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Catalogue on CMIP data provision, applicability and volume

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Executive summary

The establishment of an ensemble of global climate model (GCM) results was initiated in the mid-1990s: the Working Group on Coupled Modelling (WGCM) of WCRP (World Climate Research Programme) commenced the Coupled Model Intercomparison Project (CMIP) in 1995 with the aim of serving scientists with a database of coupled GCM simulations under standardized boundary conditions. Today the planning of CMIP6 (6th Phase of CMIP) is ongoing. Since 1995 lots of progress have been made regarding the scientific motivation, the covered time horizon, the details of the described physical processes, and the number of applied models.

Not only the GCM simulations have developed, but the user needs have also evolved and extended in the last 20 years. CMIP outputs are applied in several areas; e.g., they serve as input to the assessment reports of the Intergovernmental Panel on Climate Change (IPCC) and global climate model data provide information about the large-scale features of climate change for regional downscaling. Moreover, CMIP5 GCMs constitute the primary basis of the Copernicus C3S Climate Data Store (CDS).

The main objective of this data inventory is to provide a compact technical and scientific guideline for the potential users of CDS on applying the CMIP outputs and later the CDS data. A large amount of information about CMIP5 is collected to this report and filtered from users' perspective with provision of references to further interests. The main focus of this report is on the CMIP5 database, and within CMIP5, on the long-term global climate projections. CMIP5 climate projections have been assessed regarding their spatial and temporal characteristics, available meteorological variables and anthropogenic scenarios, uncertainty range covered by the ensemble and its feasibility and limitations in different user applications. Assessment of model quality is not the scope of the data inventory, nevertheless, we provide some information on this issue, as well.

In CMIP5, model simulations have applied the recently developed RCP (Representative Concentration Pathways) scenarios for prescribing future anthropogenic forcings. RCPs are referred to their radiative forcing values for the year 2100 compared to the pre-industrial value. Four RCP scenarios have been examined: RCP2.6, RCP4.5, RCP6.0, and RCP8.5. The latest and currently ongoing Coupled Model Intercomparison Project, CMIP6, started the planning phase in 2013. CMIP6 simulations and scientific achievements are expected to support the IPCC Sixth Assessment Report as well as diverse national and international climate assessments or special reports.

The CMIP database is intensively used in numerous studies to assess the quality of the GCM results for different territories, seasons and variables as well as to esti-

mate the range and characteristics of the uncertainty covered by the different model ensembles. CMIP5 data are resulted from various experiment types, e.g., 10- and 30-year hindcasts and predictions, pre-industrial control runs, time-slice experiments, historical ensemble simulations, atmosphere-only model simulations, future projections, and paleo-climate runs. In the data inventory, the focus is on future projections (and their historical counterparts): the future runs begin from the year 2006 and span the whole 21st century (some simulations continue even beyond 2100). The initial conditions are provided by the historical experiments covering the period of 1850–2005. In these historical experiments, the variation of solar forcing and the changes in the concentration of short-lived gas species and aerosols occur according to the observed values.

In the present work, a categorization method was designed on the CMIP5 simulations to enable a quick and objective overview. An “evaluation matrix” is defined in which every single model run is scrutinized if it fulfils the specified criteria; e.g., its horizontal resolution is in a given range. To assess the different aspects in a summarized way, a multi-criteria filtering method is also introduced to give some guidance on choosing a climate model ensemble for a certain purpose. The most valuable part of this evaluation matrix is its summarizing part, providing information about the number of ensemble members in a given category.

In principle, there are 10 different nodes available for browsing and for downloading CMIP5 simulation outputs, but only 6 nodes operate correctly for search. Taking all the available CMIP5 model results, the investigation was started with 61 GCMs. In general, model data are given on a Gaussian grid. The horizontal resolution of the model outputs varies widely from 0.56° to 5.6°. Most models have a 1°–2° (approximately 100-250 km) or a 2°–3° (approximately 200-350 km) resolution. Only few models fall on the highest (with grid distance smaller than 1 degree) and the lowest (with grid distance larger than 4 degrees) resolution categories. Upper level atmospheric data are either given on predefined pressure levels (ranging from 1000 to 10 hPa) or on the vertical model levels. Concentrating on long-term climate projections, we have omitted 14 models which do not have runs with any RCP scenario. Among the remaining 47 GCMs, 42 models have simulations until the end of the century and 13 GCMs go beyond 2100 (up to 2300).

The methods and models of the impact researchers generally require several climate variables from the same model simulation as input data. Thus, besides the existence of single variables, the joint availability of certain variable groups could also yield useful information. Therefore, several “variable packages” were defined. The *basic*, *extended basic*, *extended basic 2* and *radiation packages* are composed of surface variables. The *extended radiation package* also includes some additional radiation component at the top of the atmosphere, *pressure level packages* contain variables at multiple pressure levels, and the *model level package* consists of the variables available on the model vertical levels.

Data are archived with a monthly, daily, 6-hourly and 3-hourly frequency. Atmospheric parameters given at sub-daily resolution are the near-surface temperature, the wind components, the sea level and surface pressure, the near-surface spe-specific humidity, the precipitation, the pressure level variables and some radiation components. Daily precipitation sum, daily mean near-surface air temperature, and daily minimum and maximum temperature data are available for 39 models, while monthly means of these variables are found for 41 models (going until 2100). Also considering the surface wind components, specific humidity, sea level pressure, global radiation, cloudiness, and snowfall, the number of models with daily and monthly outputs is reduced to 22 and 29, respectively. Pressure-level data are important for dynamical downscaling, and they are stored with a 6-hour output frequency for 25 GCMs until 2100. Nevertheless, for many regional climate models, pressure-level data are not usable as driving fields, since those models require the prognostic variables on model levels. Therefore, for further request, one has to contact personally the scientists responsible for the chosen model experiment.

Evaluating the joint occurrence of the different criteria in the database, it was concluded that an 8-member ensemble can be designed, providing climate projections for all RCP scenarios at daily level for any of the selected (surface, pressure-level and radiation) atmospheric variables. Still, before recommending this sub-ensemble for elaborating climate projections, the performance of each individual model should be assessed in detail.

During the evaluation of the CMIP5 dataset, several technical difficulties and gaps were found. Many of them are related to the browsing method and the documentation, both having key importance for the users:

- An extended selection method using also logical (AND, OR etc.) functions would help to select the appropriate realization, time horizon and variables of the projections to spare the users from digging in the metadata information.
- Provision of the geographical information (e.g., orography, land-sea mask) is highly desirable to perform further interpolation on the model outputs.
- New post-processing method should be introduced to improve the unrealistic relative humidity values occurring in many GCMs.
- Some RCP scenarios are currently inadequately represented within the models. RCP4.5 and RCP8.5 are the most intensively used scenarios, covering only a part of the whole uncertainty spectrum. This gap should be filled with an accomplishment of new GCM simulations.

- The applicability of CMIP5 model outputs as boundary forcings for dynamical downscaling is limited due to the lack of model level data. Driving data can be used more widely in those regional climate models which are able to utilize pressure level data instead of model level data.
- Summary should be provided regarding the main differences between different model versions of the same model family (e.g., CMCC-CESM, CMCC-CM, CMCC-CMS), with recommendations describing which version to take for different purposes.

1 Introduction and motivation

1.1 Motivation

The establishment of an ensemble of global climate model (GCM) results was initiated in the mid-1990s: the Working Group on Coupled Modelling (WGCM) of WCRP (World Climate Research Programme) elaborated the Coupled Model Intercomparison Project (CMIP) in 1995 with the aim of serving scientists with a database of coupled GCM simulations under standardized boundary conditions. The initiative may be seen as an analogue of the Atmospheric Model Intercomparison Program (AMIP). Today the planning of CMIP6 (6th Phase of CMIP) is ongoing. Since 1995, lots of progress have been taken place regarding the scientific motivation (e.g., in the beginning the main goal was to understand the past and the present climate, recently the focus is shifted towards the description of future climate change due to anthropogenic activity); the covered time horizon (e.g., from the near-term predictions targeting the next few decades to the very long term projections going until 2300); the details of the described physical processes (e.g., increasing resolution, more and more sophisticated physical parameterizations); and the nature of the applied models (from the atmosphere-only models to the state-of-the-art Earth system models).

Not only the global climate model simulations have developed, but the user needs have also evolved and extended in the last 20 years. CMIP outputs are applied in several areas; e.g., they serve as input to the assessment reports of the Intergovernmental Panel on Climate Change (IPCC), which support the high-level decision making with up-to-date information; global climate model data provides information about the large-scale features of climate change for regional downscaling, both in dynamical and statistical methods, and also for impact assessments.

Copernicus C3S will gather all the available and scientifically sound information into the Climate Data Store (CDS) to serve as a primary data base for various users. Regarding global climate projections its primary basis will be the already existing dataset of the latest finalized CMIP phase, CMIP5. The main objective of this data inventory is to provide a compact technical and scientific guideline for the potential users of CDS on applying the CMIP outputs and later the CDS data. A large amount of information about CMIP5 is collected to the report and filtered from the users' perspective with provision of references to further interests. Our main focus is on the CMIP5 database among different CMIPs, as it is the most recent finalized CMIP utilizing the recent scenario family. From the wide range of available experiment types in CMIP5, the report is dedicated to long-term global climate projections (i.e., seasonal and decadal predictions are not concerned in the assessment). The database is evaluated based on the following aspects: data accessibility, spatial resolution of the GCM outputs, time horizon of the model experiments, applied emission scenarios, available meteorological variables, the frequency of the outputs stored in the archive, and the uncertainty range covered by the ensemble. Assessment of the quality of the different models and their results (i.e., model validation) is beyond the scope of the data inventory, nevertheless, we provide some hints on this issue in the literature review.

The deliverable is structured as follows: this motivation part is followed by an overview of the CMIP programmes from CMIP1 to the ongoing CMIP6, and the introduction section is closed with a literature review about the investigations carried out based on the CMIP data focusing on multi-decadal climate projections. Section 2 is dedicated to the approach used in the data inventory: first, the available CMIP5 experiments are described, including also paleo-climate, pre-industrial, decadal etc. experiments; thereafter, we give an overview about the global climate models involved in the assessment and the "tool" of the evaluation, i.e., the evaluation matrix is introduced. Section 3 presents the results and outcomes of the thorough assessment of the CMIP5 database in detail, while different parts of the evaluation matrix are provided in the Appendix. In Section 4, possible selections of ensembles composed of CMIP5 models are shown for Copernicus C3S Climate Data Store, considering also the interdependency of the GCMs in these ensembles; identified gaps are also discussed here, and we give a proposal for the content of a guideline supporting the potential users of CDS. The report is closed by summary of the main conclusions.

1.2 An overview of the past, current and ongoing CMIPs

The first phase of CMIP, CMIP1 focused on collecting output from control simulations in which external climate forcing was held constant at pre-industrial or present-day levels (Covey et al., 2000; Lambert and Boer, 2001). In the next phase, CMIP2, an idealized global warming scenario was included as well, and at the same time, more extensive model output was collected (Covey et al., 2003).

Whereas CMIP1 and CMIP2 only included a few experiments (control and 1%CO_2), for the later phases the number of simulations and participating models has increased: more extensive series of climate change simulations have been conducted, forced by realistic emission scenarios, taking into account also the anthropogenic activity for both the historical and the future periods. In CMIP3, simulations focused on three SRES emission scenarios (A2, A1B and B1; Nakicenovic et al., 2000; Figure 1), each of them representing a substantially different future pathway of anthropogenic activity (with approximately 850, 700, 550 ppm CO_2 concentration by 2100, respectively). The following experiments had been included:

- Control simulation with constant (pre-industrial, in a few cases present day) forcing;
- Idealized simulations starting from the control with an 1% increase in the CO_2 concentration per year until a doubling (or quadrupling) is reached, and thereafter 150 years of simulation with the constant forcing;
- Idealized simulations with a slab ocean and an instantaneous doubling of CO_2 concentration and a continuation of the simulation until equilibrium is reached;
- 20th century simulations including natural and anthropogenic forcings starting from the control about the year 1900 and extending until the year 2000 (20C3M). Another set of simulations was extended until 2100 using constant forcing from 2000;
- Climate change experiments using the SRES A2, A1B and B1 forcings; some experiments were extended to 2300 keeping the forcing constant after 2100.

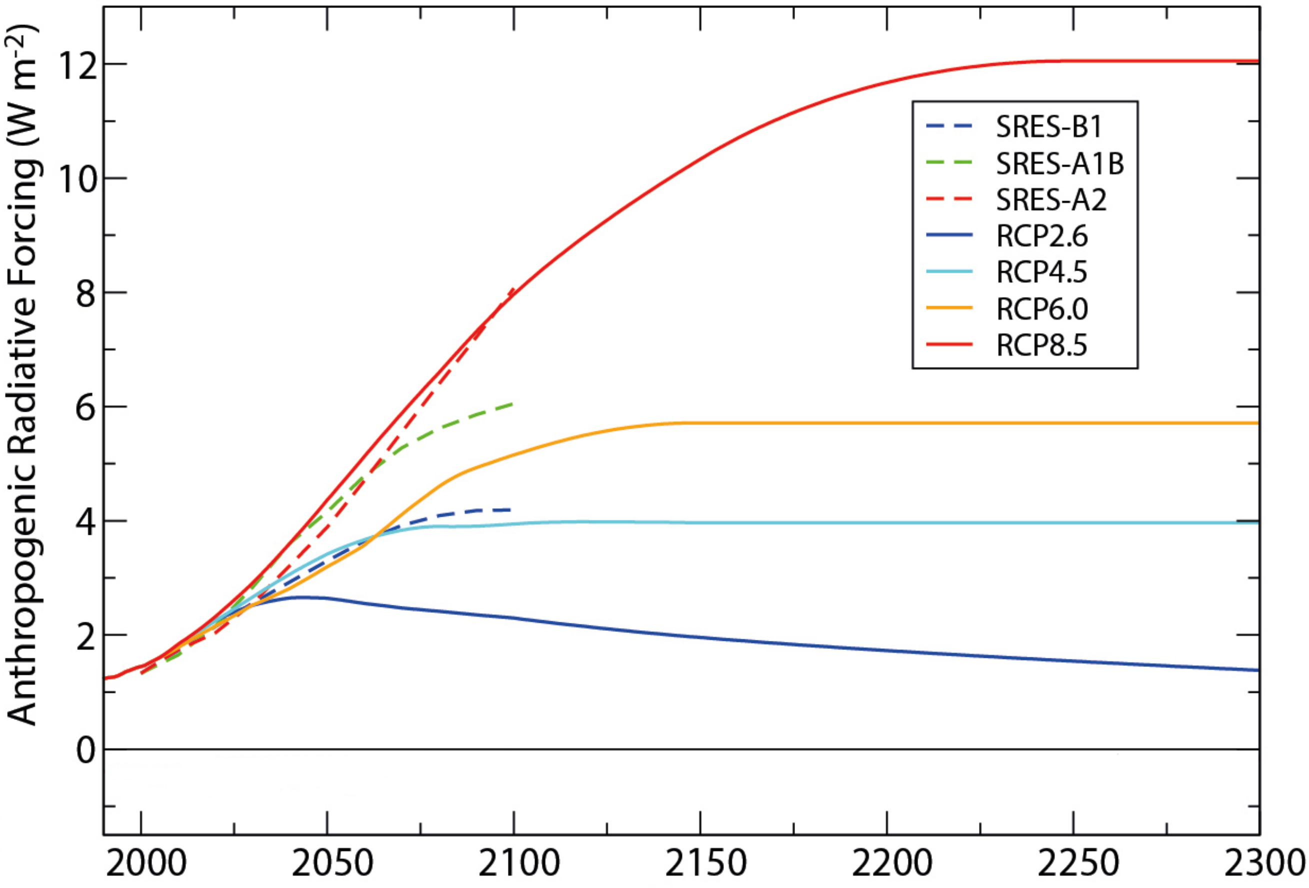

Figure 1: Time evolution of the total anthropogenic radiative forcing relative to the pre-industrial (about year 1765) level between 2000 and 2300 for the RCP scenarios, and for the SRES scenarios until 2100, as computed by the Integrated Assessment Modelling Consortium (IAMC). Source: Stocker et al., 2013.

Details on the CMIP3 scenarios, models and variables can be found at the PCMDI web page (www-pcmdi.llnl.gov/ipcc/about_ipcc.php) and an overview of the CMIP3 modelling activity is provided in Meehl et al. (2007). Results are freely available in the CMIP3 database. The simulations were used as the input to the IPCC Fourth Assessment Report (AR4; Solomon et al., 2007).

CMIP3 was followed directly by CMIP5 (Taylor et al., 2012b) in 2010; a new numbering was introduced referring to the corresponding IPCC reports (since CMIP5 results served as input for the IPCC AR5; Stocker et al., 2013). CMIP5 model simulations already applied the recently developed RCP (Representative Concentration Pathways; Moss et al., 2010) scenarios for prescribing future anthropogenic forcings. The RCP scenarios were constructed following a new methodology: using selected pathways of radiative forcings or equivalent CO_2 concentration levels, Earth system models (ESMs; i.e., climate system models) and integrated assessment models (IAMs) are integrated simultaneously and interactively to estimate the future response of climate and socio-economic conditions to the varying atmospheric and radiative forcings. RCPs cannot be identified with any given socio-economic scenario: they are referred to their radiative forcing values for the year 2100 compared to the pre-industrial value, which can be resulted along several socio-economic development paths. RCPs have four representative versions depending on their radiative forcing levels considered for 2100: RCP2.6, RCP4.5, RCP6.0, and RCP8.5 (Figure 1), with 2.6, 4.5, 6.0, and 8.5 Wm^{-2} subsequent radiative forcing in 2100. CMIP5 experiments addressed three main issues: (1) to assess the scientific background of model differences in carbon cycle and clouds feedbacks, (2) to examine climate predictability on decadal time scales, (3) to provide projections beyond 2100.

In CMIP1 and CMIP2, annual and seasonal global and zonal means were made available along with monthly mean output for a few variables. For CMIP3 and CMIP5, a huge amount of model output has been collected: monthly mean data are archived for a large number of variables, daily and 6-hourly/3-hourly outputs are available for selected variables. CMIP3 and CMIP5 data can be used to drive regional climate model simulations, which have been extensively exploited in the ENSEMBLES (van der Linden and Mitchell, 2009) as well as the CORDEX (Jones et al., 2011) initiatives. Table 1 summarizes the main characteristics of the different phases of CMIP.

Table 1: Main characteristics of different phases of CMIPs. The numbers in parenthesis (3rd row) indicate the number of models for which the given scenario run is available.

	CMIP1	CMIP2	CMIP3	CMIP5
Number of models	17	18	25	61
Available experiments	Control	Control Idealized (Only 1%CO_2)	Atmosphere-only Control Idealized Historical (20C3M) SRES-B1 (21) SRES-A1B (24) SRES-A2 (19)	Atmosphere-only Control Idealized Historical RCP2.6 (30) RCP4.5 (44) RCP6.0 (22) RCP8.5 (42) Decadal ESM Paleo
Atmospheric resolution	Longitude: 3.8° – 5° Latitude: 1.6° – 4°	Similar range but progress towards higher resolution	Continued progress towards higher resolution	Most models now had a resolution better than 3° by longitude and 2° by latitude
Flux-adjustment in the coupling between atmosphere and ocean	Used by about half (9/17) the models	Used by 2/3 of the models.	Used by 1/5 of the models	Not used by any models
Temporal resolution of atmospheric model output	Annual mean Seasonal mean Monthly mean (only surface air temperature)	Annual mean Seasonal mean Monthly mean (only surface air temperature, sea level pressure and precipitation)	Annual mean Monthly mean Daily mean 3-hourly	Annual mean Monthly mean Daily mean 6-hourly 3-hourly
Atmospheric, oceanic model data	Global and zonal means of atmospheric data 2D atmospheric data (only surface air temperature)	Global and zonal means of atmospheric data 2D atmospheric data (only surface air temperature, sea level pressure and precipitation)	2D atmospheric + land surface data 3D atmospheric data 1D and 2D ocean data	2D atmospheric + land surface data 3D atmospheric data 1D, 2D and 3D ocean data
Time horizon	Length of control: 24-1085 years	Length of control: Longer than in CMIP1, at least >80 years.	Control > 100y Historical/scenario simulations 1900-2100 or 2300	Control > 500y Historical/scenario simulations: 1850–2100 or 2300
Data amount	1 GB	500 GB	35 TB	3.5 PB
Data accessibility	Apparently unavailable	Apparently unavailable	Download from Earth System Grid Federation (ESGF)	Download from ESGF

The latest and currently ongoing Coupled Model Intercomparison Project, CMIP6, started the planning phase in 2013. As the previous CMIP phases, it is set up within the framework of the WCRP under the Working Group on Coupled Modelling. Analogously to the preceding CMIPs, CMIP6 simulations and scientific achievements are intended to support the IPCC Sixth Assessment Report (AR6) as well as other national and international climate assessments or special reports.

