolution of the datasets of the climate change projections are given in Table 1.

The second difference between CMIP3 and CMIP5 data is that different emission scenario pathways have been used to estimate possible future evolutions of greenhouse gas and aerosol emissions to the atmosphere influence the global radiation balance. In the earlier CMIP3 project, the projections are based on the scenarios specified in the Special Report on Emission Scenarios (SRES)[9]. The SRES report covers a wide range of demographic, economic, social and technical driving forces, from which different emission scenario families (A1, A2, B1, B2) have been defined. In the CMIP5 project these scenarios have been based on the Representative Concentration Pathways[10] (RCPs) that are derived from a new scenario process. RCPs as RCP8.5, RCP6, RCP4.5, and RCP2.6 are defined by the different radiative forcing levels (in watts per square metre), reached at the end of the 21st century relative to the preindustrial period (about 1765). In contrast to the previous SRES scenarios each RCP can now be directly connected to specific socio-economic developments and to the political decision making process. The RCP2.6 for example represents a very strong mitigation scenario, whereas the RCP8.5 assumes a rather continuous increase in greenhouse gas emissions

Regarding the magnitude of future radiative forcing SRES and RCP-Scenarios generally represent a rather similar range (see Figure 2) apart from the fact that for RCP2.6 the radiative forcing is lower than any of the SRES scenarios.

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[9] Nakicenovic N, Swart R (Eds.) (2000): Emission Scenarios. Cambridge University Press, UK. pp 570.
[10] Moss, R. H., J. A. Edmonds, K. A. Hibbard, M. R. Manning, S. K. Rose, D. P. van Vuuren, T. R. Carter, S. Emori, M. Kainuma, T. Kram, G. A. Meehl, J. F. B. Mitchell, N. Nakicenovic, K. Riahi, S. J. Smith, R. J. Stouffer, A. M. Thomson, J. P. Weyant & T. J. Wilbanks, (2010): The next generation of scenarios for climate change research and assessment. Nature 463:747-756.
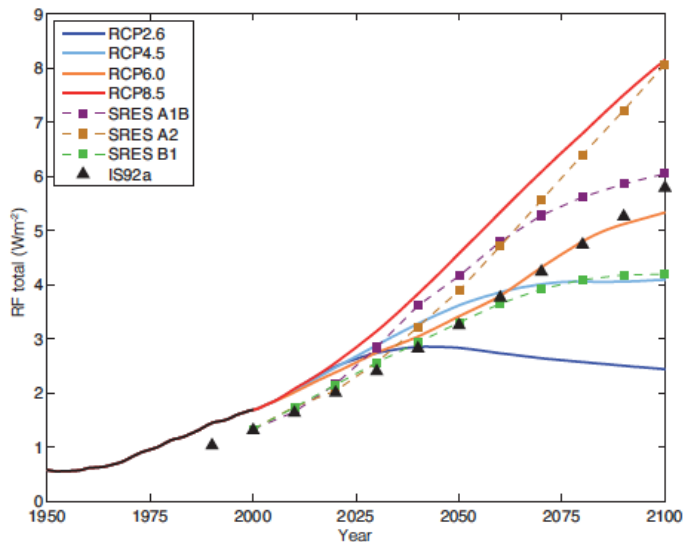
Figure 2: Historical and projected total anthropogenic radiative forcing (Wm^{-2}) relative to preindustrial (about 1765) between 1950 and 2100. Previous IPCC assessments (SAR IS92a, TAR/AR4 SRES A1B, A2 and B1) are compared with representative concentration pathway (RCP) scenarios. Source: IPCC 2013, Figure 1.15.

5.1 Handling of the different model projections and emission scenarios in the Climate-Fact-Sheets

In the Climate-Fact-Sheets, all available climate change projections from CMIP3 and CMIP5 have been included. Focus has been given on the use of the CMIP5 multi-model multi-scenario ensemble due to the fact that the CMIP5 model output for all climate parameters considered was available at a daily time resolution, which was needed to calculate the parameters depicted. Therefore, most of the numbers describing the magnitude of future climate change in the Climate-Fact-Sheets are based on the CMIP5 multi-model multi-scenario ensemble. Exceptions to this are the projected changes depicted for the global mean temperature change thresholds (below +2°C and above +4°C description; see paragraph on "iii) Ensemble Selection by a global mean temperature change" in Section 7.2.1.) for which projections from both ensembles are considered.

For the CMIP5 ensemble, a large number of global climate model projections is available for the RCP2.6, the RCP4.5 and the RCP8.5 scenario and therefore are considered within the Climate-Fact-Sheets. For simplification, these scenarios are referred to as a low (RCP2.6); a medium (RCP4.5) and a high RCP8.5) scenario[11] in the Climate-Fact-Sheets.