Since the first CMIP phase began about 20 years ago, the project has achieved many crucial breakthroughs regarding the understanding of past, present and future climate change arising from natural, unforced variability or in response to changes in radiative forcings in a multi-model context. Its scope and diversity of topics as well as the data volume involved have grown tremendously since then and more and more pressure is put on the technical infrastructure and the project set-up as a whole. Yet, the organizational structure has remained rather compact and centralized over the years. A thorough investigation at the end of CMIP5, which includes feedback from both the modelling centers and the communities working with CMIP output data, resulted in a call for change of the overall structure of CMIP (Stouffer et al., 2016).

The sixth phase of CMIP has therefore adopted a more federated structure with three major components:

1. Five common experiments: four Diagnostic, Evaluation and Characterization of Klima (DECK) experiments and a CMIP historical simulation, which can be used to establish model characteristics and serve as an entry card for participating in one of CMIP's phases or in other Model Intercomparison Projects (MIPs, see below) organized between CMIP phases.
2. Common standards: alignment of coordination, technical standards, infrastructure, and documentation. A regular benchmarking and evaluation process will provide a standardized comparison of model performance.
3. More autonomy for MIPs: projects can be endorsed by CMIP if they fulfil a list of several criteria such as addressing at least one of the key scientific questions of the current CMIP phase (CMIP6) or demonstrating connectivity to the DECK experiments and the CMIP6 historic simulation.

The four baseline experiments bundled in DECK include:

1. Historical Atmospheric Model Intercomparison Project (amip) simulation;
2. Pre-industrial control simulation (piControl or esm-piControl);
3. Simulation forced by an abrupt quadrupling of CO_2 (abrupt-4×CO2) and
4. Simulation forced by a 1% yr^{-1} CO_2 increase (1pctCO2).

The historical CMIP simulation (historical or esm-hist) requires models to simulate the historic period of 1850 until today, using observed emissions. To be able to compare both models that explicitly represent the carbon cycle and models without this capability, the more complex models should provide runs using prescribed CO_2 emissions as well as runs using prescribed CO_2 concentrations. Forcings for the DECK experiments and the historical CMIP simulation were made available in mid-2016.

Together, these five experiments aim at documenting the mean climate and response characteristics of models and providing the means to identify in performance and specific model features.

The scientific focus of CMIP6 is set around the following 3 main questions:

- How does the Earth system respond to forcing?
- What are the origins and consequences of systematic model biases?
- How can we assess future climate change given internal climate variability, climate predictability, and uncertainties in scenarios?

The CMIP6 experiments target seven specific topics through WCRP Grand Science Challenges (GCs):

1. Advancing the understanding of the role of clouds in the general atmospheric circulation and climate sensitivity;
2. Assessing the response of the cryosphere to a warming climate and its global consequences;
3. Understanding the factors that control water availability over land;
4. Assessing climate extremes, what controls them, how they have changed in the past and how they might change in the future;
5. Understanding and predicting regional sea level change and its coastal impacts;
6. Improving near-term climate predictions;
7. Determining how biogeochemical cycles and feedback control greenhouse gas concentrations and climate change.

21 MIPs with varying scientific emphases around the above-mentioned GCs have been endorsed by CMIP. Four of these MIPs are diagnostic and focus on applying output provided by other MIPs. The remaining 17 MIPs proposed 190 experiments resulting in 40 000 model simulation years. The total amount of output from CMIP6 is estimated to be 20-40 petabytes. The data will be freely available after registration through the Earth System Grid Federation (ESGF) using digital object identifiers (DOIs).

At this stage, not all technical specifications of the output have been fully defined yet: e.g., 58 pressure levels are currently planned, ranging from 1000 hPa to 0.03 hPa with the most common increments of 5, 10, 20, 25 and 50 hPa; the temporal resolution is intended to comprise at least 3-hourly, 6-hourly, daily and monthly increments.

Up until CMIP5, future scenario experiments were a part of the project core and coordinated centrally. In CMIP6 these experiments will be run as a MIP (ScenarioMIP). Forcings for the future projections are provided by the IAM community spanning the periods 2015–2100 and 2015–2300. These data sets will be available by the end of 2016. A closer look into near-term forecasts (10-30 years) is provided by the decadal climate prediction project (DCPP) with the aim of increasing the skill of the predictions and understanding forced climate change and internal variability of the near future.

For the first time, a vulnerability, impacts, adaptation and climate services advisory board (VIACS AB) is included in a CMIP phase. Its task is to improve the formal communication between the climate modelling and the user community (for more information, see Ruane et al., 2016).

Through the new organizational structure, the focus on specific scientific questions and the experimental design using WCRP Grand Science Challenges, CMIP6 is expected to contribute greatly to new scientific advancements.

1.3 Literature review on assessments of CMIP datasets

CMIP database is intensively used in different studies to assess the quality of the GCM results for different territories, seasons and variables as well as to estimate the range and characteristics of the uncertainty covered by the different ensembles. Here some examples are gathered focussing on the studies based on the CMIP3 and CMIP5 datasets.

Performance of the model results depends on the given meteorological variable. Luomaranta et al. (2014) assessed the future ice conditions over the Baltic Sea. They projected changes in the annual maximum ice extent and the maximum coastal fast ice thickness using the November-March Baltic coastal mean temperature and the local freezing degree-day sum as proxy, respectively. They started their analysis with 35 GCMs of CMIP5 providing monthly temperature data; finally however, their main conclusions were drawn based only on 28 GCMs, as the temperature and/or precipitation means described by the excluded models mostly deviated considerably from their observational counterparts over Europe for the reference period. Moreover, in some GCMs the simulated past trends in the global mean temperature were not consistent with the observed trend, or future trends for the various RCP scenarios behaved inconsistently. Ruosteenoja et al. (2016a) estimated the future climate change for Finland not only for mean temperature and precipitation conditions, but also for wind speed and diurnal temperature range based on CMIP5 outputs. The wind speed and temperature range projections were derived from a somewhat smaller model ensemble than the projected changes of the mean temperature and precipitation; because all models did not provide data for wind speed and maximum and minimum temperature. Their analysis will be continued for relative humidity, preliminary results show that unrealistic humidity values (exceeding 100%) occur very commonly in the CMIP5 outputs. This problem is concentrated on cold areas and season and acts to produce fake future trends. The phenomena may be due to post-processing, as relative humidity is often not a direct, but a post-processed parameter of the GCMs; however, the issue needs further investigation (based on personal communication with Ruosteenoja).

Study of Ruosteenoja et al. (2016b) shows an example for bias correction of global climate model data. They analysed the future changes in the thermal growing season in Europe based on the CMIP5 GCMs. The ensemble was composed of model runs having daily temperature data, resulting in 23 and 22 members under the RCP4.5 and RCP8.5 scenarios, respectively. In the study, two threshold temperature values (5 and 10 °C) were used; applying bias correction, systematic errors in the temporal mean and variability of simulated temperatures were eliminated for the past, and the data were downscaled to a 0.25-degree resolution grid covering Europe.

The quantification of uncertainties has been naturally a key focus of climate modelling research since the construction of the first ensemble of global climate model results. Hawkins and Sutton (2009) carried out a comprehensive analysis for temperature projections based on 15 coupled models of CMIP3 and 3 different SRES emission scenarios. They quantified uncertainties as from three independent sources: (i) internal variability existing in the climate system without any external forcing; (ii) model uncertainty resulting from the different formulation of climate models; (iii) scenario uncertainty due to various greenhouse gas emission pathways used for description of future anthropogenic activity. Their main conclusions were as follows: (i) decadal internal variability and model uncertainty are the competing leading uncertainty factors in the projections for the next few decades, particularly on continental scales, whereas the role of the scenario uncertainty starts to increase in the second half of the 21st century; (ii) GCMs provide valuable temperature projections over most of the investigated regions as measured quantitatively by the ratio of the decadal-averaged climate change signal to the total uncertainty. A similar assessment was done for precipitation projections (Hawkins and Sutton, 2011), indicating the low impact of emission scenario choice, especially on continental scale. Uncertainties in precipitation projections are chiefly caused by decadal internal variability and model uncertainty (in the latter case, to a substantial extent by the parameterization schemes applied for the description of precipitation-related physical processes; Dobler et al., 2012).

The background of internal variability and the role of internally versus externally forced climate change was discussed extensively by Deser et al. (2012b). They found based on the CMIP3 multi-model ensemble that internal variability accounts for at least a half of the inter-model spread in the projected climate trends before the 2060s and forced (i.e., scenario-driven) changes can be detected earlier in temperature than in precipitation. The dominant source of natural variability is the coupled ocean–atmosphere variability in the tropics and the internal atmospheric variability associated with the annular modes of circulation variability in the extratropics. Further studies (Deser et al., 2012a; Boer, 2009) proved that the role of natural variability is varying over different geographical regions and there are areas with low climate predictability due to large variability (e.g., the Carpathian Basin according to Szabó and Szépszó, 2016) and vice versa (e.g., North America as assessed in Deser et al., 2014).

Hawkins and Sutton made fundamental assumptions such as the independence of the above-mentioned three sources of uncertainty or that the ensemble of CMIP3 is a collection of independent GCMs. Yip et al. (2011) showed that globally the model–scenario interaction effect is an important contribution to uncertainty for long lead times. The study of Pennel and Reicher (2011) indicated that due to similarities in the GCM error patterns CMIP3 tends to underestimate the full range of projection uncertainty. Sanderson et al. (2015) concluded the same for the global climate projections of CMIP5 and proposed a weighting method for filtering out the co-dependence among the GCMs. Zubler et al. (2015) also assessed the dependence of CMIP5 outputs focusing on the Alpine region and proved that temperature change signal over this territory is largely sensitive to the selection methods (e.g., clustering or averaging results of similar GCMs).

2 Methodology

2.1 Available experiments in CMIP5

CMIP5 experiments provide a large set of global climate model simulations with the purpose of improving our understanding on climate, climate change and its possible consequences. This knowledge can be achieved by evaluating how accurate are the models in simulating the climate of the past few decades, by evaluating the future projections on different time scales, and by running targeted experiments focussing on certain aspects or processes of the climate system. These aims are determining the different types of model experiments in CMIP5. A short summary is presented here covering the major simulation types in CMIP5. The detailed documentation can be found in Taylor et al. (2012a). CMIP5 climate model experiments can be divided in two main groups based on the time-scale they cover: near-term (i.e., decadal) simulations and long-term (i.e., century time-scale) simulations (Table 2).

1. Near-term experiments
   - <u>10- and 30-year hindcast and prediction ensembles</u>: This group of simulations mostly consists of experiments covering 10- to 30-year long periods. The 10-year simulations are initialized from the climate states of 1960, 1965, 1970 and every 5 years until 2005 using ocean (and possibly land surface and sea ice) observations. The atmospheric concentrations of greenhouse gases follow the observed values until the end of 2005 and from 2006 the concentrations are prescribed as in the RCP4.5 scenario. These simulations aim at assessing model skill on time-scales where the initial state of the climate system may have influence on the results. The 30-year simulations are the extensions of the 10-year runs initialized in 1960, 1980 and 2005 with an additional 20 years. On this slightly longer time-scale, the effects of greenhouse gas forcing should become more notable. Every decadal experiment must consist of an ensemble with at least 3 members, but actually often more than 3 members are available. Besides the predefined years of initialization, numerous experiments were conducted with starting dates in between the given 5-year periods, forming a large ensemble of decadal simulations well spread out between 1959 and 2012.
   - <u>Shortened pre-industrial control runs</u>: Shortened pre-industrial control simulations are 100-year long unforced simulations with prescribed non-evolving pre-industrial conditions. This type of experiments helps to estimate the unforced variability of the different models, allow to identify incidental climate drifts in the unforced climate system, and can provide initial conditions or

sea surface temperature (SST) and sea ice information for other simulations, as well.

- Time-slice experiments: The highest resolution climate models require vast amount of computing capacity, and therefore, multi-decadal simulations are not always possible to conduct. Nevertheless, in order to explore the effects and potential in running high-resolution global climate models, 10-year time-slice experiments were conducted with high-resolution atmosphere-only models for certain decades in the future with the main focus on the 2026–2035 period. The surface boundary conditions were provided by the projection results of lower resolution coupled atmosphere–ocean models.
- Other experiments: Besides the main experiments described above, further more specialized model simulations were also carried out, e.g., hindcast simulations without volcanic eruptions (Agung, El Chichon, Pinatubo), or predictions with a Pinatubo-like eruption taking place in 2010.

2. Long-term experiments
   - Pre-industrial control runs: The same unforced simulations as described in the near-term experiments, but with a substantially longer, more than 500-year integration period.
   - Historical ensemble simulations: These experiments cover the period 1850–2005, including the observed anthropogenic (lived gas species and aerosols) as well as the natural effects (volcanic solar forcing variations) on climate change. Historical experiments give the basis for validation of the model results against the observed climate of the past decades, and allow to research and detect the human impact on the climate system. These simulations provide the initial conditions for future climate projections.
   - AMIP experiments: AMIP simulations are atmosphere-only (uncoupled) model simulations carried out for the past 30 years with utilizing observed SST and sea-ice data as lower boundary conditions. The nominal period for AMIP simulations is 1979–2008. The purpose of the AMIP runs is to evaluate model performance in uncoupled mode and compare the resulted errors with the coupled experiments, where SST and sea-ice data are not taken from observations.
   - Future projections: They begin from the year 2006 and span the whole 21st century (some simulations continue even beyond 2100). The initial conditions are provided by the historical experiments. All projections use the RCP scenario family as anthropogenic forcing. By evaluating the projection re-

sults, the global climate change can be estimated across a wide range of future greenhouse gas emission scenarios.

- Paleo-climate and other simulations: Paleo-climate experiments provide a possibility to evaluate climate model results under conditions significantly different from present climate, like during the Mid-Holocene (6 000 years ago) or the Last Glacial Maximum (21 000 years ago). There are some additional experiments in CMIP5 carried out with fully coupled Earth system models aimed at studying the processes of carbon cycle and the carbon-climate feedback.

Table 2: Main experiment types in CMIP5.

Near-term experiments	Ensembles of 10-year simulations initialized in 1960, 1965, 1970, …, 2005
	Ensembles of 30-year simulations initialized in 1960, 1980 and 2005
	Shortened (100-year) pre-industrial control runs
	Future time-slice experiments from 2026 to 2035
	Other experiments
Long-term experiments	Pre-industrial control runs (>500 years)
	Historical ensemble simulations from 1850 to 2005
	Atmosphere-only experiments
	Paleo-climatological and other simulations
	Future projections with RCP scenarios for period 2006–2100 and beyond

The individual members of any experiment ensemble carried out with the same model can be distinguished from each other with a code formed from the letters “r”,”i” and “p” paired with three integer numbers, e.g., r1i1p1. The first letter “r” stands for realization number. Different realization numbers signal simulations initialized with different but equally realistic initial conditions, for example historical simulations initialized from different dates of a control run. The second letter, “i” represents the initialization method. This refers to simulations initialized with different methodology, for instance by using different observational data. The third letter “p” stands for perturbed physics ensembles, meaning experiments with different physical parametrization settings. The time-independent variables (where the time frequency is set to “fx”, e.g., in case of orography) do not vary between different realizations, initialization and physical parametrization settings, thus for them r = i = p = 0 (Taylor et al., 2012a).

2.2 Investigated aspects

CMIP5 data are analysed and sorted according to their relevance, usability, accessibility and limitations with respect to their current and future level of usage. This evaluation is focusing on the aspects below:

- Accessibility: Data acquisition is not generally a straightforward part of the assessments. Within the ESGF, basically 10 nodes are available around the globe for data search and data download. Data are stored in the NetCDF format, while metadata is available in a text format. Several difficulties make the work with data complicated: e.g., there are some nodes where no CMIP5 data is officially available; there are some nodes linking to another one (i.e., there is not a real node behind); it is difficult and challenging to narrow the data search; in some cases no openID account is provided for download. In the present data inventory, we are collecting the errors and the drawbacks of the search engine of CMIP5 and we provide some suggestions about which search nodes are appropriate to find the right data and how to manage it at a basic level (more information will produce about this issue by C3S_51_Lot1).
- Spatial grid and resolution: The horizontal resolution – defined as the horizontal distance between two adjacent grid points – is a key parameter that determines the level of spatial details in model results. The parameter consists of two values representing the resolution along the longitudes and latitudes. The resolution varies strongly among the global climate models, ranging from the quite sparse resolution of several degrees to the finest resolution of a few tenths of a degree. Horizontal resolution can also be a limiting factor in the applicability of model results, since some impact assessment methods require a certain minimal resolution for climate data to be used as input. Climate models do not provide information only at the surface but also on the whole three-dimensional atmosphere, and thus the availability of pressure level and model level data is evaluated, as well. Within CMIP5 the atmospheric information is either given on pre-defined pressure levels (1000, 925, 850, 700, 600, 500, 400, 300, 250, 200, 150, 100, 70, 50, 30, 20, and 10 hPa) or on the vertical model levels, which can vary from model to model. Some applications require the model orography and the land area fraction (ratio of land to ocean areas within a grid cell) paired with the climate data, and therefore, the availability of these two time-independent fields is also inspected for each CMIP5 model. The grid type used by the atmospheric model component is also assessed (the majority of variables is given on the atmospheric grid, only the variables describing the ocean and sea ice are given on the grid of the ocean model component).

- Time horizon: Time horizons of the model runs are diverse as described in Section 2.1: decadal predictions and hindcasts (as short-term "projections"); time-slice experiments (using atmosphere-only models with sea surface temperature and sea ice specifications); paleo and pre-industrial runs; Earth system model experiments; scenarios beyond 2100; model diagnosis runs (1%/year CO2, 4xCO2, aqua-planet); detection of climate change. Some experiments are done purely for theoretical purposes. In the data inventory, the focus is put on the user needs, therefore, we are categorizing the CMIP5 ensemble mostly under historical runs from 1850 and RCP-scenario runs from 2006 until 2100 and beyond (as it was also concluded based on personal communication with the Copernicus C3S representatives in the project kick-off meeting).
- Temporal resolution: The highest accessible temporal resolution of the CMIP5 model outputs is sub-hourly data, but the availability of variables at this frequency seems not controlled within the models. It is followed by 3-hourly and 6-hourly data, this sub-daily data is mostly applied in further downscaling methods. For most user needs and for investigating future tendencies of extremes, daily resolution might be sufficient. Furthermore, the monthly outputs and yearly climatological means are all based on daily sums and averages. User requirements concerning the model output frequency are related to the meteorological variables, consequently, we handle this issue together with the aspects of available variables. In the evaluation we are dealing also with basic variables with no time-dependency (like orography).
- Available variables: Due to the large number of available variables in the data base, some classification and filtering are necessary to help the potential users in navigating through the abundant possible options. In the current work, three groups of variables were explored: atmospheric, land surface and ocean variables, with special emphasis on the atmospheric ones. The subject of the investigation was simply the availability or absence of the most frequently-used and most important variables, taking into account the different temporal frequency (monthly, daily, 6-hourly and 3-hourly) with which the given variable is available. Numerous applications require more than one meteorological variables from the same model simulation (e.g., near-surface temperature, precipitation and wind speed), and thus the joint availability of certain variables might provide useful information, as well. For this reason, several "variable packages" were defined (detailed information in Section 3.5) and their availability was also evaluated for each model.

- Bias correction: Impact researchers prefer climate model data without systematic errors, and several bias correction methods are available for the regional climate model data. Coarse resolution global climate model outputs provide primary inputs for statistical and dynamical downscaling methods requiring physically consistent driving fields. Bias correction methods violate this physical consistency, therefore, raw GCM outputs are used in dynamical downscaling and correction is usually applied on the results of downscaling. On the ESGF nodes there is a single CMIP5 model with 4 corrected variables, obtainable on a monthly basis and within decadal predictions only. Consequently, we do not assess further this issue in CMIP5, but conclude the need of bias correction techniques and their further investigation.
- Scenario uncertainty: Scenario runs produce information to investigate the effects of anthropogenic climate change. The chosen emission scenario is a key source of projection uncertainty, so the availability of model runs with different scenarios is crucial to fully cover the uncertainty cascade of the future model results. It is essential to use as many data as logically possible and scientifically solid. There are four RCP scenarios used within the CMIP5 model runs: RCP4.5 ("optimistic") and RCP8.5 ("pessimistic") scenarios, additionally, there are a medium path (RCP6.0) and a highly idealistic scenario (RCP2.6). To quantify scenario uncertainty at different levels, we are selecting several sets of the available runs.

2.3 Available models

In the evaluation of CMIP5 database, we are concentrating on the historical and RCP scenario runs as mentioned above. Table 3 provides an overview about the models involved in the investigation.

Table 3: List of CMIP5 models with responsible institutes, model types (ESM: Earth System Model, AGCM: Atmosphere General Circulation Model, AOGCM: Atmosphere–Ocean General Circulation Model), and references.

	Model	Institute	Type	Reference
1.	ACCESS1.0	Centre for Australian Weather and Climate Research (Australia)	ESM	Bi et al. (2013)
2.	ACCESS1.3			
3.	BCC-CSM1.1	Beijing Climate Center – China Meteorological Administration (China)	ESM	Xin et al. (2013)
4.	BCC-CSM1.1(m)			
5.	BNU-ESM	College of Global Change and Earth System Science – Beijing Normal University (China)	ESM	Ji et al. (2014)
6.	CCSM4	National Center for Atmospheric Research (US)	ESM	Gent et al. (2011)

7.	CESM1(BGC)	National Science Foundation; Department of Energy; National Center for Atmospheric Research (US)	ESM	Hurrell et al. (2013)
8.	CESM1(CAM5)			
9.	CESM1(CAM5.1,FV2)			
10.	CESM1(FASTCHEM)			
11.	CESM1(WACCM)			
12.	CFSv2-2011	Centre for Ocean-Land-Atmosphere Studies; National Centers for Environmental Prediction (US)	AOGCM	Saha et al. (2014)
13.	CMCC-CESM	Centro Euro-Mediterraneo per I Cambiamenti Climatici (Italy)	ESM	Alessandri et al. (2012)
14.	CMCC-CM		AOGCM	Scoccimarro et al. (2011)
15.	CMCC-CMS			
16.	CNRM-CM5	Centre National de Recherches Météorologiques; Centre Européen de Recherche et de Formation Avancée en Calcul Scientifique (France)	ESM	Voldoire et al. (2012)
17.	CNRM-CM5-2			
18.	CSIRO-Mk3.6.0	Queensland Climate Change Centre of Excellence (Australia)	AOGCM	Rotstayn et al. (2010)
19.	CSIRO-Mk3L-1-2	University of New South Wales (Australia)	AOGCM	Phipps et al. (2011)
20.	CanAM4	Canadian Centre for Climate Modelling and Analysis (Canada)	AGCM	von Salzen et al. (2013)
21.	CanCM4		AOGCM	Arora et al. (2011)
22.	CanESM2		ESM	Chylek et al. (2011)
23.	EC-EARTH	Irish Centre for High-End Computing (Ireland)	AOGCM	Hazeleger et al. (2012)
24.	FGOALS-g2	Institute of Atmospheric Physics – Chinese Academy of Sciences; Tsinghua University (China)	AOGCM	Zhang and Yu (2011)
25.	FGOALS-gl		AOGCM	Zhou et al. (2008)
26.	FGOALS-s2		ESM	Bao et al. (2013)
27.	FIO-ESM	First Institute of Oceanography (China)	ESM	Qiao et al. (2013)
28.	GEOS-5	NASA Global Modeling and Assimilation Office (US)	AGCM	Molod et al. (2012)
29.	GFDL-CM2.1	NOAA Geophysical Fluid Dynamics Laboratory (US)	AOGCM	Delworth et al. (2006)
30.	GFDL-CM3		AOGCM	Griffies et al. (2011)
31.	GFDL-ESM2G		ESM	Dunne et al. (2012)
32.	GFDL-ESM2M			
33.	GFDL-HIRAM-C180		AGCM	Zhao et al. (2009)
34.	GFDL-HIRAM-C360			
35.	GISS-E2-H	NASA Goddard Institute for Space Studies (US)	AOGCM	Schmidt et al. (2014)
36.	GISS-E2-H-CC		ESM	

37.	GISS-E2-R		AOGCM	
38.	GISS-E2-R-CC		ESM	
39.	HadCM3	Met Office Hadley Centre (UK)	AOGCM	Gordon et al. (2000)
40.	HadGEM2-A		AGCM	Collins et al. (2011)
41.	HadGEM2-AO	National Institute of Meteorological Research – Korea Meteorological Administration (Korea)	AOGCM	
42.	HadGEM2-CC	Met Office Hadley Centre (UK)	ESM	Martin et al. (2011)
43.	HadGEM2-ES	Met Office Hadley Centre (UK); National Institute for Space Research (Brazil)	ESM	Martin et al. (2011)
44.	INM-CM4	Institute for Numerical Mathematics (Russia)	ESM	Volodin et al. (2010)
45.	IPSL-CM5A-LR	Institut Pierre-Simon Laplace (France)	ESM	Dufresne et al. (2013)
46.	IPSL-CM5A-MR			
47.	IPSL-CM5B-LR			
48.	MIROC-ESM	Atmosphere and Ocean Research Institute – University of Tokyo; National Institute for Environmental Studies; Japan Agency for Marine-Earth Science and Technology (Japan)	ESM	Watanabe et al. (2011)
49.	MIROC-ESM-CHEM			
50.	MIROC4h		AOGCM	Sakamoto et al. (2012)
51.	MIROC5		AOGCM	Watanabe et al. (2010)
52.	MPI-ESM-LR	Max Planck Institute for Meteorology (Germany)	ESM	Giorgetta et al. (2013)
53.	MPI-ESM-MR			
54.	MPI-ESM-P			
55.	MRI-AGCM3.2H	Meteorological Research Institute (Japan)	AGCM	Mizuta et al. (2012)
56.	MRI-AGCM3.2S			
57.	MRI-CGCM3		AOGCM	Yukimoto et al. (2013)
58.	MRI-ESM1		ESM	Yukimoto et al. (2011)
59.	NICAM-09	Nonhydrostatic Icosahedral Atmospheric Model Group (Japan)	AGCM	Satoh et al. (2014)
60.	NorESM1-M	Norwegian Climate Centre (Norway)	ESM	Bentsen et al. (2013)
61.	NorESM1-ME		ESM	Tjiputra et al. (2013)

2.4 Construction of the evaluation matrix

Based on the investigated aspects, the available models and the focus of the data inventory, a categorization method was designed on the CMIP5 simulations which supports to get a quick and objective overview about the main conclusions. An “evaluation matrix” (EM) is defined in which every single model run is scrutinized if it fulfils the specified criteria; e.g., whether its horizontal resolution is in a given range (Table

4). To assess the different aspects of EM together in a summarized way, some multi-criteria filtering methods were also presented with the aim of giving some guidance on choosing a climate model ensemble for a general purpose. For instance, such kind of multi-criteria is that all the important atmospheric variables and two representative anthropogenic scenarios should be available (Table 5). The most valuable part of this evaluation matrix is its summarizing part, providing information about the number of ensemble members in a given category (right panel of Table 4). It has to be noticed that this values represent the numbers of the models in the ensembles and do not provide any information on the available parallel runs with the same model (e.g., on different realizations). All parts of evaluation matrix can be found in Appendix of the deliverable.

Table 4: Part of the evaluation matrix: spatial resolution of the investigated CMIP5 model simulations as categorized in the evaluation matrix.

		ACCESS1.0	ACCESS1.3	BCC-CSM1.1	BCC-CSM1.1(m)	BNU-ESM	CCSM4	CESM1(BGC)		NorESM1-M	NorESM1-ME	Number of models
Longitude resolution (The longitudinal distance between adjacent grid points in degrees)	0°-1°											**8**
	1°-2°	x	x		x		x	x				**25**
	2°-3°			x		x				x	x	**20**
	3°-4°											**6**
	4°-5°											**1**
	> 5°											**1**
Latitude resolution (The latitudinal distance between adjacent grid points. Valid over the equator region. At higher latitudes, deviations may occur due to the Gaussian grid type)	0°-1°						x	x				**13**
	1°-2°	x	x		x				…	x	x	**30**
	2°-3°			x		x						**14**
	3°-4°											**3**
	4°-5°											**1**
	> 5°											**0**
Horizontal resolution (The lower of the Longitude and Latitude resolution)	0°-1°											**8**
	1°-2°	x	x		x		x	x		x	x	**25**
	2°-3°			x		x						**20**
	3°-4°											**6**
	4°-5°											**1**
	> 5°											**1**
Land area fraction available		x	x	x	x	x	x	x		x	x	**55**
Orography available		x	x	x	x	x	x	x		x	x	**55**
Pressure level data available		x	x	x	x	x	x	x		x	x	**51**
Model level data available		x	x	x	x	x	x	x		x	x	**46**

Table 5: An example for multiplied criteria regarding available variables (the pre-defined *extended basic*, *radiation* and *pressure level packages* with daily and monthly outputs) and scenario runs (with both RCP8.5 and RCP4.5) applied on the investigated CMIP5 model simulations in the evaluation matrix.

Extended basic, Radiation, Pressure level	
historical, RCP8.5, RCP4.5	
daily data	monthly data
ACCESS1.0	ACCESS1.0
ACCESS1.3	ACCESS1.3
BCC-CSM1.1	BCC-CSM1.1
BCC-CSM1.1(m)	BCC-CSM1.1(m)
BNU-ESM	BNU-ESM
CSIRO-Mk3.6.0	CNRM-CM5
CanESM2	CSIRO-Mk3.6.0
GFDL-CM3	CanESM2
GFDL-ESM2G	GFDL-CM3
GFDL-ESM2M	GFDL-ESM2G
HadGEM2-CC	GFDL-ESM2M
HadGEM2-ES	GISS-E2-H
IPSL-CM5A-LR	GISS-E2-H-CC
IPSL-CM5A-MR	GISS-E2-R
IPSL-CM5B-LR	GISS-E2-R-CC
MIROC-ESM	HadGEM2-CC
MIROC-ESM-CHEM	HadGEM2-ES
MIROC5	INM-CM4
MRI-CGCM3	IPSL-CM5A-LR
NorESM1-M	IPSL-CM5A-MR
	IPSL-CM5B-LR
	MIROC-ESM
	MIROC-ESM-CHEM
	MIROC5
	MRI-CGCM3
	NorESM1-M
Number of models **20**	**Number of models** **26**

3 Thorough assessment of CMIP5 dataset

3.1 Accessibility

There are 10 different nodes available for browsing and for downloading the CMIP5 simulation outputs:

1. CEDA: https://esgf-index1.ceda.ac.uk/search/cmip5-ceda, in the United Kingdom;
2. DKRZ: https://esgf-data.dkrz.de/search/cmip5-dkrz, in Germany;
3. LLNL: https://pcmdi.llnl.gov/search/cmip5, in the United States;
4. IPSL: https://esgf-node.ipsl.upmc.fr/search/cmip5-ipsl, in France;
5. JPL: https://esgf-node.jpl.nasa.gov/search/cmip5, in the United States;
6. NCCS: https://esgf.nccs.nasa.gov/search/esgf-gsfc, in the United States;
7. NCI: https://esgf.nci.org.au/search/cmip5, in Australia;
8. ESRL: https://esgf.esrl.noaa.gov/search/esgf-esrl, in the United States;
9. GFDL: https://esgdata.gfdl.noaa.gov/search/cmip5, in the United States;
10. LIU: https://esg-dn1.nsc.liu.se/search/cmip5; in Sweden.

It has to be noticed that there is no data on JPL and ESRL data nodes. An appropriate searching algorithm helps to narrow and specify the data that users need. However, such a good method is not available on the JPL, NCI and GFDL nodes. To perform a download, an openID account is needed that is not provided on the NCCS node.

Consequently, 6 nodes operate correctly for search: CEDA, DKRZ, LLNL, IPSL, ESRL, LIU. Altogether, data from 61 models are available in the CMIP5 database, and by default, 46 of them appear on most nodes, with the exception of IPSL and CEDA with 40 models. On the search engine “all replicas” (not “all versions”) must be selected to find all the available models (Figure 2). When “all replicas” is clicked on, the number of data is non-equal for 17 models on the different nodes. Nevertheless, when narrowing the selection for scenario runs, 8 models have different amount of data on the 6 nodes (4 out of it is a GISS model). Even though CEDA, DKRZ, LLNL are the most common nodes for physical data storage and DKRZ seems to have the fullest data collection, due to the absence of metadata information about time horizons on this node, **we recommend using CEDA node for Europe**.

Tailoring the search is very straightforward for most cases, but here is an example on a node how to find data on heatwaves change. After entering CEDA search page, select “CMIP5” under project option, and then select “Show all replicas” (Figure 2). Supposed that the impact of different anthropogenic scenarios is of interest, one must click under the experiment option “historical”, “rcp45” and “rcp85”. Heatwaves are presented on a daily basis that can be set at the option of “time frequency” and it is based on a near-surface air temperature, so “atmospheric variable” is set and “near-surface air temperature” under the option of “variable long name”. Since institutions usually made lots of parallel runs, one could select “r1i1p1” (the most commonly used basic) member of the model runs to access to the most available models.

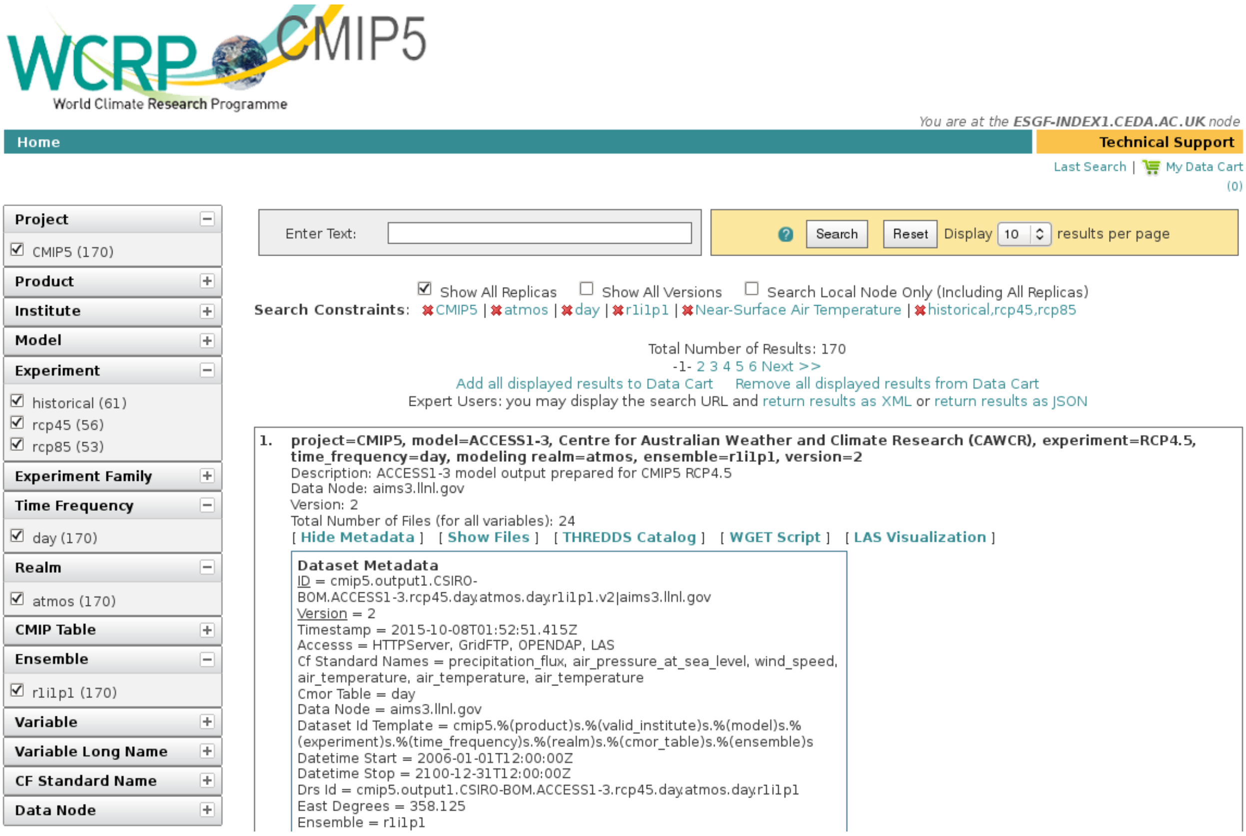

Figure 2: Search options in the CEDA node of ESGF.

If a user prefers to concentrate on a single model, the model has to be chosen (Figure 3). After this, the desired variables (“tas” in our case) must be selected under the results of the historical and RCP experiment group of files by using the “Show Files” option, and then to click on “Add to Data Cart” or simply use the “HTTPServer” link for direct download. Some institutions split their runs into time slices, therefore, all of them must be gathered to fully cover the requested time horizon (Figure 4). Note also that there can be duplicates of files from different nodes since we selected the “all replicas” option.

1. **project=CMIP5, model=MIROC5, Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology, experiment=historical, time_frequency=day, modeling realm=atmos, ensemble=r1i1p1, version=20120710**
   Description: MIROC5 model output prepared for CMIP5 historical
   Data Node: esgf-data1.diasjp.net
   Version: 20120710
   Total Number of Files (for all variables): 254
   [Show Metadata] [Show Files] [THREDDS Catalog] [WGET Script] [LAS Visualization]
   Add to Data Cart
2. **project=CMIP5, model=MIROC5, Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology, experiment=RCP4.5, time_frequency=day, modeling realm=atmos, ensemble=r1i1p1, version=20120710**
   Description: MIROC5 model output prepared for CMIP5 RCP4.5
   Data Node: esgf-data1.diasjp.net
   Version: 20120710
   Total Number of Files (for all variables): 319
   [Show Metadata] [Show Files] [THREDDS Catalog] [WGET Script] [LAS Visualization]
   Add to Data Cart
3. **project=CMIP5, model=MIROC5, Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology, experiment=RCP8.5, time_frequency=day, modeling realm=atmos, ensemble=r1i1p1, version=20120710**
   Description: MIROC5 model output prepared for CMIP5 RCP8.5
   Data Node: esgf-data1.diasjp.net
   Version: 20120710
   Total Number of Files (for all variables): 330
   [Show Metadata] [Show Files] [THREDDS Catalog] [WGET Script] [LAS Visualization]
   Add to Data Cart

Figure 3: Search results in the CEDA node of ESGF: different experiments with the MIROC5 model.