Although at present many factors point to a strong increase in future greenhouse gas emissions, it is currently not possible to indicate which of the scenarios is most likely to occur in the future (especially when thinking towards the end of the 21st century). In this regard, projected changes in the Climate-Fact-Sheets are examined jointly together for all three scenarios. Nevertheless,

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[11] The classifications low, medium and high refer to an increase in greenhouse-gas concentrations in the future atmosphere. The projected development of the CO_2 concentration is here used as an appropriate example. The current level is approximately 450 ppm (level as of 2015). Up to the year 2100, the following atmospheric CO_2 concentrations are projected, depending on the scenario: RCP8.5 >1,370 CO_2-equivalent in 2100, RCP6.0 ~850 CO_2- equivalent (at stabilization after 2100), RCP4.5 ~650 CO_2- equivalent (at stabilization after 2100), RCP2.6 Peak at ~490 CO_2-equivalent (before 2100 then decline). For more information on scenarios look into *Moss RH, Edmonds JA, Hibbard KA, Manning MR, Rose SK, van Vuuren DP, Carter TR, Emori S, Kainuma M, Kram T et al (2010): The next generation of scenarios for climate change research and assessment. Nature 463:747–756*

separate consideration of the scenarios might become useful for planning purposes. Therefore, it is also estimated which ranges of climate change signals are projected under the "best case scenario" (low emission scenario – RCP2.6) or under the "worst case scenario" (high emission scenario – RCP8.5).

In order to be able to relate the magnitude of projected climate change from the previous version of the Climate-Fact-Sheets to the updated version, we also included the projected changes from the previous CMIP3 ensemble. However, projected changes from the latter ensemble are not presented separately for the different emission scenarios and, due to data issues, only for two dedicated future time periods. Apart from relating the different versions of Climate-Fact-Sheets to each other, comparing projected changes originating from two different generations of multi-model ensembles also helps to increase the robustness of the projected changes, especially if the range of the projected changes in CMIP3 is reproduced by the CMIP5 ensemble.

Finally it has to be noted that the database is not identical for all climate parameters described in one Climate-Fact-Sheet. Although the CMIP5 ensemble currently reflects the largest and most harmonized dataset of global climate change projections available, not all models provide the output for the same set of variables. In order to have a database as large as possible for each climate parameter, the maximum number of climate change projections available was identified, quality checked and eventually included into the analysis. Therefore, the number of underlying climate change projections slightly differs from climate parameter to climate parameter and also from scenario to scenario (see Table 2).

Table 2: Overview on the number of analysed projections for each of the multi-model ensemble, emission scenarios and the various climate parameters.

Emissions scenarios	Climate Parameters											
	Annual mean temperature	Annual maximum temperature	Annual minimum temperature	Heat waves	Cold spells	Annual total precipitation	Evaporation	Climatic water balance	Dry spells	Heavy rainfall events	Solar irradiance	Wind speed
Low (RCP2.6) scenario	20	20	20	20	20	20	15	15	20	20	17	15
Medium (RCP4.5) scenario	27	27	26	27	27	27	17	16	27	27	21	20
High (RCP8.5) scenario	29	28	27	29	29	29	18	17	29	29	22	20
All RCP scenarios together *	76	75	73	76	76	76	50	48	76	76	60	55
All SRES scenarios together **	63	19	19	46	45	62	60	59	50	50	61	53

* In the Climate-Fact-Sheets this is referred to as IPCC AR5 and represents the full CMIP5 multi-model multi-scenario ensemble (it is the sum of the three RCP subsets)

** This is referred to as IPCC AR4 in the Climate-Fact-Sheets and represents the full CMIP3 multi-model multi-scenario ensemble (this is the databasis of the original Climate-Fact-Sheets)

6. The bandwidth of climate change projections

On the basis of climate change projections from a multi-model multi-scenario ensemble, it is not possible to only state a concrete single value of future climate change. However, it is possible to indicate a range of possible developments. In order to characterise and specify this range of projected changes in the Climate-Fact-Sheets, the approach suggested in IPCC AR4 and IPCC AR5[12] is applied. Here, the range of projected changes is subdivided into two categories - a "*likely*" range and a "*very likely*" range.

According to the IPCC, a range of change is to be categorized as "*likely*" when 66% of all changes projected through the various models and for the various scenarios lie within this range. Furthermore, if the range contains 90% of all projected changes, then it can, according to the IPCC, be categorized as "*very likely*".

In the Climate-Fact-Sheets, these ranges have in each case been defined around the median (50% value) of the projected changes, in order to exclude single extreme outliers (represented in Figure 3 as the area in-between the grey bands and the minimum and maximum, respectively). This means that 33% of the projected changes in a range categorized as "*likely*" lie above and 33% below the median of all changes. In the case of the "*very likely*" category, we find 45% of the changes above and 45% below the median (see Figure 3).