129	**tas_day_MIROC5_historical_r1i1p1_19300101-19391231.nc** Checksum: 168fabedbc147f5b54318da790d8d907614d57db226cbed58c702f7a3a09cff0 Size: 478517800 Tracking Id: 06445818-5b2f-448b-b583-a040766bef1f [More File Metadata]	HTTPServer OPENDAP
130	**tas_day_MIROC5_historical_r1i1p1_19100101-19191231.nc** Checksum: 9641e9209bd32b8148a2bd71cce9635cd5d83ef7b40c1cbad55e7b152620e9e7 Size: 478517800 Tracking Id: 07ce8f39-33b3-43f7-9bf9-30e32450caa7 [More File Metadata]	HTTPServer OPENDAP
131	**tas_day_MIROC5_historical_r1i1p1_19400101-19491231.nc** Checksum: fbb58c7637375d4204b48fe418a39666335895f2f3298d6506b24a6bab70fba2 Size: 478517800 Tracking Id: bef05d73-bb1e-4bc0-9168-72566768cbbc [More File Metadata]	HTTPServer OPENDAP
132	**tas_day_MIROC5_historical_r1i1p1_19600101-19691231.nc** Checksum: a370fc87c95c5cfcadc97ba7f1b9ef20b383fe09b7ad733bc9ed173e40b992f3 Size: 478517800 Tracking Id: 4a55be56-b9e6-4ec4-a8d1-8f4cd27e6811 [More File Metadata]	HTTPServer OPENDAP
133	**tas_day_MIROC5_historical_r1i1p1_19000101-19091231.nc** Checksum: 2b6127afade7ad4647399fee7d4a027e77ae84f6648b0f4440a94f50f2011b55 Size: 478517800 Tracking Id: 61469c33-1bca-44a4-b48f-6e3d574a3891 [More File Metadata]	HTTPServer OPENDAP
134	**tas_day_MIROC5_historical_r1i1p1_19700101-19791231.nc** Checksum: e293657fa88a196d1e20ceb850844bbd61a41e05e0feda98b594d3d1a4d115ff Size: 478517800 Tracking Id: 9491838d-9094-4717-a56f-d8f497633658 [More File Metadata]	HTTPServer OPENDAP
135	**tas_day_MIROC5_historical_r1i1p1_19500101-19591231.nc** Checksum: 417d0832b4be455c2fc9769f4066ee84bffe25850684bc7e9bb915cda555649a Size: 478517800 Tracking Id: c6bfbad4-19a7-490b-849f-d99916c28c6d [More File Metadata]	HTTPServer OPENDAP
136	**tas_day_MIROC5_historical_r1i1p1_19200101-19291231.nc** Checksum: 61475b9f14cc521761b486bc8c644d2daf7778bca50f0c2fd09183e7aeb5cf93 Size: 478517800 Tracking Id: 2038ae97-ec4f-4dcc-a03a-c81f187c03a4 [More File Metadata]	HTTPServer OPENDAP

Figure 4: Search results in the CEDA node of ESGF: different time slices of a MIROC5 experiment.

3.2 Spatial resolution

As mentioned earlier, the spatial properties of the model outputs were evaluated based on the following aspects:

- Horizontal (longitude and latitude) resolution;
- Availability of pressure level and model level data;
- Availability of constant fields: orography and land-sea area fraction;
- The type of atmospheric grid.

All CMIP5 model outputs are given on a Gaussian grid, which is a rectangular grid with constant longitude and (slightly) varying latitude resolution. The horizontal resolution of the model outputs varies widely from 0.56° as the highest to 5.6° as the most sparse resolution.

In the evaluation matrix, all the models were grouped into six categories based on the longitude, latitude and horizontal resolution (combined from the two former ones by choosing the larger value, i.e., the worse resolution). The chosen categories are: 0°–1°; 1°–2°; 2°–3°; 3°–4°; 4°–5°; >5° (Table 9 in Appendix). **Most models have a 1°–2°** (approximately 100-250 km) resolution, with a total of 25 members belonging to that category. The second most frequent category is the **2°–3°** (approximately 200-350 km) **resolution** with 20 models. 8 models (only 6 from different model families) are found in the highest, 0°–1° resolution category. However, most of these high-resolution models do not have future RCP scenarios available (Table 6), only the CMCC-CM and the MIROC4h models do. 2 of the total 61 models have a horizontal resolution lower than 4 degrees: the CSIRO-Mk3L-1-2 and the FGOALS-gl, and the latter one has only paleo-climate experiments.

Table 6: The highest-resolution models and their available experiments. Bold characters represent the models for which scenario runs are available.

Model	Available experiments
CFSv2-2011	decadal experiments only
CMCC-CM	**RCP, historical, control, AMIP and decadal experiments available**
GFDL-HIRHAM-C180	no RCP experiment, but AMIP available
GFDL-HIRHAM-C360	no RCP experiment, but AMIP available
MIROC4h	**RCP, Historical, control and decadal experiments also available**
MRI-AGCM3.2H	no RCP experiment, but AMIP available
MRI-AGCM3.2S	no RCP experiment, but AMIP available
NICAM-09	no RCP experiment, other specialized simulations available

Availability of the upper-level atmospheric variables is important especially for downscaling the GCM data with regional climate models and applying GCM outputs as lateral boundary conditions. Therefore, the existence of three-dimensional data was also considered in the data inventory. In CMIP5, the upper level atmospheric data is either given on predefined pressure levels (on 1000, 925, 850, 700, 600, 500, 400, 300, 250, 200, 150, 100, 70, 50, 30, 20, and 10 hPa) or on the vertical model levels. Pressure level variables are available for the most models: 51 out of the 61 GCMs contain some pressure level information (Table 9). Different vertical coordinates are used in the models, e.g., terrain following, theta (potential temperature), sigma (pressure) or hybrid (combination of terrain following and pressure) coordinates. When the pressure of model levels cannot be calculated from the vertical coordinate information, the annual pressure climatology on model levels is also provided. 46 GCMs have data available on the model levels (although not for the prognostic variables which are used in dynamical downscaling methods; see Table 12 in Appendix).

Constant fields such as model orography and land-sea fraction (ratio of land to ocean areas over a grid cell) can be essential in certain studies and applications (e.g., in interpolation, vertical correction of 2-meter temperature), and thus their existence was inspected. Both constant fields can be downloaded for 55 models (Table 9).

3.3 Time horizon

Different experiment types and their varying time horizons were explained in Section 2.2 in detail. In this section we are concentrating on simulations with RCP scenarios, narrowing the ensemble of 61 GCMs to that of 47 ones. With the simulated time span reaching 2100, they can provide input data for long-term adaptation, while simulations going beyond 2100 serve as essential information about the relevant paths towards the far-future, which might orientate the decision making related to mitigation to climate change. The present data inventory does not discuss the shorter model runs (e.g., decadal and seasonal predictions), as they are beyond the scope of the ABC4CDE project.

4 out of the 47 selected models have runs only until 2035/2040: CanCM4, GFDL-CM2.1, HadCM3, and MIROC4h. CSIRO-Mk3L-1-2 has no data before 2100, but goes from 2101 for few atmospheric variables. Accordingly, **42 GCMs provide data for impact studies and downscaling until 2100** (Table 10 in Appendix). Altogether **13 models have simulations beyond 2100 until 2300** for atmospheric variables: BCC-CSM1.1, CCSM4, CNRM-CM5, CSIRO-Mk3.6.0, GFDL-CM3, GISS-E2-H, GISS-E2-R, HadGEM2-ES, IPSL-CM5A-LR, IPSL-CM5A-MR, MIROC-ESM, MPI-ESM-LR, and NorESM1-M (Table 10). Even though originally these multi-centennial simulations were planned as tier experiments for RCP2.6 and RCP8.5 scenarios, the outputs are in diverse. All models

have projections for the RCP4.5 scenario at monthly level, most of them also for the RCP8.5 scenario and/or at daily level (but very few with the RCP6.0 scenario and 6-hourly data; c.f. Table 10 and Table 16 in Appendix).

3.4 Temporal resolution

Temporal frequency of the data storage in CMIP5 has also been explored in the data inventory, focusing on the 3-hourly, 6-hourly, daily and monthly scales. Additionally, the existence of the constant, time-independent variables (orography and land-sea mask) is assessed.

Monthly outputs are archived at 60 out of 61 models (excluding CSIRO-Mk3L-1-2), while the daily, 6- and 3-hourly outputs are stored for 53, 39 and 38 models, respectively (Table 11 in the Appendix). Looking at the RCP scenario runs, 46 models out of 47 provide monthly data (excluding CSIRO-Mk3L-1-2 having only daily outputs). **41 GCMs have daily resolution** data [CESM1(WACCM), FGOALS-s2, FIO-ESM, GFDL-CM2.1, GISS-E2-H-CC, and GISS-E2-R-CC models have only monthly data], 32 and 26 models serve 6- and 3-hourly outputs, respectively (Table 11). For 11 GCMs, topography information is not archived. Limiting the search for atmospheric variables, it turns out that NorESM1-ME does not have daily data (it has only SST fields on daily scale).

3.5 Available variables

Considering all climate models and all the different experiment types within CMIP5, the total number of available variables adds up to more than 600 (Taylor, 2012a). The availability of a given variable is different between the models, experiment types and even temporal resolutions. This large number of options and diverse structure makes it difficult to have general assumptions on the availability of the specific variables to be interested by the users. In order to help the potential user to narrow the number of options, only the most frequently applied variables were selected. The focus was put on the atmospheric (Table 12), the land surface (Table 13) and the ocean variables (Table 14) of those GCMs that have any RCP-driven projections or any historical simulations. The atmospheric variables were divided into three further groups (marked with different colours in the Table): surface, pressure level and model level variables. Presence of these key variables is evaluated for each climate model and for each (monthly, daily, 6- and 3-hourly) frequency.

The results show that most of the selected atmospheric, land surface and ocean variables are available on monthly timescale for at least 30-40 different models. On daily resolution the availability is reduced for each geosphere. The main atmospheric variables describing the temperature, precipitation, pressure, wind component, humidity and radiation are still accessible on daily resolution, but among the land surface variables only the moisture in upper portion of soil column and the total runoff are available. Three of the ocean parameters can be downloaded with daily output frequency: sea surface temperature, sea ice fraction and sea ice thickness. Atmospheric parameters available with sub-daily resolution are the near-surface temperature, the wind components, the sea level and surface pressure, the near-surface specific humidity, the precipitation, the pressure level variables (in every 6 hours) and some radiation components (in every 3 hours). Concerning the land surface data, the above-mentioned two variables can be reached for every 3 hours, but for a smaller number of models than on daily scale.

The methods and models of impact researchers generally require several climate variables from the same model simulation as input data; therefore, besides the existence of single variables, the joint existence of certain groups of variables could yield also useful information. To address this issue, several **"variable packages"** were defined and evaluated for each climate model. The variable packages are listed in Table 7. There are normal packages as well as their extended version containing extra parameters often available for a smaller number of model runs. The *basic*, *extended basic*, *extended basic 2* and *radiation packages* are composed of surface variables. The *extended radiation package* includes also some additional radiation component at the top of the atmosphere, *pressure level packages* obviously contain pressure level variables, and *model level package* consists of the variables available on models' vertical levels.

Variables belonging to the **basic package** are the near-surface air temperature, the daily minimum near-surface temperature, the daily maximum near-surface temperature, and the precipitation. The package **is stored with monthly and daily output frequency for more than 40 models** (Table 15). Basic package is extended with wind components, sea level pressure, specific humidity (we did not take relative humidity because of its often unrealistic values, discussed in Section 1.3), cloudiness, global radiation, and snowfall; monthly means or sums of this group are found for 31 models, while daily values for 23 models. Adding the water vapour path to the list, the extended basic 2 package is available only on monthly scale and in 29 GCMs. The radiation package consisting of 2 shortwave and 2 longwave surface radiation components is found with monthly, daily and 3-hourly archive frequency for 44, 33 and 24 models, respectively. Its extended version has no sub-daily occurrence. The pressure level packages are widely available among the models, with more than 40 monthly, around 30 daily and 26 6-hourly occurrence. The few model level variables are archived mostly with monthly frequency for 29 models.

Table 7: The defined variable packages.

Package name	Variable long name	Variable name	Unit
Basic	Near-Surface Air Temperature	tas	K
	Daily Maximum Near-Surface Air Temperature	tasmax	K
	Daily Minimum Near-Surface Air Temperature	tasmin	K
	Precipitation	pr	kg m^{-2} s^{-1}
Extended basic	Basic +		
	Sea Level Pressure	slp	Pa
	Eastward Near-Surface Wind	uas	m s^{-1}
	Northward Near-Surface Wind	vas	m s^{-1}
	Near-Surface Specific Humidity	huss	1
	Surface Downwelling Shortwave Radiation	rsds	Wm^{-2}
	Total Cloud Fraction	clt	%
	Snowfall Flux	prsn	kg m^{-2} s^{-1}
Extended basic 2	Extended basic +		
	Water Vapour Path	prw	kg m^{-2}
Radiation	Surface Downwelling Longwave Radiation	rlds	Wm^{-2}
	Surface Upwelling Longwave Radiation	rlus	Wm^{-2}
	Surface Downwelling Shortwave Radiation	rsds	Wm^{-2}
	Surface Upwelling Shortwave Radiation	rsus	Wm^{-2}
Extended radiation	Radiation +		
	TOA Incident Shortwave Radiation	rsdt	Wm^{-2}
	TOA Outgoing Shortwave Radiation	rsut	Wm^{-2}
	TOA Outgoing Longwave Radiation	rlut	Wm^{-2}
Pressure level	Air Temperature	ta	K
	Eastward Wind	ua	m s^{-1}
	Northward Wind	va	m s^{-1}
	Specific Humidity	hus	1
Extended pressure level	Pressure level +		
	Relative Humidity	hur	%
	Omega (dp/dt)	wap	Pa s^{-1}
	Geopotential Height	zg	m
Model level	Cloud Area Fraction	cl	%
	Mass Fraction of Cloud Liquid Water	clw	1
	Mass Fraction of Cloud Ice	cli	1
	Convective Mass Flux	mc	kg m^{-2} s^{-1}

3.6 Available RCP scenario runs

The uncertainty range arising from the description of future anthropogenic activity in the model simulations is important both from a scientific point of view and from users' perspective. 51 models out of 61 have historical runs, but a smaller sub-ensemble, 47 GCMs provide one RCP run at minimum [CESM1(CAM5.1,FV2), CESM1(FASTCHEM), CNRM-CM5-2, MPI-ESM-P have solely historical simulations; Table 16 in the Appendix]. The most commonly used scenarios are RCP4.5 and RCP8.5: 44 and 42 GCMs have simulations forced by them, respectively. These two groups produce the core simulations of CMIP5. The highly idealistic RCP2.6 scenario is used with 30 models, while the medium RCP6.0 scenario is the least exploited one with 22 GCMs.

Analysing the joint availability of different scenario runs, no model was found to be forced with only the RCP2.6 or RCP6.0 scenarios, i.e., if a model run is available with any of these scenarios it is also available either with RCP4.5 or RCP8.5. Five model versions (CSIRO-Mk3L-1-2, CanCM4, GFDL-CM2.1, HadCM3, MIROC4h) have only simulations with RCP4.5 and 2 models (CMCC-CESM, MRI-ESM1) only with RCP8.5. Altogether **21 models have simulations for all RCPs**. Projected temperature change shows a nearly linear relationship with the greenhouse gas emissions (Stocker et al., 2013), so the largest spread in temperature projections can be captured already by examining 3 RCPs, RCP2.6, RCP4.5 and RCP8.5, available for 29 models. Considering the "probability" of the different forcing scenarios (i.e., noting that RCP2.6 is an ultra-optimistic scenario), the possible range of future warming is reflected by taking RCP4.5, RCP6.0 and RCP8.5. This option is available for 21 models, i.e., for the same GCMs which have experiments with all RCPs. Focusing only on the core experiments, **39 models provide simulations with both RCP4.5 and RCP8.5,** forming an ensemble catching the optimistic and pessimistic paths of the future.

4 Proposals for CDS

Copernicus C3S Climate Data Store is merging all the climate change information relevant for the users. Since the users and their requirements regarding the global climate projections are diverse, we provide some aspects how a selection of the existing CMIP5 projections might serve them. First, a multi-criteria method is shown to estimate the size of the available ensembles for different purposes. Thereafter, the model interdependency in these ensembles is discussed in order to narrow the GCM selection to the independent models. Also, some gaps and shortcomings of CMIP5 are listed which could be handled in CDS. Finally, a proposal is given for the content of a user manual providing guideline for applying and interpreting CMIP5 data.

4.1 Multi-criteria method

To assess the different aspects of the evaluation matrix together, in a summarized way, a multi-criteria filtering method is presented with the aim of giving some guidance on choosing a climate model ensemble from all of the available options. The first criterion is applied on the available variables, the second is concerning the spatial resolution and the third one is related the available scenarios. The different criteria are marked with different colours in Table 17 and Table 18 in the Appendix.

Considering the first criterion, those models are selected, for which the extended basic, the radiation and the pressure level packages are all available, either with daily or monthly output frequency. This condition remains the same throughout all the columns. The second criterion gives a stricter (0°–2°) and a more tolerant (0°–3°) option regarding the horizontal resolution. The third criterion specifies the availability of scenario runs:

- Historical and RCP8.5 runs;
- Historical, RCP8.5 and RCP4.5 runs;
- Historical, RCP8.5, RCP4.5 and RCP2.6 runs;
- Historical and runs with all RCPs.

In the cases where the RCP6.0 scenario run is available, runs with all the other scenarios are also available. Consequently, it was unnecessary to define a separate group for the "historical, RCP8.5, RCP4.5 and RCP6.0 runs" option.

It is clearly visible that between the ensembles obtained using the different criteria, the included models differ significantly. Looking at the strictest criterion group (i.e., **high-resolution runs with all scenarios and their daily outputs covering all the defined variable packages**; top right block in Table 17), only **5 CMIP5 models remain** from the total of 61. Three of them are AOGCMs, namely CSIRO-Mk3.6.0, MIROC5 and MRI-CGCM3; the other two are ESMs: BCC-CSM1.1(m) and HadGEM2-ES. It must be emphasised that this table does not present any qualitative assessment of the model outputs and gives no information on model skills and validation results. Therefore, **these models are not considered the "best ones" only the ones with the most abundant available (and downloadable) data**.

Loosening up the criterion regarding the available scenarios for just the RCP8.5, 9 models are left (top left block in Table 17). In this case, however, the ensemble has several members from the same model family (ACCESS, HadGEM, MRI). This fact must be considered when choosing a model ensemble for evaluation.

If we extend the upper limit of the horizontal resolution to 3 degrees, twice or almost three times as much models meet the criterion than above (bottom row in Table 17, but the lists contain even more models from the same model families. If the **criterion regarding spatial resolution is completely ignored** (Table 18), the lists expand only slightly further (recall that horizontal resolution exceeds 3 degrees only for a few models): **27 GCMs have data from experiments conducted with RCP8.5 scenario and 16 of them have been run with all the four RCP scenarios (with monthly outputs)**.

4.2 Suggestions for CMIP5 ensemble selection

Looking at the suggested models available for RCP8.5, the largest set of them consists of 27 models (Table 18), but not all of them are independent from each other. Here we are presenting the subsets of model families and providing a selection neglecting the extra sibling models:

- ACCESS1-3 is a newer version than ACCESS1-0, but according to the validation the latter one gives better temperature results for Central Europe (Csorvási, 2015). Depending on the region, we suggest using the older version (i.e., ACCESS1-0).
- BCC-CSM1-1(m) is an updated model version of BCC-CSM1-1. When both versions are available, m one is recommended to be used.
- GFDL-ESM2G being an Earth system model can describe more fully the climate system than GFDL-CM3, which is an AOGCM. GFDL-ESM2M is an older version of the ESM2G, but provides better results (Luomaranta et al., 2014), thus we suggest applying ESM2M when all other versions are also available.
- GISS-E2-R and GISS-E2-H are coupled with different ocean models, Russell and HYCOM ocean models, respectively. For most global measures Russell ocean model produces better results (Schmidt et al., 2014). Adding an interactive carbon cycle to this model (R-CC) is an advantage, so we suggest using GISS-E2-R-CC when possible.

- Since HadGEM2-CC is the newest version in the Earth system model family of HadGEM, we recommend using the HadGEM2-CC model.
- IPSL-CM5A-MR model is available at finer resolution than IPSL-CM5A-LR, but a slightly newer model version is used with very different atmospheric parameterization in IPSL-CM5B-LR. This latter model family member overall has considerably better global results than the previous version (Hourdin et al., 2013). Depending on the validation results over the area of interest and resolution desire, we suggest selecting either CM5B-LR or CM5A-MR.
- MIROC5 has considerably better resolution than its ESM counterparts within the same family. At the same time, MIROC-ESM and MIROC-ESM-CHEM are more complex Earth system models, especially MIROC-ESM-CHEM including a coupled atmospheric chemistry module. Depending on the purpose, we suggest to use MIROC-ESM-CHEM or MIROC5.
- MRI-CGCM3 is a coupled climate model as a subset of MRI-ESM1. Even though the former one has better ocean resolution, one should clearly use the Earth system model part of this group (ESM1) providing more comprehensive description of the climate system.
- As mentioned above, this data inventory does not assess the quality of the model results and it does not provide validation for any region. However, it has to be remarked that based on the literature review some models have to be applied with care (for instance, IPSL-CM5B-LR produces weaker results for Northern Europe according to Luomaranta et al., 2014).