For all cases when the different scenarios were analysed jointly together, only the "*likely*" and "*very likely*" ranges are described. However, for the parts that distinguish between the different scenarios we also included the median (50% value – also indicated in Figure 3) of the range of projected changes (see also Section 7.2). An exception to this is the information on changes in mean sea level, where no data for the median but only the mean change was available.
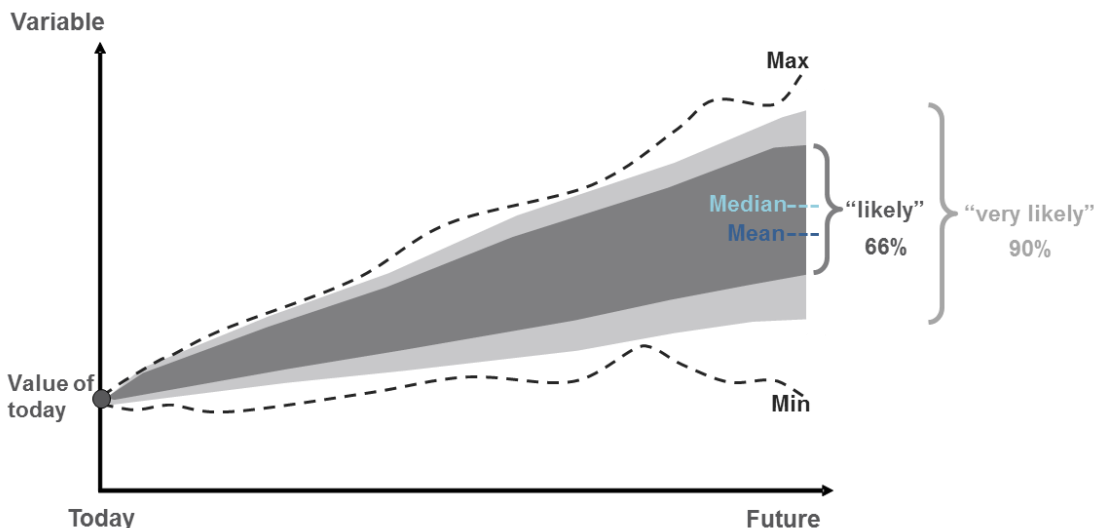

Figure 3: Theoretical scheme to highlight the bandwidth of climate projections using different statistical metrics

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[12] Among others: Mastrandrea M, Field C, Stocker T, Edenhofer O, Ebi K, Frame D, Held H, Kriegler E, Mach K, Matschoss P, Plattner G, Yohe G, Zwiers F (2010) Guidance note for lead authors of the IPCC Fifth Assessment Report on consistent treatment of uncertainties, IPCC. Available online at www.ipccwg2.gov/meetings/CGCs/index.html.

7. Explanation of diagrams used in the Climate-Fact-Sheets

7.1. Climate diagrams

Walter-Lieth climate diagrams (see Figure 4) are used in the Climate-Fact-Sheets to present the various current climate conditions within a specific country/region. These diagrams show observed values for temperature and precipitation based on 30-year mean values (normal climatic period) and offer a useful overview of the annual cycles of temperature and precipitation as well as annual mean temperature and annual total precipitation. In extremely simplified form, a dependence of evapotranspiration on air temperature is assumed. This means that conditions will be humid when the precipitation curve is above the temperature curve and arid in the opposite case. The boundary between arid and humid conditions runs through the point where the precipitation value [mm] is double of the value of the mean temperature [°C]. The temperature and precipitation scales are therefore plotted in a ratio of 1:2.

In the example given in Figure 4, we can see that the period from mid-March to mid-November is humid (blue areas); while in the other months arid conditions (light-red coloured areas) predominate. The months from April until October show high rainfall (a change in rainfall level of a factor of 10 – dark blue area). The mean annual temperature is 24.7°C, the annual total precipitation is 1564 mm.
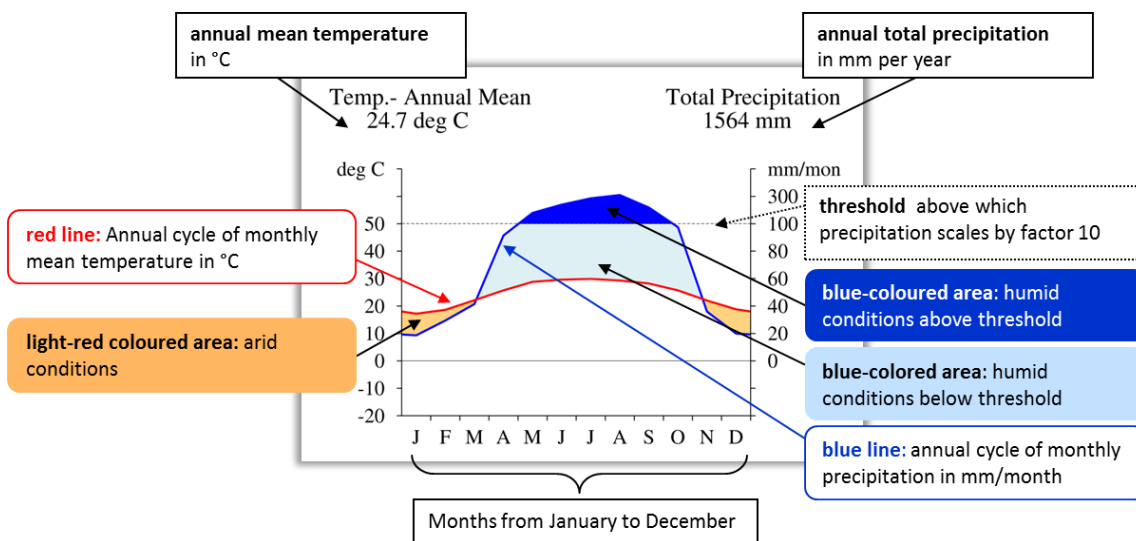
Figure 4: Climate diagram after Walter-Lieth. Temperature and precipitation scaled to 100mm in ratio 1:2. This serves to mark months with arid (bright red) and humid (blue) conditions. Monthly precipitation values above 100mm are shown in compressed form.

7.2. Explanation of the climate change charts

In the Climate-Fact-Sheets the range of projected future climate changes is depicted by three different kinds of diagrams. For all climate parameters apart from mean sea level, the range of projected changes is depicted in a "*comprehensive trend chart*". For projected changes in precipitation, an "*annual cycle chart*" is additionally included. For mean sea level the projected changes are depicted in a "*sea level box-plot chart*". The different types of climate change charts used within the Climate-Fact-Sheets are further explained below.

7.2.1. Comprehensive trend chart

The comprehensive trend chart is the main diagram to present the range of projected future climate change for a specific parameter in the Climate-Fact-Sheets. An example for the case of projected changes in the duration of long-lasting cold spells (in days) is given in Figure 5.
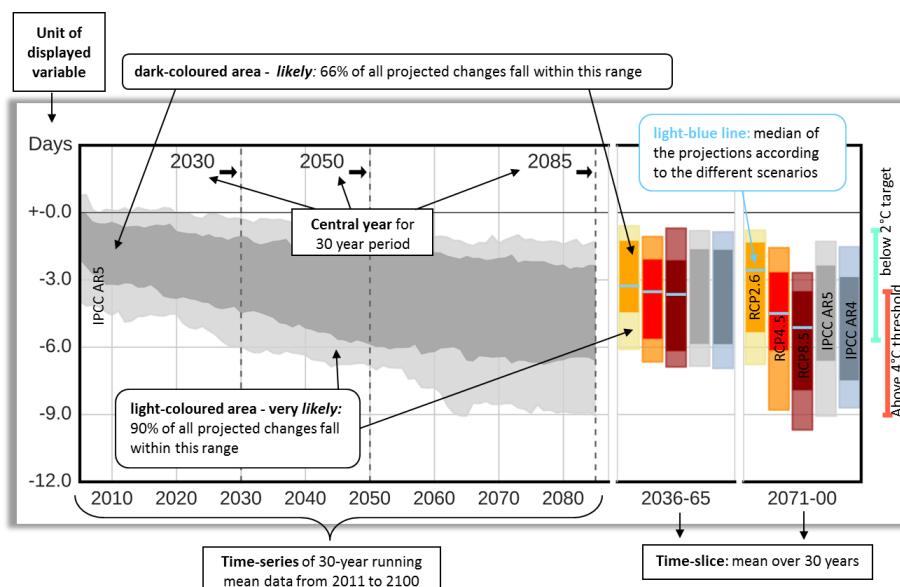

Figure 5: Example for the standard diagram used to present time series of projected changes of global climate models in the Climate-Fact-Sheets. In this case the projected change in the duration of long-lasting cold spells is shown.

In general these charts consist of three different parts:

(i) Time series: The left part of the climate change figure shows the bandwidth of projected changes (compared to the mean of the reference period from 1971 to 2000) combined for all scenarios over the 21st century (from 2006 to 2085) of data used in the AR5 IPCC (CMIP5 multi-model multi-scenario ensemble). All values, except the indices that are already calculated using a 30 year period, are smoothed in time by a 30 year running mean. Therefore the bandwidth indicated for the year 2085 is actually the bandwidth of the period 2071 to 2100. The three dedicated periods indicated with stippled line (2030; 2050; 2085) represent the 30 year periods for which either more detailed information is provided in the text and/or are presented in more detail on the right part (see (ii) Box Plots) of the diagram.

The time series band is separated into two ranges: the dark grey area contains 66% of all projected values and is here denoted as "likely" (as defined in Section 6). 90% of all projected values lie within the light grey and are denoted here as "very likely" (as defined in Section 6).

In the example given in Figure 5, we can see that between today and 2100, the projected change in the duration of long-lasting cold spells is likely to be in the range of -2 to -7 days and very likely to be in the range of -1 and -9 days.

(ii) Box Plots: The right part of the climate change figure shows a more detailed view on the projected changes for two specific future 30 year periods centred around 2050 (period from 2036 to 2065) and 2085 (period from 2071 to 2100) with respect to the reference period 1971 to 2000.