Selecting the time series of a single model run which covers the period 1850–2100, the volume of the downloaded data is 2–18 GB (depending on the horizontal grid distance) for a given variable at daily resolution and less than 1 GB at monthly resolution. Considering the proposed ensemble for the RCP4.5 and RCP8.5 scenarios, consisting of 11 members with daily output frequency, the amount of the requested data can be 24–265 GB for a selected variable, while the data volume does not exceed 11 GB for the monthly outputs of the 14-member ensemble. Requiring the subset of models available for all RCPs, storage of 27–300 GB is needed for a given variable at daily level.

Table 8: A tentative proposal for selection of CMIP5 GCM simulations considering the availability of given scenarios, atmospheric variables and the model interdependency.

Extended basic, Radiation, Pressure level		Extended basic, Radiation, Pressure level	
historical, RCP8.5		historical, RCP8.5, RCP4.5	
daily data	monthly data	daily data	monthly data
ACCESS1.0	ACCESS1.0	ACCESS1.0	ACCESS1.0
BCC-CSM1.1(m)	BCC-CSM1.1(m)	BCC-CSM1.1(m)	BCC-CSM1.1(m)
BNU-ESM	BNU-ESM	BNU-ESM	BNU-ESM
	CNRM-CM5		CNRM-CM5
CSIRO-Mk3.6.0	CSIRO-Mk3.6.0	CSIRO-Mk3.6.0	CSIRO-Mk3.6.0
CanESM2	CanESM2	CanESM2	CanESM2
GFDL-ESM2M	GFDL-ESM2M	GFDL-ESM2M	GFDL-ESM2M
	GISS-E2-R-CC		GISS-E2-R-CC
HadGEM2-CC	HadGEM2-CC	HadGEM2-CC	HadGEM2-CC
	INM-CM4		INM-CM4
IPSL (CM5A-MR or CM5B-LR)	IPSL (CM5A-MR or CM5B-LR)	IPSL (CM5A-MR or CM5B-LR)	IPSL (CM5A-MR or CM5B-LR)
MIROC (ESM-CHEM or MIROC5)	MIROC (ESM-CHEM or MIROC5)	MIROC (ESM-CHEM or MIROC5)	MIROC (ESM-CHEM or MIROC5)
MRI-CGCM3	MRI-CGCM3	MRI-CGCM3	MRI-CGCM3
MRI-ESM1	MRI-ESM1		
NorESM1-M	NorESM1-M	NorESM1-M	NorESM1-M
Number of models	**Number of models**	**Number of models**	**Number of models**
12	**15**	**11**	**14**

Extended basic, Radiation, Pressure level		Extended basic, Radiation, Pressure level	
historical, RCP8.5, RCP4.5, RCP2.6		historical, all RCPs	
daily data	monthly data	daily data	monthly data
BCC-CSM1.1(m)	BCC-CSM1.1(m)	BCC-CSM1.1(m)	BCC-CSM1.1(m)
BNU-ESM	BNU-ESM		
	CNRM-CM5		
CSIRO-Mk3.6.0	CSIRO-Mk3.6.0	CSIRO-Mk3.6.0	CSIRO-Mk3.6.0
CanESM2	CanESM2		
GFDL-ESM2M	GFDL-ESM2M	GFDL-ESM2M	GFDL-ESM2M
	GISS-E2-R		GISS-E2-R
HadGEM2-ES	HadGEM2-ES	HadGEM2-ES	HadGEM2-ES
IPSL-CM5A-MR	IPSL-CM5A-MR	IPSL-CM5A-MR	IPSL-CM5A-MR
MIROC (ESM-CHEM or MIROC5)	MIROC (ESM-CHEM or MIROC5)	MIROC (ESM-CHEM or MIROC5)	MIROC (ESM-CHEM or MIROC5)
MRI-CGCM3	MRI-CGCM3	MRI-CGCM3	MRI-CGCM3
NorESM1-M	NorESM1-M	NorESM1-M	NorESM1-M
Number of models	**Number of models**	**Number of models**	**Number of models**
10	**12**	**8**	**9**

4.3 Identification of gaps

During the evaluation of the CMIP5 dataset, several technical difficulties and gaps were concluded. Many of them are related to the browsing method and the documentation, both having key importance for the users:

- Description of “all replicas” and “all versions” options is missing from the ESGF data search nodes. To find all data, one must tick all replicas and not all versions. Furthermore, even when “all versions” is not selected, more versions are resulted, which can be confusing. Not all experiment types can be chosen in the drop-down list „Experiment” on ESGF search pages (e.g., time-slice experiments can be found among the decadal experiments, since they have no separate category).
- No information is found on the available parallel runs. Not always r1i1p1 is the most commonly used realization through the different scenarios within a single model.
- Selecting the time horizon is missing from the search options. User must dig into metadata information to find out which collection of variables is available up to 2100 or below/beyond. DKRZ node does not provide this information.
- When one variable is selected, still all variables appear in the output list making it extremely time-consuming to find the desired parameter. Browsing the variables lacks the option selecting multiple variables at the same time. In general, introduction of the AND logical function would be useful within each search category.
- Encoding the meteorological variables is not unified along the whole database, e.g., near-surface relative humidity is abbreviated as ”rhs” in daily data and ”hurs” in monthly and sub-daily data.
- Topographic data (e.g., orography, land-sea mask) is highly desirable to perform further interpolations of the model outputs, so they should be completed.
- The usage of leap years is not common within the model calendars, complicating the treatments of different model results.
- Lots of GCMs produce unrealistic relative humidity values, maybe due to the post-processing method employed for the calculation of the relative humidity. Since many users are interested to apply relative humidity instead of specific humidity, a new reliable algorithm should be constructed in CDS.
- The wide applicability of CMIP5 model outputs as boundary forcings for dynamical downscaling is limited due to the lack of model level data. Driving data can be used in those regional climate models which are able to utilize pressure level data instead of model level data.

- Lots of errors were identified and fixed through the CMIP5 website (http://cmip-pcmdi.llnl.gov/cmip5/errata/cmip5errata.html), but some leftovers are still ahead of getting fixed. Last update on errors was in February 2015.
- Some scenarios are inadequately represented within the models, RCP6.0 being the least extensively used scenarios, resulting in a less sound uncertainty estimation of the results. This forces the users to analyse basically two future pathways (RCP4.5 and RCP8.5).
- No collected information was found on the main differences between different model versions of the same model-family (e.g., CMCC-CESM, CMCC-CM, CMCC-CMS). A short summary with some recommendation describing which version to take for different purposes would be useful.

4.4 Suggestions for a user guide on global climate projections

Climate Data Store supplies not only data for the users, but also a support for them to apply the data. This is particularly needed in the case of climate projections due to their special interpretation. To write a user guide is not the task of the ABC4CDE project. Nonetheless, here we provide some content elements which should be included in a guidance on global climate projections:

- Scientific background of the climate projections: introduction of the main components and physical processes of the climate system; summary of the available climate modelling tools with focus on global climate models; explaining the main scientific questions of climate modelling (description of the response of the climate system to the anthropogenic activity etc.)
- Basics of numerical modelling (particularly climate modelling): explanation of the horizontal resolution and vertical levels; nature of physical parameterizations (and their role in large deviation of model results); scenario approach to quantify the anthropogenic effects in the models; evolution of global climate models from the AOGCMs to the ESMs;
- Interpretation of the climate model data: distinguishing the projections, predictions and forecasts; explaining the area represented by a grid cell and the time horizon represented by a climate projection; explaining what kind of phenomena can be reflected by a climate model as well as limitations of climate modelling; showing some example for the typical outputs (climatological means, distributions etc.);
- Validation: explaining the importance and process of the validation; showing some possibilities to handle the systematic model errors; clarifying the meaning of the reference period and its selection;

- Uncertainties: introducing the main sources of projection uncertainties and estimating their role in the projection results; presenting the ensemble approach; showing concrete methods for quantification of uncertainty (intervals, probabilities etc.); emphasizing the importance of using a well-balanced ensemble instead of a single model run.

5 Conclusions

In the data inventory, climate projections of the CMIP5 database were assessed regarding their spatial and temporal characteristics (horizontal and vertical resolutions, archived outputs, covered time horizons etc.), their available variables and anthropogenic scenarios, and their feasibility and limitations in different user applications (downscaling, impact research). The same aspects were concisely summarized for the previous and ongoing CMIP programmes, as well.

Considering all the available CMIP5 model results, our investigation was started with 61 GCMs. Concentrating on long-term climate projections, 14 models were left out which do not have runs with any RCP scenario. Among the remaining 47 GCMs, 42 models have simulations until the end of the century and 13 GCMs go beyond 2100 (up to 2300). Data are archived with monthly, daily, 6- and 3-hourly frequency. For the ocean, only monthly outputs are available, apart from the daily sea surface temperature, the daily sea ice fraction and the daily sea ice thickness. Sub-daily atmospheric parameters are the near-surface temperature, the wind components, the sea level and surface pressure, the near-surface specific humidity, the precipitation, the pressure level variables and some radiation components. Daily precipitation sum, daily mean near-surface air temperature, daily minimum and maximum temperature data are available for 39 models, while monthly means of these variables are found for 41 models (going until 2100). Taking also the surface wind components, specific humidity, sea level pressure, global radiation, cloudiness, and snowfall, the number of models with daily and monthly outputs is reduced to 22 and 29, respectively. Pressure-level data are important for dynamical downscaling. They are stored with a 6-hour output frequency for 25 GCMs until 2100. Nevertheless, in the case of some regional climate models, pressure-level data are not sufficient as driving fields, since those models require the prognostic variables on model levels. Model level data are available only with monthly frequency and for cloud parameters. So for further request, one has to contact personally the scientist responsible for the chosen model experiment (contact details are usually provided in the meta information of model output files).

Evaluating the joint occurrence of the different criteria in the database, it was concluded that an 8-member ensemble can be designed from climate projections with all the 4 representative RCP scenarios which have daily outputs for any of the selected (surface, pressure-level and radiation) atmospheric variables. Not requiring the RCP6.0 scenario, two can be added to the selection, resulting in a 10-member ensemble; while focusing only on RCP4.5 and RCP8.5 runs, a further additional model family also steps into the group. In the case of monthly data requests, the ensemble can be further extended. Finally if the spatial resolution is required to be higher than 2 degrees, only 5 GCMs are left: their results are available for all the relevant atmospheric and surface variables on daily scale under each of the 4 representative anthropogenic scenarios.

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Appendix

Different parts of the evaluation matrix

Table 9: Spatial resolution of the investigated CMIP5 model simulations.

		ACCESS1.0	ACCESS1.3	BCC-CSM1.1	BCC-CSM1.1(m)	BNU-ESM	CCSM4	CESM1(BGC)	CESM1(CAM5)	CESM1(CAM5.1,FV2)	CESM1(FASTCHEM)	CESM1(WACCM)	CFSv2-2011	CMCC-CESM	CMCC-CM	CMCC-CMS	CNRM-CM5	CNRM-CM5-2	CSIRO-Mk3.6.0	CSIRO-Mk3L-1-2	CanAM4	CanCM4	CanESM2	EC-EARTH	FGOALS-g2	FGOALS-gl	FGOALS-s2	FIO-ESM	GEOS-5	GFDL-CM2.1	GFDL-CM3	GFDL-ESM2G	GFDL-ESM2M	GFDL-HIRAM-C180	GFDL-HIRAM-C360	GISS-E2-H	GISS-E2-H-CC	GISS-E2-R	GISS-E2-R-CC	HadCM3	HadGEM2-A	HadGEM2-AO	HadGEM2-CC	HadGEM2-ES	INM-CM4	IPSL-CM5A-LR	IPSL-CM5A-MR	IPSL-CM5B-LR	MIROC-ESM	MIROC-ESM-CHEM	MIROC4h	MIROC5	MPI-ESM-LR	MPI-ESM-MR	MPI-ESM-P	MRI-AGCM3.2H	MRI-AGCM3.2S	MRI-CGCM3	MRI-ESM1	NICAM-09	NorESM1-M	NorESM1-ME	Number of models
Longitude resolution (The longitudinal distance between adjacent grid points in degrees)	0°-1°												x		x																			x	x																x					x	x			x			8
	1°-2°	x	x		x		x	x	x	x	x	x					x	x	x					x								x									x	x	x	x	x							x	x	x	x			x	x				25
	2°-3°			x		x															x	x	x		x		x	x		x	x		x			x	x	x	x								x		x	x											x	x	20
	3°-4°													x		x													x											x						x		x															6
	4°-5°																									x																																					1
	> 5°																			x																																											1
Latitude resolution (The latitudinal distance between adjacent grid points. Valid over the equator region. At higher latitudes, deviations may occur due to the Gaussian grid type)	0°-1°						x	x	x	x	x		x		x																			x	x																x					x	x			x			13
	1°-2°	x	x		x												x	x	x					x			x		x		x					x	x	x	x		x	x	x	x	x	x	x	x				x	x	x	x			x	x		x	x	30
	2°-3°			x		x						x									x	x	x		x			x		x		x	x							x									x	x													14
	3°-4°													x		x				x																																											3
	4°-5°																									x																																					1
	> 5°																																																														0
Horizontal resolution (The lower of the Longitude and Latitude resolution)	0°-1°												x		x																			x	x																x					x	x			x			8
	1°-2°	x	x		x		x	x	x	x	x						x	x	x					x																	x	x	x	x	x							x	x	x	x			x	x		x	x	25
	2°-3°			x		x						x									x	x	x		x		x	x		x	x	x	x			x	x	x	x								x		x	x													20
	3°-4°													x		x													x											x						x		x															6
	4°-5°																									x																																					1
	> 5°																			x																																											1
Land area fraction available		x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x			x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	55
Orography available		x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x			x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	55
Pressure level data available		x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x			x	x	x	x		x	x		x	x	x	x	x		x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x			x	x		x	x	51
Model level data available		x	x	x	x	x	x	x	x	x	x	x		x	x	x			x				x		x		x	x		x	x	x	x	x		x	x	x	x			x	x	x	x	x	x	x	x	x	x	x	x	x	x			x	x		x	x	46

Table 10: Time horizon of the investigated CMIP5 model simulations.

Time horizon	ACCESS1.0	ACCESS1.3	BCC-CSM1.1	BCC-CSM1.1(m)	BNU-ESM	CCSM4	CESM1(BGC)	CESM1(CAM5)	CESM1(CAM5.1,FV2)	CESM1(FASTCHEM)	CESM1(WACCM)	CFSv2-2011	CMCC-CESM	CMCC-CM	CMCC-CMS	CNRM-CM5	CNRM-CM5-2	CSIRO-Mk3.6.0	CSIRO-Mk3L-1-2	CanAM4	CanCM4	CanESM2	EC-EARTH	FGOALS-g2	FGOALS-gl	FGOALS-s2	FIO-ESM	GEOS-5	GFDL-CM2.1	GFDL-CM3	GFDL-ESM2G	GFDL-ESM2M	GFDL-HIRAM-C180	GFDL-HIRAM-C360	GISS-E2-H	GISS-E2-H-CC	GISS-E2-R	GISS-E2-R-CC	HadCM3	HadGEM2-A	HadGEM2-AO	HadGEM2-CC	HadGEM2-ES	INM-CM4	IPSL-CM5A-LR	IPSL-CM5A-MR	IPSL-CM5B-LR	MIROC-ESM	MIROC-ESM-CHEM	MIROC4h	MIROC5	MPI-ESM-LR	MPI-ESM-MR	MPI-ESM-P	MRI-AGCM3.2H	MRI-AGCM3.2S	MRI-CGCM3	MRI-ESM1	NICAM-09	NorESM1-M	NorESM1-ME	Number of models
RCP experiment not reaching 2100																					x								x										x											x												4
RCO experiment until 2100	x	x	x	x	x	x	x	x			x		x	x	x	x		x				x	x	x		x	x			x	x	x			x	x	x	x			x	x	x	x	x	x	x	x	x		x	x	x				x	x		x	x	42
RCP experiment beyond 2100			x			x										x		x	x											x					x		x						x		x	x		x				x								x		14
											1		2											3																	1																				3	

1 Simulation until 2099

2 On some nodes it does not reach 2100

3 Simulation until 2101

Table 11: Temporal output frequency of the investigated CMIP5 model simulations.

Output frequency	ACCESS1.0	ACCESS1.3	BCC-CSM1.1	BCC-CSM1.1(m)	BNU-ESM	CCSM4	CESM1(BGC)	CESM1(CAM5)	CESM1(CAM5.1,FV2)	CESM1(FASTCHEM)	CESM1(WACCM)	CFSv2-2011	CMCC-CESM	CMCC-CM	CMCC-CMS	CNRM-CM5	CNRM-CM5-2	CSIRO-Mk3.6.0	CSIRO-Mk3L-1-2	CanAM4	CanCM4	CanESM2	EC-EARTH	FGOALS-g2	FGOALS-gl	FGOALS-s2	FIO-ESM	GEOS-5	GFDL-CM2.1	GFDL-CM3	GFDL-ESM2G	GFDL-ESM2M	GFDL-HIRAM-C180	GFDL-HIRAM-C360	GISS-E2-H	GISS-E2-H-CC	GISS-E2-R	GISS-E2-R-CC	HadCM3	HadGEM2-A	HadGEM2-AO	HadGEM2-CC	HadGEM2-ES	INM-CM4	IPSL-CM5A-LR	IPSL-CM5A-MR	IPSL-CM5B-LR	MIROC-ESM	MIROC-ESM-CHEM	MIROC4h	MIROC5	MPI-ESM-LR	MPI-ESM-MR	MPI-ESM-P	MRI-AGCM3.2H	MRI-AGCM3.2S	MRI-CGCM3	MRI-ESM1	NICAM-09	NorESM1-M	NorESM1-ME	Number of models
3-hourly	x	x	x	x	x	x		x				x		x	x					x			x	x		x				x	x	x	x	x	x		x			x			x	x	x	x	x	x	x	x	x	x			x	x	x	x	x	x		38
6-hourly	x	x	x	x	x	x								x		x		x		x	x	x	x	x		x				x	x	x			x		x			x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x		39
daily	x	x	x	x	x	x	x	x	x	x			x	x	x	x	x	x	x	x	x	x	x	x		x				x	x	x	x	x	x		x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	53
monthly	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	60
time-independent (fx)	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x			x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	56
When RCP experiments available																																																														
3-hourly	x	x	x	x	x	x								x		x							x	x						x	x	x			x		x						x	x	x	x		x	x	x	x						x	x		x		26
6-hourly	x	x	x	x	x	x								x		x		x				x	x	x						x	x	x			x		x					x	x	x	x	x	x	x	x	x	x	x	x				x	x		x		32
daily	x	x	x	x	x	x	x	x					x	x	x	x		x	x		x	x	x	x						x	x	x			x		x		x		x	x	x	x	x	x	x	x	x	x	x	x	x				x	x		x	x	41
monthly	x	x	x	x	x	x	x	x			x		x	x	x	x		x			x	x	x	x		x	x		x	x	x	x			x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x				x	x		x	x	46
time-independent (fx)	x	x	x			x	x	x			x		x			x		x				x	x	x					x	x	x	x			x		x					x	x	x	x	x	x	x	x	x	x	x	x				x	x		x	x	35

Table 12: Availability of different atmospheric and surface variables in the investigated CMIP5 model simulations. Green, yellow and red colours represent the surface, pressure and model level variables, respectively.