As for planning purposes, it might be interesting to know how projected changes differ under different greenhouse gas scenarios; the projected changes are here separated by colours for the different scenarios (represented by different RCPs). The yellow bar represents the low (RCP2.6) scenario the orange bar the medium (RCP4.5) scenario and the red bar the high (RCP8.5) scenario, respectively. The grey bar represents the bandwidth of projected changes combined for all three scenarios (IPCC AR5 only) and repeats the identical information given on the left part of the figure at the same time periods (either 2050 or 2085; both indicated by the stippled lines; see (i) Time series).

The blueish bar represents the bandwidth of projected changes from data used in the IPCC AR4 (CMIP3 multi-model-multi-scenario ensemble) and reflects the information which was provided in the earlier version of the Climate-Fact-Sheets (see also Sections 4 and 5).

The different colour shadings within each bar reflects the "*likely*" and "*very likely*" range (as defined in Section 6) and the blue line in the centre of the three bars for the different scenarios represents the median (50% value) of the projected changes. Please note that the "*likely*" and "*very likely*" ranges have been defined for each of the scenarios as well as for the full ensembles separately. It is therefore not necessary, that the grey bar (IPCC AR5) covers the full range span by the three coloured scenario bars.

In the example given in Figure 5, we can see that the median projection of change in the duration of long-lasting cold spells is for a decrease by 4 days for the time period from 2071 to 2100 according to the medium scenario (RCP4.5). This decrease is likely to be in the range of -2 to -5 days and very likely to be in the range of -1 and -9 days.

(iii) Ensemble selection by a global mean temperature change: In the frame of developing mitigation strategies and/or adaptation options, it might become important to connect regional climate change signals to global temperature thresholds often referred to in the context of policy discussions. From this perspective, the +2°C (or even +1.5°C) global mean warming threshold can be used as a comprehensive mitigation target whereas from an adaptation viewpoint maybe more extreme climate change scenarios pose the largest challenges.

For this purpose, we added some information on the range of projected change under two different assumptions of global mean temperature change on the right edge of the climate change figures. The turquoise bar represents the range of projected changes of all model simulations (IPCC AR4 and AR5) which project a global mean warming by end of the century of below or equal +2°C (2°C target; compared to preindustrial). Likewise the red bar represents the range of projected changes of all model simulations that project a global mean warming by end of the century equal or above +4°C (also compared to preindustrial).

The information used to draw these ranges is based on the same data as depicted in the other parts of the diagram (the full data ensembles building the base for IPCC AR4 and AR5), however, only

model simulations are selected that project a global mean temperature change by the end of the century and compared to preindustrial which is below +2°C (turquoise bar) or above +4°C (red bar). In order to be consistent with the other parts of the diagram, all projections that project a climate change signal for the specific climate parameter which is by the end of the century located outside of the "*very likely*" range (central 90%) of change, are removed from the respective subsets. The entire range of projected changes of this reduced ensemble of global climate model projections is then illustrated. It is important to note that the two bars sometimes overlap and sometimes not, indicating that for some climate parameters and/or countries/regions the projected change might be independent from the global mean warming.

In the example given in Figure 5, we can see that in a world with a global mean temperature increase below or equal +2°C the projected changes in the duration of long-lasting cold spells are in the range of -6 to -1 days, whereas for a world above or equal +4°C the projected changes are the a range of -9 to -4 days for end of the century.

7.2.2. Annual cycle chart

The projected changes in the annual precipitation cycle are additionally presented. An example for this is given in Figure 6 (precipitation amounts in %). The change refers to a thirty-year average at the end of the century (2071 to 2100), as compared to the reference period 1971-2000. As in the previous illustrations, two ranges are indicated for all model simulations: the dark grey area contains 66% of all projected values. It is denoted here as "*likely*" (as defined in Section 6). The light grey area contains 90% of all projected values. In keeping with the previous diagram, this area is denoted as "*very likely*" (as defined in Section 6).

Another piece of information that we can extract from the illustration is the difference in the projected changes in the annual precipitation cycle according to the individual scenarios. To facilitate ease of overview, only the median of projected changes will be represented in the case of each of the scenarios RCP2.6 (yellow curve), RCP4.5 (orange curve) and RCP8.5 (red curve).

As relative changes in the annual cycle are shown, the observed annual precipitation cycle averaged for the specific country/region is additionally shown. However this does not necessarily mean that the models reproduce the same annual precipitation cycle. A specific test on this issue is conducted while estimating the confidence into the projected climate change signals (see Section 8.2.).
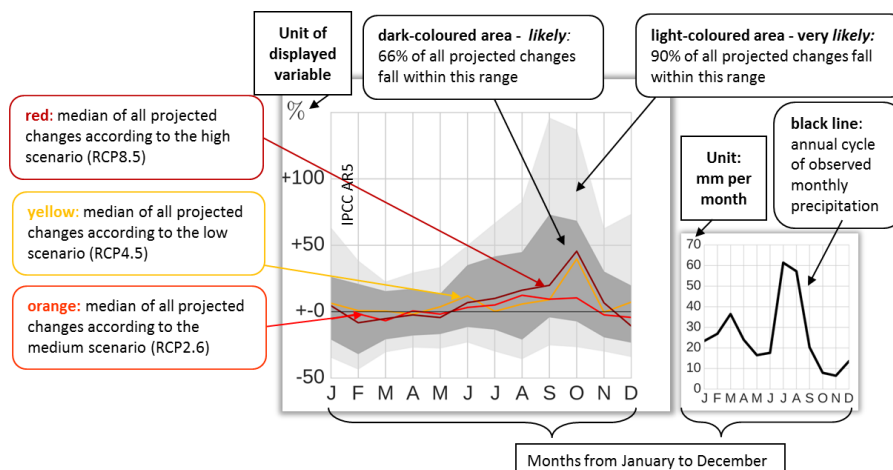