Long name	Name	Unit	Freq.	ACCESS1.0	ACCESS1.3	BCC-CSM1.1	BCC-CSM1.1(m)	BNU-ESM	CCSM4	CESM1(BGC)	CESM1(CAM5)	CESM1(CAM5.1,FV2)	CESM1(FASTCHEM)	CESM1(WACCM)	CFSv2-2011	CMCC-CESM	CMCC-CM	CMCC-CMS	CNRM-CM5	CNRM-CM5-2	CSIRO-Mk3.6.0	CSIRO-Mk3L-1-2	CanAM4	CanCM4	CanESM2	EC-EARTH	FGOALS-g2	FGOALS-gl	FGOALS-s2	FIO-ESM	GEOS-5	GFDL-CM2.1	GFDL-CM3	GFDL-ESM2G	GFDL-ESM2M	GFDL-HIRAM-C180	GFDL-HIRAM-C360	GISS-E2-H	GISS-E2-H-CC	GISS-E2-R	GISS-E2-R-CC	HadCM3	HadGEM2-A	HadGEM2-AO	HadGEM2-CC	HadGEM2-ES	INM-CM4	IPSL-CM5A-LR	IPSL-CM5A-MR	IPSL-CM5B-LR	MIROC-ESM	MIROC-ESM-CHEM	MIROC4h	MIROC5	MPI-ESM-LR	MPI-ESM-MR	MPI-ESM-P	MRI-AGCM3.2H	MRI-AGCM3.2S	MRI-CGCM3	MRI-ESM1	NICAM-09	NorESM1-M	NorESM1-ME	Number of models
Near-Surface Air Temperature	tas	K	3 h	x	x	x	x	x	x									x		x									x	x						x	x	x			x		x						x	x	x	x		x	x	x	x						x	x		x		26
			6 h																																																														0
			day	x	x	x	x	x	x	x	x	x	x			x	x	x			x					x	x	x						x	x	x	x		x		x		x		x	x	x	x	x	x	x	x	x	x	x	x	x	x			x	x		x		41
			month	x	x	x	x	x	x	x	x			x		x	x	x	x		x			x	x	x	x		x	x		x	x	x	x	x		x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x				x	x		x	x	47
Surface Temperature	ts	K	3 h																													x																																	1
			6 h																																																														0
			day																													x			x																														2
			month	x	x	x	x	x	x	x	x			x		x	x	x	x		x			x	x	x	x		x	x		x	x	x	x	x		x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x				x	x		x	x	47
Daily Minimum Near-Surface Air Temperature	tasmin	K	3 h																																																														0
			6 h																																																														0
			day	x	x	x	x	x	x	x	x	x	x			x	x	x			x			x	x	x	x						x	x	x	x		x		x		x		x	x	x	x	x	x	x	x	x	x	x	x	x	x			x	x		x		42
			month	x	x	x	x	x	x	x	x			x		x	x	x	x		x				x	x	x			x			x	x	x	x		x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x				x	x		x		43
Daily Maximum Near-Surface Air Temperature	tasmax	K	3 h																																																														0
			6 h																																																														0
			day	x	x	x	x	x	x	x	x	x	x			x	x	x			x			x	x	x	x						x	x	x	x		x		x		x		x	x	x	x	x	x	x	x	x	x	x	x	x	x			x	x		x		42
			month	x	x	x	x	x	x	x	x			x		x	x	x	x		x				x	x	x			x			x	x	x	x		x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x				x	x		x		43
Sea Level Pressure	psl	Pa	3 h																																																														0
			6 h	x	x	x	x		x									x		x		x					x	x	x						x	x	x			x		x					x	x	x	x	x	x	x	x	x	x	x	x	x			x	x		x		32
			day	x	x	x	x	x	x	x	x	x	x			x	x	x			x			x	x	x	x						x	x	x	x		x		x		x		x	x	x	x	x	x	x	x	x	x	x	x	x	x			x	x		x		42
			month	x	x	x	x	x	x	x	x			x		x	x	x	x		x			x	x	x	x		x	x		x	x	x	x	x		x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x				x	x		x	x	47
Surface Air Pressure	ps	Pa	3 h	x	x	x	x	x	x									x		x									x	x						x	x	x			x		x								x	x	x		x	x	x	x						x	x		x		25
			6 h	x	x	x	x	x	x									x		x		x					x		x						x	x	x			x		x						x		x	x	x	x	x	x	x						x			x		26
			day																							x																					x		x	x	x	x			x	x					x					9
			month	x	x	x	x	x	x	x	x			x		x	x	x	x		x				x	x	x		x	x		x	x	x	x	x		x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x				x	x		x	x	46
Eastward Near-Surface Wind	uas	$m\,s^{-1}$	3 h	x	x	x	x	x										x		x									x							x	x	x			x		x						x	x	x	x		x	x	x	x						x	x				23
			6 h																																																														0
			day	x	x	x	x	x								x	x	x			x			x	x								x	x	x	x								x	x	x	x	x	x	x	x	x	x	x	x	x	x			x	x		x		32
			month	x	x	x	x	x								x	x	x	x		x				x	x			x			x	x	x	x	x		x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x				x	x		x	x	40
Northward Near-Surface Wind	vas	$m\,s^{-1}$	3 h	x	x	x	x	x										x		x									x							x	x	x			x		x						x	x	x	x		x	x	x	x						x	x				23
			6 h																																																														0
			day	x	x	x	x	x								x	x	x			x			x	x								x	x	x	x								x	x	x	x	x	x	x	x	x	x	x	x	x	x			x	x		x		32
			month	x	x	x	x	x								x	x	x	x		x				x	x			x			x	x	x	x	x		x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x				x	x		x	x	40
Near-Surface Wind Speed	sfcWind	$m\,s^{-1}$	3 h																																																														0
			6 h																																																														0
			day	x	x	x		x								x		x	x		x					x							x	x	x	x		x		x		x		x	x	x	x	x	x	x	x	x	x	x	x	x	x			x	x				32
			month	x	x			x	x		x			x		x		x	x		x				x	x			x				x	x	x	x		x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x				x	x				37
Near-Surface Relative Humidity	hurs	%	3 h																																																														0
			6 h																																																														0
			day	x	x	x	x	x	x												x	x			x								x	x	x	x		x		x					x	x	x	x	x	x	x	x	x	x						x	x		x		28
			month	x	x	x	x	x	x	x	x			x					x		x				x				x				x	x	x	x		x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x						x	x		x	x	37

Long name	Name	Unit	Freq.	ACCESS1.0	ACCESS1.3	BCC-CSM1.1	BCC-CSM1.1(m)	BNU-ESM	CCSM4	CESM1(BGC)	CESM1(CAM5)	CESM1(CAM5.1,FV2)	CESM1(FASTCHEM)	CESM1(WACCM)	CFSv2-2011	CMCC-CESM	CMCC-CM	CMCC-CMS	CNRM-CM5	CNRM-CM5-2	CSIRO-Mk3.6.0	CSIRO-Mk3L-1-2	CanAM4	CanCM4	CanESM2	EC-EARTH	FGOALS-g2	FGOALS-gl	FGOALS-s2	FIO-ESM	GEOS-5	GFDL-CM2.1	GFDL-CM3	GFDL-ESM2G	GFDL-ESM2M	GFDL-HIRAM-C180	GFDL-HIRAM-C360	GISS-E2-H	GISS-E2-H-CC	GISS-E2-R	GISS-E2-R-CC	HadCM3	HadGEM2-A	HadGEM2-AO	HadGEM2-CC	HadGEM2-ES	INM-CM4	IPSL-CM5A-LR	IPSL-CM5A-MR	IPSL-CM5B-LR	MIROC-ESM	MIROC-ESM-CHEM	MIROC4h	MIROC5	MPI-ESM-LR	MPI-ESM-MR	MPI-ESM-P	MRI-AGCM3.2H	MRI-AGCM3.2S	MRI-CGCM3	MRI-ESM1	NICAM-09	NorESM1-M	NorESM1-ME	Number of models
Near-Surface Specific Humidity	huss	1	3 h	x	x	x	x	x	x										x								x						x	x	x			x		x						x	x	x	x		x	x	x	x						x	x		x		24
			6 h																																																														0
			day	x	x	x	x	x	x		x	x									x			x		x						x	x	x	x		x		x		x	x	x	x	x	x	x	x	x	x	x	x						x	x		x		32
			month	x	x	x	x	x	x	x	x			x					x		x				x		x		x	x			x	x	x	x		x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x						x	x		x	x	39
Precipitation	pr	$kg\ m^{-2}\ s^{-1}$	3 h	x	x	x	x	x	x									x		x							x	x						x	x	x	x		x		x						x	x	x	x		x	x	x	x						x	x		x		27
			6 h																																																														0
			day	x	x	x	x	x	x	x	x	x	x			x	x	x			x			x	x	x	x						x	x	x	x		x		x		x		x	x	x	x	x	x	x	x	x	x	x	x	x	x			x	x		x		42
			month	x	x	x	x	x	x	x	x			x		x	x	x	x		x			x	x	x	x		x	x		x	x	x	x	x		x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x				x	x		x	x	47
Snowfall Flux	prsn	$kg\ m^{-2}\ s^{-1}$	3 h	x	x	x	x	x	x									x		x							x	x						x	x	x												x	x	x	x		x	x	x	x						x	x		x		24
			6 h																																																														0
			day	x	x	x	x	x	x								x	x	x			x				x	x	x						x	x	x	x										x	x		x	x	x	x	x	x	x	x	x	x			x	x		x		32
			month	x	x	x	x	x	x	x	x			x		x	x	x	x		x				x	x	x		x	x			x	x	x	x		x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x				x	x		x	x	45
Convective Precipitation	prc	$kg\ m^{-2}\ s^{-1}$	3 h	x	x	x	x	x	x									x		x							x	x						x	x	x			x		x						x	x	x	x		x	x	x	x						x	x		x		26
			6 h																																																														0
			day	x	x	x	x	x	x	x	x	x	x			x	x	x			x	x			x	x	x						x	x	x	x								x	x	x	x	x	x	x	x	x	x	x	x	x	x			x	x		x		39
			month	x	x	x	x	x	x	x	x			x		x	x	x	x		x				x	x	x		x	x			x	x	x	x		x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x				x	x		x	x	45
Evaporation	evspsbl	$kg\ m^{-2}\ s^{-1}$	3 h																																																														0
			6 h																																																														0
			day																																																														0
			month	x	x	x	x	x	x	x	x			x		x	x		x		x				x	x	x		x	x		x	x	x	x	x		x	x	x	x	x			x	x	x	x	x	x	x	x	x	x	x	x				x	x		x	x	44
Surface Downward Eastward Wind Stress	tauu	Pa	3 h																																																														0
			6 h																																																														0
			day																																																														0
			month	x	x	x	x	x	x	x	x			x		x	x	x	x		x			x	x		x		x	x			x	x	x	x		x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x				x	x		x	x	45
Surface Downward Northward Wind Stress	tauv	Pa	3 h																																																														0
			6 h																																																														0
			day																																																														0
			month	x	x	x	x	x	x	x	x			x		x	x	x	x		x			x	x		x		x	x			x	x	x	x		x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x				x	x		x	x	45
Surface Downwelling Longwave Radiation	rlds	$W\ m^{-2}$	3 h	x	x	x	x	x	x									x		x							x	x						x	x	x			x		x						x	x	x	x		x	x	x	x						x	x		x		26
			6 h																																																														0
			day	x	x	x	x	x	x								x	x	x			x	x			x	x	x						x	x	x	x									x	x	x	x	x	x	x	x	x	x	x	x	x	x			x	x		x		34
			month	x	x	x	x	x	x	x	x			x		x	x	x	x		x			x	x	x	x		x	x		x	x	x	x	x		x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x				x	x		x	x	47
Surface Upwelling Longwave Radiation	rlus	$W\ m^{-2}$	3 h	x	x	x	x	x	x									x		x								x						x	x	x			x		x						x	x	x	x		x	x	x	x						x	x		x		25
			6 h																																																														0
			day	x	x	x	x	x	x								x	x	x			x	x			x		x						x	x	x	x									x	x	x	x	x	x	x	x	x	x	x	x	x	x			x	x		x		33
			month	x	x	x	x	x	x	x	x			x		x	x	x	x		x			x	x		x		x			x	x	x	x	x		x	x	x	x	x			x	x	x	x	x	x	x	x	x	x	x	x				x	x		x	x	44
Surface Downwelling Shortwave Radiation	rsds	$W\ m^{-2}$	3 h	x	x	x	x	x	x									x		x							x	x						x	x	x			x		x						x	x	x	x		x	x	x	x						x	x				25
			6 h																																																														0
			day	x	x	x	x	x	x								x	x	x			x	x			x	x	x						x	x	x	x								x	x	x	x	x	x	x	x	x	x	x	x	x	x			x	x		x		35
			month	x	x	x	x	x	x	x	x			x		x	x	x	x		x			x	x	x	x		x	x		x	x	x	x	x		x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x				x	x		x	x	47

Long name	Name	Unit	Freq.	ACCESS1.0	ACCESS1.3	BCC-CSM1.1	BCC-CSM1.1(m)	BNU-ESM	CCSM4	CESM1(BGC)	CESM1(CAM5)	CESM1(CAM5.1,FV2)	CESM1(FASTCHEM)	CESM1(WACCM)	CFSv2-2011	CMCC-CESM	CMCC-CM	CMCC-CMS	CNRM-CM5	CNRM-CM5-2	CSIRO-Mk3.6.0	CSIRO-Mk3L-1-2	CanAM4	CanCM4	CanESM2	EC-EARTH	FGOALS-g2	FGOALS-gl	FGOALS-s2	FIO-ESM	GEOS-5	GFDL-CM2.1	GFDL-CM3	GFDL-ESM2G	GFDL-ESM2M	GFDL-HIRAM-C180	GFDL-HIRAM-C360	GISS-E2-H	GISS-E2-H-CC	GISS-E2-R	GISS-E2-R-CC	HadCM3	HadGEM2-A	HadGEM2-AO	HadGEM2-CC	HadGEM2-ES	INM-CM4	IPSL-CM5A-LR	IPSL-CM5A-MR	IPSL-CM5B-LR	MIROC-ESM	MIROC-ESM-CHEM	MIROC4h	MIROC5	MPI-ESM-LR	MPI-ESM-MR	MPI-ESM-P	MRI-AGCM3.2H	MRI-AGCM3.2S	MRI-CGCM3	MRI-ESM1	NICAM-09	NorESM1-M	NorESM1-ME	Number of models
Surface Upwelling Shortwave Radiation	rsus	W m^{-2}	3 h	x	x	x	x	x	x								x		x								x						x	x	x			x		x						x	x	x	x		x	x	x	x						x	x				24
			6 h																																																														0
			day	x	x	x	x	x	x							x	x	x			x	x			x		x						x	x	x	x									x	x	x	x	x	x	x	x	x	x	x	x	x			x	x		x		33
			month	x	x	x	x	x	x	x	x			x		x	x	x	x		x			x	x		x		x	x		x	x	x	x	x		x	x	x	x	x			x	x	x	x	x	x	x	x	x	x	x	x				x	x		x	x	45
TOA Incident Shortwave Radiation	rsdt	W m^{-2}	3 h																																																														0
			6 h																																																														0
			day																						x																					x		x	x	x	x	x		x	x					x					10
			month	x	x	x	x	x	x	x	x			x		x	x	x	x		x			x	x	x	x		x	x			x	x	x	x		x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x				x	x		x	x	46
TOA Outgoing Shortwave Radiation	rsut	W m^{-2}	3 h																																																														0
			6 h																																																														0
			day																						x																					x		x	x	x	x	x		x	x					x					10
			month	x	x	x	x	x	x	x	x			x		x	x	x	x		x				x		x		x	x		x	x	x	x	x		x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x				x	x		x	x	45
TOA Outgoing Longwave Radiation	rlut	W m^{-2}	3 h																																																														0
			6 h																																																														0
			day	x	x	x	x	x								x	x	x			x	x			x	x	x						x	x	x	x								x	x	x	x	x	x	x	x	x	x	x	x	x	x			x	x		x		34
			month	x	x	x	x	x	x	x	x			x		x	x	x	x		x			x	x	x	x		x	x		x	x	x	x	x		x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x				x	x		x	x	47
Water vapor path	prw	kg m^{-2}	3 h																																																														0
			6 h																																																														0
			day																																																														0
			month	x	x	x	x	x	x	x	x			x		x	x	x	x		x				x	x	x		x	x			x	x	x	x		x	x	x	x				x	x	x	x	x	x	x	x	x	x	x	x				x	x		x	x	43
Total Cloud Fraction	clt	%	3 h	x	x	x	x	x	x								x		x							x	x						x	x	x			x		x						x	x	x	x		x	x	x	x						x	x		x		26
			6 h																																																														0
			day	x	x	x	x	x	x							x	x	x			x	x			x	x	x						x	x	x	x									x	x	x	x	x	x	x	x	x	x	x	x	x			x	x		x		34
			month	x	x	x	x	x	x	x	x			x		x	x	x	x		x				x	x	x		x	x			x	x	x	x		x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x				x	x		x	x	45
Condensed Water Path	clwvi	kg m^{-2}	3 h																																																														0
			6 h																																																														0
			day																						x																					x		x	x	x				x	x					x					8
			month	x	x	x	x	x	x	x	x			x		x	x	x	x		x				x		x		x	x			x	x	x	x		x	x	x	x				x	x	x	x	x	x	x	x	x	x	x	x				x	x		x	x	42
Ice Water Path	clivi	kg m^{-2}	3 h																																																														0
			6 h																																																														0
			day																						x																					x		x	x	x				x	x					x					8
			month	x	x	x	x	x	x	x	x			x		x	x	x	x		x				x		x		x	x			x	x	x	x		x	x	x	x				x	x	x	x	x	x	x	x	x	x	x	x				x	x		x	x	42
Air Pressure at Convective Cloud Base	ccb	Pa	3 h																																																														0
			6 h																																																														0
			day																						x																					x		x	x	x				x						x					7
			month			x	x	x																	x				x	x			x	x	x	x		x	x	x	x						x	x	x	x	x	x	x	x						x	x		x	x	26
Air Pressure at Convective Cloud Top	cct	Pa	3 h																																																														0
			6 h																																																														0
			day																						x																					x		x	x	x				x	x					x					8
			month			x	x	x								x	x	x							x				x	x			x	x	x	x		x	x	x	x						x	x	x	x	x	x	x	x	x	x				x	x		x	x	31