Figure 6: Example for the standard diagram used to present projected changes in the annual cycle of parameters simulated by global climate models in the Climate-Fact-Sheets.

In the example given in Figure 6, we can see that that the majority of model simulations project an increase in future precipitation amounts for the months July to October (main rainy season; monsoon season), whereas for the remaining months no clear tendency is visible. Largest relative increase is projected for the end of the monsoon season and start of the dry season (September, October). For the winter rainfall season (January to March), many model simulations project a decrease in precipitation amounts. Under RCP8.5, a more pronounced change in the precipitation seasonality is projected than under RCP2.6.

7.2.3. Sea level box-plot chart

An example for the climate change diagram to illustrate projected changes in mean sea level is given in Figure 7. Due to data availability, it was not possible to provide information on projected changes continuously throughout the 21st century, but only as average for two 20-year-periods from 2046 to 2065 and 2081 to 2100 (compared to the reference period 1986 to 2005). The changes are presented separately for each of the three emission scenarios: low (RCP2.6) - orange bars; medium (RCP4.5) - red bars and high (RCP8.5) - dark red bars. The bars represent the spread (5% and 95%; upper and lower 90% confidence interval; for details see paragraph "*iii). Information on the mean sea level*" in Section 4) of possible future sea level changes at each respective location. The blue lines crossing the bars represent the mean changes.
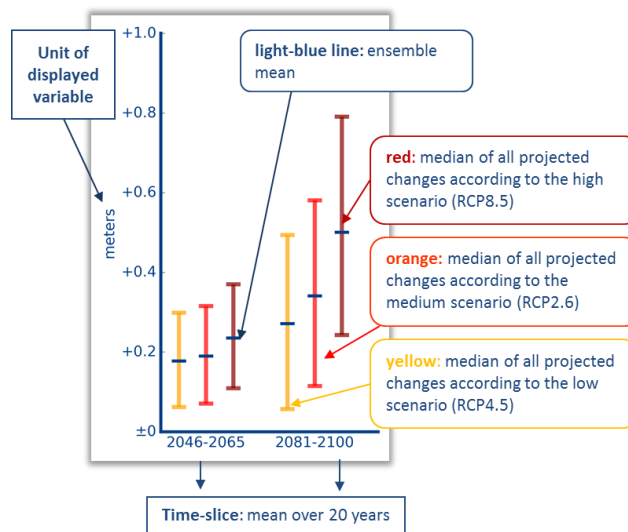

Figure 7: Example for the standard diagram used to present projected changes in the sea level simulated by global coupled atmosphere-ocean general circulation models in the Climate-Fact-Sheets.

In the example given in Figure 7, we can see that the mean projection of change in regional sea level rise is for an increase of +0.24 m by 2056 under the RCP8.5 scenario, with an uncertainty range for the increase from 0.11 to 0.37 m.

Additionally to the climate change figure more details to observed past sea level changes (if available) as well as some information about the vulnerability of the respective country/region to potential mean sea level rise are provided in text statements.

8. Expert judgment on signal strength and confidence

In addition to the quantitative representation of the magnitude of projected climate changes, the Climate-Fact-Sheets also provide a more qualitative expert judgment of the projected climate changes in terms of the confidence in the changes and the signal strength. The expert judgment is depicted in a combined diagram in the Climate-Fact-Sheets (see Figure 9). The signal strength of the projected change signal is depicted in a threefold thermometer scale representing a *weak*, a *medium-strong* or a *strong* climate change signal, respectively. If the signal strength is estimated to be stronger (weaker), the red colour of the thermometer rises (falls). Likewise the confidence in the projected changes is depicted by a threefold pointer diagram representing a *low*, a *medium* or a *high* confidence into the projected changes, respectively. In cases with higher (lower) confidence in the projected changes, there is a swing of the pointer upwards (downwards) on the confidence scale. More details on the assumptions made for the expert judgment are provided below.
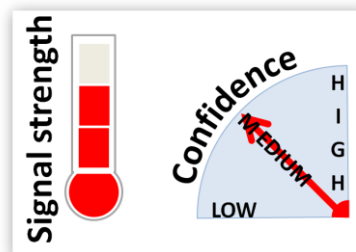

Figure 9: Graphic representation of confidence in the projected changes and the respective signal strength of the projected climate change signal using an example of medium confidence and moderate signal strength.