Long name	Name	Unit	Freq.	ACCESS1.0	ACCESS1.3	BCC-CSM1.1	BCC-CSM1.1(m)	BNU-ESM	CCSM4	CESM1(BGC)	CESM1(CAM5)	CESM1(CAM5.1,FV2)	CESM1(FASTCHEM)	CESM1(WACCM)	CFSv2-2011	CMCC-CESM	CMCC-CM	CMCC-CMS	CNRM-CM5	CNRM-CM5-2	CSIRO-Mk3.6.0	CSIRO-Mk3L-1-2	CanAM4	CanCM4	CanESM2	EC-EARTH	FGOALS-g2	FGOALS-gl	FGOALS-s2	FIO-ESM	GEOS-5	GFDL-CM2.1	GFDL-CM3	GFDL-ESM2G	GFDL-ESM2M	GFDL-HIRAM-C180	GFDL-HIRAM-C360	GISS-E2-H	GISS-E2-H-CC	GISS-E2-R	GISS-E2-R-CC	HadCM3	HadGEM2-A	HadGEM2-AO	HadGEM2-CC	HadGEM2-ES	INM-CM4	IPSL-CM5A-LR	IPSL-CM5A-MR	IPSL-CM5B-LR	MIROC-ESM	MIROC-ESM-CHEM	MIROC4h	MIROC5	MPI-ESM-LR	MPI-ESM-MR	MPI-ESM-P	MRI-AGCM3.2H	MRI-AGCM3.2S	MRI-CGCM3	MRI-ESM1	NICAM-09	NorESM1-M	NorESM1-ME	Number of models
Surface Upward Latent Heat Flux	hfls	W m-2	3 h	x	x	x	x	x	x								x		x							x	x						x	x	x			x		x						x	x	x	x		x	x	x	x						x	x		x		26
			6 h																																																										0
			day	x	x	x	x	x	x								x	x	x			x	x			x	x	x						x	x	x	x								x	x	x	x	x	x	x	x	x	x	x	x	x	x			x	x		x		35
			month	x	x	x	x	x	x	x	x			x		x	x	x	x		x			x	x	x	x		x	x			x	x	x	x		x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x				x	x		x	x	46
Surface Upward Sensible Heat Flux	hfss	W m-2	3 h	x	x	x	x	x	x								x		x							x	x						x	x	x			x		x						x	x	x	x		x	x	x	x						x	x		x		26
			6 h																																																										0
			day	x	x	x	x	x	x								x	x	x			x	x			x	x	x						x	x	x	x									x	x	x	x	x	x	x	x	x	x	x	x	x			x	x		x		34
			month	x	x	x	x	x	x	x	x			x		x	x	x	x		x			x	x	x	x		x	x		x	x	x	x	x		x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x				x	x		x	x	47
Air Temperature	ta	K	3 h																																																										0
			6 h	x	x	x	x	x	x								x		x		x				x	x	x						x	x	x			x		x					x	x	x	x	x	x	x	x	x	x	x	x	x			x	x		x		33
			day	x	x	x	x	x	x								x	x	x			x				x	x	x						x	x	x	x		x		x		x		x	x	x	x	x	x	x	x	x	x	x	x	x	x			x	x		x		37
			month	x	x	x	x	x	x	x	x			x		x	x	x	x		x			x	x	x	x		x	x		x	x	x	x	x		x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x				x	x		x	x	47
Eastward Wind	ua	m s-1	3 h																																																										0
			6 h	x	x	x	x	x	x								x		x		x				x	x	x						x	x	x			x		x					x	x	x	x	x	x	x	x	x	x	x	x	x			x	x		x		33
			day	x	x	x	x	x	x								x	x	x			x				x	x	x						x	x	x	x						x		x	x	x	x	x	x	x	x	x	x	x	x	x	x			x	x		x		35
			month	x	x	x	x	x	x	x	x			x		x	x	x	x		x			x	x	x	x		x	x		x	x	x	x	x		x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x				x	x		x	x	47
Northward Wind	va	m s-1	3 h																																																										0
			6 h	x	x	x	x	x	x								x		x		x				x	x	x						x	x	x			x		x					x	x	x	x	x	x	x	x	x	x	x	x	x			x	x		x		33
			day	x	x	x	x	x	x								x	x	x			x				x	x	x						x	x	x	x						x		x	x	x	x	x	x	x	x	x	x	x	x	x	x			x	x		x		35
			month	x	x	x	x	x	x	x	x			x		x	x	x	x		x			x	x	x	x		x	x		x	x	x	x	x		x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x				x	x		x	x	47
Specific Humidity	hus	1	3 h																																																										0
			6 h	x	x	x	x	x	x								x		x		x				x		x						x	x	x			x		x						x		x	x	x	x	x	x	x						x			x		26
			day	x	x	x	x	x	x								x	x	x			x				x	x	x						x	x	x	x		x		x				x	x	x	x	x	x	x	x	x	x	x	x	x	x			x	x		x		36
			month	x	x	x	x	x	x	x	x			x		x	x	x	x		x				x	x	x		x	x		x	x	x	x	x		x	x	x	x			x	x	x	x	x	x	x	x	x	x	x	x	x				x	x		x	x	45
Relative Humidity	hur	%	3 h																																																										0
			6 h																																																										0
			day	x	x	x	x	x	x								x	x	x			x				x		x						x	x	x	x								x	x	x	x	x	x	x	x	x	x	x	x	x	x			x	x		x		33
			month	x	x	x	x	x	x	x	x			x		x	x	x	x		x				x		x		x	x			x	x	x	x		x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x				x	x		x	x	44
Omega (dp/dt)	wap	Pa s-1	3 h																																																										0
			6 h																																																										0
			day	x	x	x	x	x	x								x	x	x			x				x		x						x	x	x	x									x	x		x	x	x	x	x	x	x	x	x	x			x	x		x		31
			month	x	x	x	x	x	x	x	x			x		x	x	x	x		x				x	x	x		x	x		x	x	x	x	x		x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x				x	x		x	x	46
Geopotential Height	zg	m	3 h																																																										0
			6 h																																																										0
			day	x	x	x	x	x	x								x	x	x							x	x	x						x	x	x	x						x		x	x	x		x	x	x	x	x		x	x	x	x			x	x		x		32
			month	x	x	x	x	x	x	x	x			x		x	x	x	x		x			x	x	x	x		x	x		x	x	x	x	x		x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x				x	x		x	x	47

Long name	Name	Unit	Freq.	ACCESS1.0	ACCESS1.3	BCC-CSM1.1	BCC-CSM1.1(m)	BNU-ESM	CCSM4	CESM1(BGC)	CESM1(CAM5)	CESM1(CAM5.1,FV2)	CESM1(FASTCHEM)	CESM1(WACCM)	CFSv2-2011	CMCC-CESM	CMCC-CM	CMCC-CMS	CNRM-CM5	CNRM-CM5-2	CSIRO-Mk3.6.0	CSIRO-Mk3L-1-2	CanAM4	CanCM4	CanESM2	EC-EARTH	FGOALS-g2	FGOALS-gl	FGOALS-s2	FIO-ESM	GEOS-5	GFDL-CM2.1	GFDL-CM3	GFDL-ESM2G	GFDL-ESM2M	GFDL-HIRAM-C180	GFDL-HIRAM-C360	GISS-E2-H	GISS-E2-H-CC	GISS-E2-R	GISS-E2-R-CC	HadCM3	HadGEM2-A	HadGEM2-AO	HadGEM2-CC	HadGEM2-ES	INM-CM4	IPSL-CM5A-LR	IPSL-CM5A-MR	IPSL-CM5B-LR	MIROC-ESM	MIROC-ESM-CHEM	MIROC4h	MIROC5	MPI-ESM-LR	MPI-ESM-MR	MPI-ESM-P	MRI-AGCM3.2H	MRI-AGCM3.2S	MRI-CGCM3	MRI-ESM1	NICAM-09	NorESM1-M	NorESM1-ME	Number of models
Cloud Area Fraction	cl	%	3 h																																																														0
			6 h																																																														0
			day																																													x	x	x															3
			month	x	x	x	x	x	x	x	x			x		x	x	x			x				x		x		x	x		x	x	x	x	x		x	x	x	x				x	x	x	x	x	x	x	x	x	x	x	x				x	x		x	x	42
Mass Fraction of Cloud Liquid Water	clw	1	3 h																																																													0
			6 h																																																													0
			day																																													x	x	x															3
			month	x	x	x	x	x	x	x	x			x		x	x	x			x				x		x		x	x			x	x	x	x		x	x	x	x				x	x	x	x	x	x	x	x	x	x	x	x				x	x		x	x	41
Mass Fraction of Cloud Ice	cli	1	3 h																																																													0
			6 h																																																														0
			day																																													x	x	x															3
			month	x	x	x	x	x	x	x	x			x		x	x	x			x				x		x		x	x			x	x	x	x		x	x	x	x				x	x	x	x	x	x	x	x	x	x	x	x				x	x		x	x	41
Convective Mass Flux	mc	$kg\ m^{-2}\ s^{-1}$	3 h																																																														0
			6 h																																																													0
			day																																													x	x	x															3
			month			x	x	x	x	x	x			x							x				x				x	x			x	x	x			x	x	x	x				x	x		x	x	x			x	x						x	x		x	x	29

Table 13: Availability of different land surface variables in the investigated CMIP5 model simulations.

Long name	Name	Unit	Freq.	ACCESS1.0	ACCESS1.3	BCC-CSM1.1	BCC-CSM1.1(m)	BNU-ESM	CCSM4	CESM1(BGC)	CESM1(CAM5)	CESM1(CAM5.1,FV2)	CESM1(FASTCHEM)	CESM1(WACCM)	CFSv2-2011	CMCC-CESM	CMCC-CM	CMCC-CMS	CNRM-CM5	CNRM-CM5-2	CSIRO-Mk3.6.0	CSIRO-Mk3L-1-2	CanAM4	CanCM4	CanESM2	EC-EARTH	FGOALS-g2	FGOALS-gl	FGOALS-s2	FIO-ESM	GEOS-5	GFDL-CM2.1	GFDL-CM3	GFDL-ESM2G	GFDL-ESM2M	GFDL-HIRAM-C180	GFDL-HIRAM-C360	GISS-E2-H	GISS-E2-H-CC	GISS-E2-R	GISS-E2-R-CC	HadCM3	HadGEM2-A	HadGEM2-AO	HadGEM2-CC	HadGEM2-ES	INM-CM4	IPSL-CM5A-LR	IPSL-CM5A-MR	IPSL-CM5B-LR	MIROC-ESM	MIROC-ESM-CHEM	MIROC4h	MIROC5	MPI-ESM-LR	MPI-ESM-MR	MPI-ESM-P	MRI-AGCM3.2H	MRI-AGCM3.2S	MRI-CGCM3	MRI-ESM1	NICAM-09	NorESM1-M	NorESM1-ME	Number of models
Moisture in Upper Portion of Soil Column	mrsos	kg m^{-2}	3 h	x	x	x		x											x								x											x		x						x	x	x	x	x	x	x	x	x						x	x		x		20
			6 h																																																												0
			day			x		x													x				x		x						x	x	x	x										x	x	x				x	x	x	x						x	x		x		19
			month	x	x	x	x	x	x	x	x			x					x		x			x	x		x		x				x	x	x	x		x	x	x	x	x			x	x	x	x	x	x	x	x	x	x						x	x		x	x	38
Total Soil Moisture Content	mrso	kg m^{-2}	3 h																																																												0
			6 h																																																												0
			day																																																													0
			month	x	x	x	x	x	x	x	x			x		x	x	x	x		x			x	x		x		x			x	x	x	x	x		x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x				x	x		x	x	45
Soil Frozen Water Content	mrfso	kg m^{-2}	3 h																																																												0
			6 h																																																												0
			day																																																													0
			month	x	x	x	x	x	x	x	x			x					x					x	x		x		x				x	x	x	x		x	x	x	x	x		x	x	x	x				x	x	x	x						x	x		x	x	35
Surface Runoff	mrros	kg m^{-2}	3 h																x																																										1
			6 h																																																												0
			day																																																													0
			month	x	x	x	x	x	x	x	x			x					x		x				x	x	x			x			x	x	x	x		x	x	x	x	x		x			x	x	x	x	x	x	x	x	x	x				x	x		x	x	39
Total Runoff	mrro	kg m^{-2} s^{-1}	3 h			x	x	x									x		x								x											x		x							x	x	x	x	x	x	x	x						x	x		x		19
			6 h																																																												0
			day			x	x	x								x	x	x			x	x			x		x						x	x	x	x									x		x				x	x	x	x	x	x	x			x	x		x		26
			month			x	x	x	x	x	x			x		x	x	x	x		x				x		x			x		x	x	x	x	x		x	x	x	x	x					x	x	x	x	x	x	x	x	x	x				x	x		x	x	39
Water Evaporation from Soil	evspsblsoi	kg m^{-2} s^{-1}	3 h																																																												0
			6 h																																																												0
			day																																																													0
			month	x	x	x	x	x	x	x	x			x		x	x		x						x		x		x	x				x	x	x		x	x	x	x			x			x	x	x	x	x	x	x	x						x	x		x	x	36
Transpiration	tran	kg m^{-2} s^{-1}	3 h																																																												0
			6 h																																																												0
			day																																																													0
			month			x	x	x	x	x	x			x		x			x						x					x			x	x	x	x		x	x	x	x			x			x	x	x	x	x	x	x	x	x	x				x	x		x	x	34
Water Content of Soil Layer	mrlsl	kg m^{-2}	3 h																																																												0
			6 h																																																												0
			day																																																													0
			month	x	x	x	x	x	x	x	x			x					x						x		x		x	x			x	x	x	x		x	x	x	x	x			x	x	x				x	x	x	x									x	x	32
Temperature of Soil	tsl	K	3 h																																																												0
			6 h																																																												0
			day																																																													0
			month	x	x	x	x	x	x	x	x			x		x	x	x	x						x		x		x	x			x	x	x	x		x	x	x	x	x			x	x	x	x	x	x	x	x		x	x	x				x	x		x	x	41
Carbon Mass in Vegetation	cVeg	kg m^{-2}	3 h																																																												0
			6 h																																																												0
			day																																																													0
			month					x	x	x	x			x		x									x					x				x	x										x	x	x	x	x	x	x	x			x	x					x		x	x	23

Long name	Name	Unit	Freq.	ACCESS1.0	ACCESS1.3	BCC-CSM1.1	BCC-CSM1.1(m)	BNU-ESM	CCSM4	CESM1(BGC)	CESM1(CAM5)	CESM1(CAM5.1,FV2)	CESM1(FASTCHEM)	CESM1(WACCM)	CFSv2-2011	CMCC-CESM	CMCC-CM	CMCC-CMS	CNRM-CM5	CNRM-CM5-2	CSIRO-Mk3.6.0	CSIRO-Mk3L-1-2	CanAM4	CanCM4	CanESM2	EC-EARTH	FGOALS-g2	FGOALS-gl	FGOALS-s2	FIO-ESM	GEOS-5	GFDL-CM2.1	GFDL-CM3	GFDL-ESM2G	GFDL-ESM2M	GFDL-HIRAM-C180	GFDL-HIRAM-C360	GISS-E2-H	GISS-E2-H-CC	GISS-E2-R	GISS-E2-R-CC	HadCM3	HadGEM2-A	HadGEM2-AO	HadGEM2-CC	HadGEM2-ES	INM-CM4	IPSL-CM5A-LR	IPSL-CM5A-MR	IPSL-CM5B-LR	MIROC-ESM	MIROC-ESM-CHEM	MIROC4h	MIROC5	MPI-ESM-LR	MPI-ESM-MR	MPI-ESM-P	MRI-AGCM3.2H	MRI-AGCM3.2S	MRI-CGCM3	MRI-ESM1	NICAM-09	NorESM1-M	NorESM1-ME	Number of models
Carbon Mass in Litter Pool	cLitter	kg m-2	3 h																																																														0
			6 h																																																														0
			day																																																														0
			month					x	x	x	x			x											x					x																		x	x	x	x	x			x	x					x		x	x	17
Carbon Mass in Soil Pool	cSoil	kg m-2	3 h																																																														0
			6 h																																																														0
			day																																																														0
			month					x	x	x	x			x		x									x					x				x	x			x	x	x	x				x	x	x	x	x	x	x	x			x	x					x		x	x	27
Tree Cover Fraction	treeFrac	%	3 h																																																														0
			6 h																																																														0
			day																																																														0
			month	x	x			x								x																	x	x	x	x									x	x	x	x	x	x	x	x	x	x	x	x									20
Natural Grass Fraction	grassFrac	%	3 h																																																														0
			6 h																																																														0
			day																																																														0
			month	x	x			x								x																	x	x	x	x									x	x	x	x	x	x	x	x	x	x	x	x									20
Crop Fraction	cropFrac	%	3 h																																																														0
			6 h																																																														0
			day																																																														0
			month		x																												x	x	x	x											x	x	x	x	x	x	x	x	x	x	x									15
Natural Grass Fraction	grassFrac	%	3 h																																																														0
			6 h																																																														0
			day																																																														0
			month	x	x			x								x																	x	x	x	x									x	x	x	x	x	x	x	x	x	x	x	x									20
Anthropogenic Pasture Fraction	pastureFrac	%	3 h																																																														0
			6 h																																																														0
			day																																																														0
			month																														x	x	x	x														x	x	x		x	x										9

Table 14: Availability of different ocean and sea ice variables in the investigated CMIP5 model simulations.

Long name	Name	Unit	Freq.	ACCESS1.0	ACCESS1.3	BCC-CSM1.1	BCC-CSM1.1(m)	BNU-ESM	CCSM4	CESM1(BGC)	CESM1(CAM5)	CESM1(CAM5.1,FV2)	CESM1(FASTCHEM)	CESM1(WACCM)	CFSv2-2011	CMCC-CESM	CMCC-CM	CMCC-CMS	CNRM-CM5	CNRM-CM5-2	CSIRO-Mk3.6.0	CSIRO-Mk3L-1-2	CanAM4	CanCM4	CanESM2	EC-EARTH	FGOALS-g2	FGOALS-gl	FGOALS-s2	FIO-ESM	GEOS-5	GFDL-CM2.1	GFDL-CM3	GFDL-ESM2G	GFDL-ESM2M	GFDL-HIRAM-C180	GFDL-HIRAM-C360	GISS-E2-H	GISS-E2-H-CC	GISS-E2-R	GISS-E2-R-CC	HadCM3	HadGEM2-A	HadGEM2-AO	HadGEM2-CC	HadGEM2-ES	INM-CM4	IPSL-CM5A-LR	IPSL-CM5A-MR	IPSL-CM5B-LR	MIROC-ESM	MIROC-ESM-CHEM	MIROC4h	MIROC5	MPI-ESM-LR	MPI-ESM-MR	MPI-ESM-P	MRI-AGCM3.2H	MRI-AGCM3.2S	MRI-CGCM3	MRI-ESM1	NICAM-09	NorESM1-M	NorESM1-ME	Number of models
Sea Surface Temperature	tos	K	3 h																																																										0
			6 h																																																										0
			day	x	x	x	x	x	x		x					x	x	x			x				x		x						x	x	x			x		x		x			x	x	x	x	x	x	x	x	x	x	x	x	x			x	x		x	x	36
			month	x	x	x	x	x	x	x	x			x		x	x	x	x		x			x	x	x			x	x		x	x	x	x	x		x	x	x	x	x		x	x	x	x	x	x	x	x	x		x	x	x				x	x		x	x	45
Sea Surface Salinity	sos	psu	3 h																																																										0
			6 h																																																										0
			day																																																										0
			month	x	x				x	x	x			x		x	x	x	x		x			x	x	x				x		x	x	x	x			x	x	x	x	x		x	x	x	x	x	x	x	x	x		x	x	x							x	x	38
Sea Surface Height Above Geoid	zos	m	3 h																																																										0
			6 h																																																										0
			day																																																										0
			month	x	x	x	x		x	x	x			x		x	x	x	x		x			x	x	x	x		x	x		x	x	x	x					x	x				x	x	x	x	x	x	x	x	x	x	x	x				x	x		x	x	41
Sea Ice Fraction	sic	%	3 h																																																										0
			6 h																																																										0
			day	x	x	x	x	x								x	x	x	x	x	x	x			x		x						x	x	x			x		x					x	x	x	x	x	x	x	x	x	x	x	x	x			x	x		x		35
			month	x	x	x	x	x	x	x	x			x		x	x	x	x		x			x	x	x	x			x		x	x	x	x	x		x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x				x	x		x	x	46
Sea Ice Thickness	sit	m	3 h																																																										0
			6 h																																																										0
			day	x	x	x	x	x								x	x	x	x	x	x				x		x						x	x	x										x	x	x	x	x	x	x	x	x	x	x	x	x			x	x		x		32
			month	x	x	x	x	x	x	x	x			x		x	x	x	x		x			x	x	x	x			x		x	x	x	x			x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x				x	x		x	x	45
Snow Depth	snd	m	3 h																																																										0
			6 h																																																										0
			day																																																										0
			month	x	x	x	x	x	x	x	x			x		x	x	x	x		x				x	x	x			x			x	x	x			x	x	x	x				x	x	x				x	x	x	x	x	x				x	x		x	x	38
Sea Ice Plus Surface Snow Amount	sim	kg m^{-2}	3 h																																																											0
			6 h																																																										0
			day																																																										0
			month	x	x			x								x	x	x	x						x																				x	x								x	x	x	x				x	x		x	x	18
Surface Temperature of Sea Ice	tsice	K	3 h																																																										0
			6 h																																																										0
			day																																																										0
			month			x	x	x	x	x	x			x		x	x	x	x						x	x	x			x			x	x	x												x	x	x	x	x	x	x	x						x	x		x	x	30

Table 15: Availability of different variable packages in the investigated CMIP5 model simulations.