In the example given in Figure 9, we can see a case with a medium-strong climate change signal and a medium confidence into the projected changes.

8.1. Signal strength

For the signal strength the magnitude of the absolute value of the climate change signal and the statistical significance of the projected changes (both at the end of the century) are considered.
For the magnitude, fixed thresholds are given in Table 3. For the statistical significance a Mann-Whitney-Wilcoxon test or U-test has been applied to test against the null hypothesis that the distribution of a given climate parameter simulated by an individual model for today does not differ from the distribution that is projected for the future. The confidence level applied for the significance test is 0.95.
The magnitude and the statistical significance are tested on the basis of the individual model simulations. In order to classify a projected change as strong, it has to fulfil the threshold criteria and it has to be statistically significant. If the projected changes are above the threshold, but are not significant, it is classified as medium-strong. In the end the individual signal strengths of all simulations are combined into ensemble signal strength. To classify the ensemble signal strength as strong/weak at least 50% of all analysed simulations (independent of the emission scenario) have to be strong/weak signal. Otherwise the signal is classified as medium-strong.

Table 3: Criteria to estimate the signal strength

Signal Strength (of individual cc projection)	Magnitude of projected change	Significance of projected change
Weak	< 1.5 °C; < 15%	yes or no
Medium-strong	≥1.5 °C to ≤3.0 °C; ≥15% to ≤30%	yes or no
Strong	> 3°C; >30 %	yes

8.2. Confidence

Not every parameter described in the Climate-Fact-Sheets can be extracted from climate models at the same reliability. To estimate the confidence into the projected changes, two individual tests are applied. In the first test, the ability of the individual models to represent today's climate is tested. In the second test, the directions of projected changes of the individual climate change signals at the end of the century are examined.

For each of the two tests, an individual rating (from 1 to 3, poor to good, respectively) is achieved. Finally all individual ratings are then combined into an overall rating. For this purpose, the rounded arithmetic mean of the individual test ratings is calculated. The results of this overall ranking are then classified into the three confidence levels as follows: rounded mean rating of 1 = low confidence; rounded mean rating of 2 = medium confidence; rounded mean rating of 3 = high confidence.

8.2.1. Validation against observations

To test the ability of the models to represent today's climate, the simulations are compared to CRU, the ERA-40 Reanalysis product from ECMWF, and the WATCH forcing data for the 30yr validation period from 1971 to 2000. In general, the mean bias and the representation of the interannual seasonality are tested individually. For temperature and precipitation the model's representation of the seasonal cycle is additionally taken into account. The criteria for the validation tests are as follows:

i) Mean bias: The mean bias of each individual model simulation to the observations is calculated for the 30-year validation period. If the bias is smaller than 1°C (in the case of temperature) or 15% (for all other climate parameters), the simulation is rated as good. If the respective bias is larger than 1°C or 15% but smaller than 3°C or 40%, the quality of the simulation is rated as medium. For all other cases the simulation is rated as poor.

(ii) Interannual variability: The representation of the year-to-year fluctuations in the climate model simulations is evaluated via the interannual variability calculated as the standard deviation of the annual means over the 30-year validation period (see Equation 1 below).

(1) $Ratio_{Var} = \left| \frac{std(model_{yearly})}{std(obs_{yearly})} \right|$

Table 4: Criteria to judge on the representation of internal variability

Ratio of internal variability (Ratio$_{Var}$)	Rating
≥0.9 & < 1.1	good (3)
≥0.67 & < 0.9 ≥1.1 & < 1.33	medium (2)
< 0.67 or > 1.33	poor (1)

If the simulated variability deviates less than 10% from the observed one, the simulation is rated as good, if the deviation is less than 33%, it is rated as medium, and for larger deviations it is rated as poor (see Table 4).

(iii) Seasonal Cycle: For the temperature indices (annual mean, minimum and maximum temperatures) and for precipitation, the representation of the mean annual cycle by the model simulations is additionally investigated. The test is based on monthly mean data but only applied if the observed difference between the warmest/coldest is more than 1°C or between the wettest/driest months is larger than 15%. To judge on the quality of the simulations, the root-mean-square error (RMSE) of the (30-year) mean annual cycle with removed mean bias is calculated. If the RMSE is smaller than 1°C (in the case of temperature) or 15 % (in the case of precipitation), the simulation is rated as good. If the respective RMSE is larger than 1°C or 15 % but smaller than 3°C or 40%, the quality of the simulation is rated as medium, and for all other cases the simulation is rated as poor.

To combine all the individual validation ratings, the following two steps are conducted. First, for each individual test the individual rating (good, medium or poor) is taken, if at least 66% of all simulations agree on this rating,; otherwise it is set to medium. Second, the overall validation ranking is calculated as the rounded arithmetic mean of the estimated individual test ratings. It has to be kept in mind that for temperature and precipitation, three individual tests are performed but only two tests for all other parameters.

8.2.2. The direction of change of the individual climate change signals

The robustness of the signal is determined by evaluating both the agreement of the sign of the signal among the simulations and the ensemble spread. If more than 90% of the simulations agree in the sign of change or the spread of the central 90% of the simulations ("*very likely*" range) is less than 1.5°C or 15%, the robustness is considered as high (3). If less than 66% of the simulations agree in the sign of change or the spread of the inner 90% of the simulations is larger than 3°C or 30%, the robustness is considered as low (1). For all other cases, the robustness is considered as medium (2).

It shall be made very clear at this point that state-of-the-art climate models are not able to simulate all variables presented in the Climate-Fact-Sheets with the same quality. Best performance of the models is in general achieved for all parameters related to temperature (e.g. annual mean, maximum and minimum temperature, cold spells and heatwaves). Climate models perform less good in simulating precipitation or evapotranspiration amounts, as these variables usually vary strongly from region to region and hence show some characteristics, which especially coarse resolution global models are not able to resolve. This issue of resolution is also crucial in the simulation of heavy rain events, which are usually strongly underestimated in global (and to a lesser extent also in regional) climate models. A lower performance of the models is present generally in the simulation of wind fields and of solar irradiance, with the latter depending strongly on the simulation of the spatial and vertical cloud distribution – one of the major uncertainties in climate models. Finally, for parameters like the climatic water balance, which are calculated from two or more parameters, the uncertainty of the input parameters also adds up. Therefore, these parameters have to be dealt with caution. However, even though individual climate models not always perform well with respect to observations, the utilization of a large ensemble of models often improves the quality of the results.

9. Glossary - Description of parameters examined in the Climate-Fact-Sheets

Temperature:
Those temperatures examined in the Climate-Fact-Sheets refer to the air temperature close to the surface of the earth. We distinguish between annual mean temperature and maximum and minimum temperatures. The annual mean temperature is the average of daily mean temperatures throughout the year. The maximum and minimum temperatures are obtained from daily data which are then averaged for each month, with the respective highest/lowest mean temperatures being selected. The maximum (minimum) temperature provides the highest (lowest) monthly averaged daily maximum (minimum) temperature for a specific year.

Long-lasting heatwaves:
Heatwaves are defined as a number of consecutive days with a daily mean temperature above a given temperature threshold. For heatwaves the threshold has been set at the 95th percentile of the daily mean temperatures (on 95% of all days the daily mean temperature is lower than this value) within the control period 1971 to 2000. Since long heatwaves are especially important, only the 95th percentile (95% of all heatwaves are shorter than this value) of the duration of heatwaves are examined and described as long-lasting heatwaves.

Long-lasting cold spells:
Cold spells are defined as a number of consecutive days with a mean daily temperature below a given temperature threshold. For cold spells the threshold has been set at the 5th percentile of the daily mean temperature (on 95% of all days the daily mean temperature is higher than this value) for the control period 1971 to 2000. Since long cold spells are especially important, only the 95th percentile (95% of all cold spells are shorter than this value) of cold spells are examined and described as long-lasting cold spells.

Precipitation:
Both the annual total precipitation and monthly total precipitation amounts are represented in the Climate-Fact-Sheets. Both amounts are calculated by adding together daily precipitation values over the corresponding time periods.

Long-lasting dry spells:
Dry spells are defined as a number of consecutive days with total precipitation below a given precipitation threshold. For dry spells the threshold value was set at the 5th percentile of daily precipitation (on 95% of all days the total daily precipitation is higher than this value) within the control period 1971 to 2000. Since long dry spells are especially important, the 95th percentile of the duration of dry spells (95% of all dry spells are shorter than this value) is defined as a long-lasting dry spells.

Intensity of heavy rainfall events:
The heavy rainfall intensity is defined as the 95th percentile of total daily precipitation values. This is the precipitation value which is not reached on 95% of all days (only rainy days with 1 mm/day precipitation are considered).

Frequency of heavy rainfall events:
The heavy rainfall frequency is defined as the number days when the total daily precipitation exceeds the above-defined heavy rainfall intensity.

Actual evaporation:
In the Climate-Fact-Sheets the annual total actual evaporation is presented in %. The amounts are reached by adding together daily evaporation values over the corresponding time periods

Climatic water balance:
The climatic water balance is the difference between the annual total precipitation and the annual total actual evaporation. Its unit is mm/yr and it provides information about the amount of water that is theoretically available on the earth's surface. In scientific language this is often referred to as runoff, whereby this should not be confused with the river runoff.

Solar irradiation:
Solar irradiation refers to the solar radiation that reaches the earth's surface. In the Climate-Fact-Sheets it is presented in kWh/m^2 per year.

Wind speed:
Mean wind speed is defined in the models as wind speed at a height of 10 m above ground surface. As a result of the rough horizontal resolution of global climate models, confidence in this parameter is limited. Its unit is in %.

Sea level:
The changes in sea level are presented from different sources: the general information of global mean sea level changes, the vulnerability of a specific country/region to a 1m sea level rise, and the observed data about regional sea level changes are compiled from a literature review. The projected sea level changes are based on different coupled atmosphere-ocean general circulation model simulations. Its unit is in meter.