Package name	Variables	Freq.	ACCESS1.0	ACCESS1.3	BCC-CSM1.1	BCC-CSM1.1(m)	BNU-ESM	CCSM4	CESM1(BGC)	CESM1(CAM5)	CESM1(CAM5.1,FV2)	CESM1(FASTCHEM)	CESM1(WACCM)	CFSv2-2011	CMCC-CESM	CMCC-CM	CMCC-CMS	CNRM-CM5	CNRM-CM5-2	CSIRO-Mk3.6.0	CSIRO-Mk3L-1-2	CanAM4	CanCM4	CanESM2	EC-EARTH	FGOALS-g2	FGOALS-gl	FGOALS-s2	FIO-ESM	GEOS-5	GFDL-CM2.1	GFDL-CM3	GFDL-ESM2G	GFDL-ESM2M	GFDL-HIRAM-C180	GFDL-HIRAM-C360	GISS-E2-H	GISS-E2-H-CC	GISS-E2-R	GISS-E2-R-CC	HadCM3	HadGEM2-A	HadGEM2-AO	HadGEM2-CC	HadGEM2-ES	INM-CM4	IPSL-CM5A-LR	IPSL-CM5A-MR	IPSL-CM5B-LR	MIROC-ESM	MIROC-ESM-CHEM	MIROC4h	MIROC5	MPI-ESM-LR	MPI-ESM-MR	MPI-ESM-P	MRI-AGCM3.2H	MRI-AGCM3.2S	MRI-CGCM3	MRI-ESM1	NICAM-09	NorESM1-M	NorESM1-ME	Number of models
Basic	tas, tasmax, tasmin, pr	3 h																																																															0
		6 h																																																															0
		day	x	x	x	x	x	x	x	x	x	x			x	x	x			x				x	x	x						x	x	x	x		x		x		x		x	x	x	x	x	x	x	x	x	x	x	x	x	x			x	x		x		41
		month	x	x	x	x	x	x	x	x			x		x	x	x	x		x				x	x	x			x			x	x	x	x		x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x				x	x		x		43
Extended basic	tas, tasmax, tasmin, pr, slp, uas, vas, huss, rsds, clt, prsn,	3 h																																																															0
		6 h																																																															0
		day	x	x	x	x	x													x				x								x	x	x	x									x	x		x	x	x	x	x	x	x						x	x		x		23
		month	x	x	x	x	x											x		x				x								x	x	x	x		x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x						x	x		x		31
Extended basic 2	tas, tasmax, tasmin, pr, slp, uas, vas, huss, rsds, clt, prsn, prw	3 h																																																															0
		6 h																																																															0
		day																																																															0
		month	x	x	x	x	x											x		x				x								x	x	x	x		x	x	x	x				x	x	x	x	x	x	x	x	x	x						x	x		x		29
Radiation	rlds, rlus, rsds, rsus,	3 h	x	x	x	x	x	x								x		x								x						x	x	x			x		x						x	x	x	x		x	x	x	x						x	x				24
		6 h																																																															0
		day	x	x	x	x	x	x							x	x	x			x	x			x		x						x	x	x	x									x	x	x	x	x	x	x	x	x	x	x	x	x			x	x		x		33
		month	x	x	x	x	x	x	x	x			x		x	x	x	x		x			x	x		x		x			x	x	x	x	x		x	x	x	x	x			x	x	x	x	x	x	x	x	x	x	x	x				x	x		x	x	44
Extended Radiation	rlds, rlus, rsds, rsus, rsdt, rsut, rlut	3 h																																																															0
		6 h																																																															0
		day																						x																					x		x	x	x	x	x		x	x					x					10
		month	x	x	x	x	x	x	x	x			x		x	x	x	x		x				x		x		x				x	x	x	x		x	x	x	x	x			x	x	x	x	x	x	x	x	x	x	x	x				x	x		x	x	42
Pressure level	ta, ua, va, hus	3 h																																																															0
		6 h	x	x	x	x	x	x								x		x		x				x		x						x	x	x			x		x						x		x	x	x	x	x	x	x						x			x		26
		day	x	x	x	x	x	x							x	x	x			x				x	x	x						x	x	x	x								x	x	x	x	x	x	x	x	x	x	x	x	x	x			x	x		x		34
		month	x	x	x	x	x	x	x	x			x		x	x	x	x		x				x	x	x		x	x		x	x	x	x	x		x	x	x	x			x	x	x	x	x	x	x	x	x	x	x	x	x				x	x		x	x	45
Extended Pressure level	ta, ua, va, hus, hur, wap, zg	3 h																																																															0
		6 h																																																															0
		day	x	x	x	x	x	x							x	x	x							x		x						x	x	x	x									x	x		x	x	x	x	x		x	x	x	x			x	x		x		29
		month	x	x	x	x	x	x	x	x			x		x	x	x	x		x				x		x		x	x			x	x	x	x		x	x	x	x			x	x	x	x	x	x	x	x	x	x	x	x	x				x	x		x	x	43
Model level	cl, clw, cli, mc	3 h																																																															0
		6 h																																																															0
		day																																													x	x	x															3
		month			x	x	x	x	x	x			x							x				x				x	x			x	x	x			x	x	x	x				x	x		x	x	x			x	x						x	x		x	x	29

	Freq.	ACCESS1.0	ACCESS1.3	BCC-CSM1.1	BCC-CSM1.1(m)	BNU-ESM	CCSM4	CESM1(BGC)	CESM1(CAM5)	CESM1(CAM5.1,FV2)	CESM1(FASTCHEM)	CESM1(WACCM)	CFSv2-2011	CMCC-CESM	CMCC-CM	CMCC-CMS	CNRM-CM5	CNRM-CM5-2	CSIRO-Mk3.6.0	CSIRO-Mk3L-1-2	CanAM4	CanCM4	CanESM2	EC-EARTH	FGOALS-g2	FGOALS-gl	FGOALS-s2	FIO-ESM	GEOS-5	GFDL-CM2.1	GFDL-CM3	GFDL-ESM2G	GFDL-ESM2M	GFDL-HIRAM-C180	GFDL-HIRAM-C360	GISS-E2-H	GISS-E2-H-CC	GISS-E2-R	GISS-E2-R-CC	HadCM3	HadGEM2-A	HadGEM2-AO	HadGEM2-CC	HadGEM2-ES	INM-CM4	IPSL-CM5A-LR	IPSL-CM5A-MR	IPSL-CM5B-LR	MIROC-ESM	MIROC-ESM-CHEM	MIROC4h	MIROC5	MPI-ESM-LR	MPI-ESM-MR	MPI-ESM-P	MRI-AGCM3.2H	MRI-AGCM3.2S	MRI-CGCM3	MRI-ESM1	NICAM-09	NorESM1-M	NorESM1-ME	Number of models
All packages	3 h																																																													0
	6 h																																																													0
	day																																																													0
	month			x	x	x													x				x								x	x	x			x	x	x	x				x	x		x	x	x			x	x						x	x		x		22
All packages except Model level	3 h																																																													0
	6 h																																																													0
	day																																																														0
	month	x	x	x	x	x											x		x				x								x	x	x	x		x	x	x	x				x	x	x	x	x	x	x	x	x	x						x	x		x		29
Extended basic, Radiation, Pressure level	3 h																																																													0
	6 h																																																													0
	day	x	x	x	x	x													x				x								x	x	x	x									x	x		x	x	x	x	x	x	x						x	x		x		23
	month	x	x	x	x	x											x		x				x								x	x	x	x		x	x	x	x				x	x	x	x	x	x	x	x	x	x						x	x		x		29

Table 16: Availability of different scenarios in the investigated CMIP5 model simulations.

Available experiments	ACCESS1.0	ACCESS1.3	BCC-CSM1.1	BCC-CSM1.1(m)	BNU-ESM	CCSM4	CESM1(BGC)	CESM1(CAM5)	CESM1(CAM5.1,FV2)	CESM1(FASTCHEM)	CESM1(WACCM)	CFSv2-2011	CMCC-CESM	CMCC-CM	CMCC-CMS	CNRM-CM5	CNRM-CM5-2	CSIRO-Mk3.6.0	CSIRO-Mk3L-1-2	CanAM4	CanCM4	CanESM2	EC-EARTH	FGOALS-g2	FGOALS-gl	FGOALS-s2	FIO-ESM	GEOS-5	GFDL-CM2.1	GFDL-CM3	GFDL-ESM2G	GFDL-ESM2M	GFDL-HIRAM-C180	GFDL-HIRAM-C360	GISS-E2-H	GISS-E2-H-CC	GISS-E2-R	GISS-E2-R-CC	HadCM3	HadGEM2-A	HadGEM2-AO	HadGEM2-CC	HadGEM2-ES	INM-CM4	IPSL-CM5A-LR	IPSL-CM5A-MR	IPSL-CM5B-LR	MIROC-ESM	MIROC-ESM-CHEM	MIROC4h	MIROC5	MPI-ESM-LR	MPI-ESM-MR	MPI-ESM-P	MRI-AGCM3.2H	MRI-AGCM3.2S	MRI-CGCM3	MRI-ESM1	NICAM-09	NorESM1-M	NorESM1-ME	Number of models
historical	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x		x	x	x	x		x	x		x	x	x	x			x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x			x	x		x	x	51
RCP8.5	x	x	x	x	x	x	x	x			x		x	x	x	x		x				x	x	x		x	x			x	x	x			x	x	x	x			x	x	x	x	x	x	x	x	x		x	x	x				x	x		x	x	42
RCP4.5	x	x	x	x	x	x	x	x			x			x	x	x		x	x		x	x	x	x			x		x	x	x	x			x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x				x			x	x	44
RCP2.6			x	x	x	x		x			x					x		x				x	x	x		x	x			x	x	x			x		x				x		x		x	x		x	x		x	x	x				x			x	x	30
RCP6			x	x		x		x										x								x	x			x	x	x			x		x				x		x		x	x		x	x		x						x			x	x	22
historical + RCP8.5	x	x	x	x	x	x	x	x			x		x	x	x	x		x				x	x	x		x	x			x	x	x			x	x	x	x			x	x	x	x	x	x	x	x	x		x	x	x				x	x		x	x	42
historical + RCP8.5 + RCP4.5	x	x	x	x	x	x	x	x			x			x	x	x		x				x	x	x			x			x	x	x			x	x	x	x			x	x	x	x	x	x	x	x	x		x	x	x				x			x	x	39
historical + RCP8.5 + RCP4.5 + RCP2.6			x	x	x	x		x			x					x		x				x	x	x			x			x	x	x			x		x				x		x		x	x		x	x		x	x	x				x			x	x	29
historical + all RCPs[1]			x	x		x		x										x									x			x	x	x			x		x				x		x		x	x		x	x		x						x			x	x	21

1 This criteria gives the same results as: historical + RCP8.5 + RCP4.5 + RCP6

Table 17: Joint availability of given resolution ranges, scenarios and atmospheric variables in the investigated CMIP5 model simulations.

Extended basic, Radiation, Pressure level		Extended basic, Radiation, Pressure level		Extended basic, Radiation, Pressure level		Extended basic, Radiation, Pressure level	
Horizontal resolution: 0°-2°		Horizontal resolution: 0°-2°		Horizontal resolution: 0°-2°		Horizontal resolution: 0°-2°	
historical, RCP8.5		historical, RCP8.5, RCP4.5		historical, RCP8.5, RCP4.5, RCP2.6		historical, all RCPs	
daily data	monthly data	daily data	monthly data	daily data	monthly data	daily data	monthly data
ACCESS1.0	ACCESS1.0	ACCESS1.0	ACCESS1.0	BCC-CSM1.1(m)	BCC-CSM1.1(m)	BCC-CSM1.1(m)	BCC-CSM1.1(m)
ACCESS1.3	ACCESS1.3	ACCESS1.3	ACCESS1.3	CSIRO-Mk3.6.0	CNRM-CM5	CSIRO-Mk3.6.0	CSIRO-Mk3.6.0
BCC-CSM1.1(m)	BCC-CSM1.1(m)	BCC-CSM1.1(m)	BCC-CSM1.1(m)	HadGEM2-ES	CSIRO-Mk3.6.0	HadGEM2-ES	HadGEM2-ES
CSIRO-Mk3.6.0	CNRM-CM5	CSIRO-Mk3.6.0	CNRM-CM5	MIROC5	HadGEM2-ES	MIROC5	MIROC5
HadGEM2-CC	CSIRO-Mk3.6.0	HadGEM2-CC	CSIRO-Mk3.6.0	MRI-CGCM3	MIROC5	MRI-CGCM3	MRI-CGCM3
HadGEM2-ES	HadGEM2-CC	HadGEM2-ES	HadGEM2-CC		MRI-CGCM3		
MIROC5	HadGEM2-ES	MIROC5	HadGEM2-ES				
MRI-CGCM3	INM-CM4	MRI-CGCM3	INM-CM4				
MRI-ESM1	MIROC5		MIROC5				
	MRI-CGCM3		MRI-CGCM3				
	MRI-ESM1						
Number of models	**Number of models**	**Number of models**	**Number of models**	**Number of models**	**Number of models**	**Number of models**	**Number of models**
9	**11**	**8**	**10**	**5**	**6**	**5**	**5**

Extended basic, Radiation, Pressure level		Extended basic, Radiation, Pressure level		Extended basic, Radiation, Pressure level		Extended basic, Radiation, Pressure level	
Horizontal resolution: 0°-3°		Horizontal resolution: 0°-3°		Horizontal resolution: 0°-3°		Horizontal resolution: 0°-3°	
historical, RCP8.5		historical, RCP8.5, RCP4.5		historical, RCP8.5, RCP4.5, RCP2.6		historical, all RCPs	
daily data	monthly data	daily data	monthly data	daily data	monthly data	daily data	monthly data
ACCESS1.0	ACCESS1.0	ACCESS1.0	ACCESS1.0	BCC-CSM1.1	BCC-CSM1.1	BCC-CSM1.1	BCC-CSM1.1
ACCESS1.3	ACCESS1.3	ACCESS1.3	ACCESS1.3	BCC-CSM1.1(m)	BCC-CSM1.1(m)	BCC-CSM1.1(m)	BCC-CSM1.1(m)
BCC-CSM1.1	BCC-CSM1.1	BCC-CSM1.1	BCC-CSM1.1	BNU-ESM	BNU-ESM	CSIRO-Mk3.6.0	CSIRO-Mk3.6.0
BCC-CSM1.1(m)	BCC-CSM1.1(m)	BCC-CSM1.1(m)	BCC-CSM1.1(m)	CSIRO-Mk3.6.0	CNRM-CM5	GFDL-CM3	GFDL-CM3
BNU-ESM	BNU-ESM	BNU-ESM	BNU-ESM	CanESM2	CSIRO-Mk3.6.0	GFDL-ESM2G	GFDL-ESM2G
CSIRO-Mk3.6.0	CNRM-CM5	CSIRO-Mk3.6.0	CNRM-CM5	GFDL-CM3	CanESM2	GFDL-ESM2M	GFDL-ESM2M
CanESM2	CSIRO-Mk3.6.0	CanESM2	CSIRO-Mk3.6.0	GFDL-ESM2G	GFDL-CM3	HadGEM2-ES	GISS-E2-H
GFDL-CM3	CanESM2	GFDL-CM3	CanESM2	GFDL-ESM2M	GFDL-ESM2G	IPSL-CM5A-MR	GISS-E2-R
GFDL-ESM2G	GFDL-CM3	GFDL-ESM2G	GFDL-CM3	HadGEM2-ES	GFDL-ESM2M	MIROC-ESM	HadGEM2-ES
GFDL-ESM2M	GFDL-ESM2G	GFDL-ESM2M	GFDL-ESM2G	IPSL-CM5A-MR	GISS-E2-H	MIROC-ESM-CHEM	IPSL-CM5A-MR
HadGEM2-CC	GFDL-ESM2M	HadGEM2-CC	GFDL-ESM2M	MIROC-ESM	GISS-E2-R	MIROC5	MIROC-ESM
HadGEM2-ES	GISS-E2-H	HadGEM2-ES	GISS-E2-H	MIROC-ESM-CHEM	HadGEM2-ES	MRI-CGCM3	MIROC-ESM-CHEM
IPSL-CM5A-MR	GISS-E2-H-CC	IPSL-CM5A-MR	GISS-E2-H-CC	MIROC5	IPSL-CM5A-MR	NorESM1-M	MIROC5
MIROC-ESM	GISS-E2-R	MIROC-ESM	GISS-E2-R	MRI-CGCM3	MIROC-ESM		MRI-CGCM3
MIROC-ESM-CHEM	GISS-E2-R-CC	MIROC-ESM-CHEM	GISS-E2-R-CC	NorESM1-M	MIROC-ESM-CHEM		NorESM1-M
MIROC5	HadGEM2-CC	MIROC5	HadGEM2-CC		MIROC5		
MRI-CGCM3	HadGEM2-ES	MRI-CGCM3	HadGEM2-ES		MRI-CGCM3		
MRI-ESM1	INM-CM4	NorESM1-M	INM-CM4		NorESM1-M		
NorESM1-M	IPSL-CM5A-MR		IPSL-CM5A-MR				
	MIROC-ESM		MIROC-ESM				
	MIROC-ESM-CHEM		MIROC-ESM-CHEM				
	MIROC5		MIROC5				
	MRI-CGCM3		MRI-CGCM3				
	MRI-ESM1		NorESM1-M				
	NorESM1-M						
Number of models	**Number of models**	**Number of models**	**Number of models**	**Number of models**	**Number of models**	**Number of models**	**Number of models**
19	**25**	**18**	**24**	**15**	**18**	**13**	**15**

Table 18: Joint availability of given scenarios and atmospheric variables in the investigated CMIP5 model simulations.

Extended basic, Radiation, Pressure level		Extended basic, Radiation, Pressure level	
historical, RCP8.5		historical, RCP8.5, RCP4.5	
daily data	monthly data	daily data	monthly data
ACCESS1.0	ACCESS1.0	ACCESS1.0	ACCESS1.0
ACCESS1.3	ACCESS1.3	ACCESS1.3	ACCESS1.3
BCC-CSM1.1	BCC-CSM1.1	BCC-CSM1.1	BCC-CSM1.1
BCC-CSM1.1(m)	BCC-CSM1.1(m)	BCC-CSM1.1(m)	BCC-CSM1.1(m)
BNU-ESM	BNU-ESM	BNU-ESM	BNU-ESM
CSIRO-Mk3.6.0	CNRM-CM5	CSIRO-Mk3.6.0	CNRM-CM5
CanESM2	CSIRO-Mk3.6.0	CanESM2	CSIRO-Mk3.6.0
GFDL-CM3	CanESM2	GFDL-CM3	CanESM2
GFDL-ESM2G	GFDL-CM3	GFDL-ESM2G	GFDL-CM3
GFDL-ESM2M	GFDL-ESM2G	GFDL-ESM2M	GFDL-ESM2G
HadGEM2-CC	GFDL-ESM2M	HadGEM2-CC	GFDL-ESM2M
HadGEM2-ES	GISS-E2-H	HadGEM2-ES	GISS-E2-H
IPSL-CM5A-LR	GISS-E2-H-CC	IPSL-CM5A-LR	GISS-E2-H-CC
IPSL-CM5A-MR	GISS-E2-R	IPSL-CM5A-MR	GISS-E2-R
IPSL-CM5B-LR	GISS-E2-R-CC	IPSL-CM5B-LR	GISS-E2-R-CC
MIROC-ESM	HadGEM2-CC	MIROC-ESM	HadGEM2-CC
MIROC-ESM-CHEM	HadGEM2-ES	MIROC-ESM-CHEM	HadGEM2-ES
MIROC5	INM-CM4	MIROC5	INM-CM4
MRI-CGCM3	IPSL-CM5A-LR	MRI-CGCM3	IPSL-CM5A-LR
MRI-ESM1	IPSL-CM5A-MR	NorESM1-M	IPSL-CM5A-MR
NorESM1-M	IPSL-CM5B-LR		IPSL-CM5B-LR
	MIROC-ESM		MIROC-ESM
	MIROC-ESM-CHEM		MIROC-ESM-CHEM
	MIROC5		MIROC5
	MRI-CGCM3		MRI-CGCM3
	MRI-ESM1		NorESM1-M
	NorESM1-M		
Number of models 21	**Number of models 27**	**Number of models 20**	**Number of models 26**

Extended basic, Radiation, Pressure level		Extended basic, Radiation, Pressure level	
historical, RCP8.5, RCP4.5, RCP2.6		historical, all RCPs	
daily data	monthly data	daily data	monthly data
BCC-CSM1.1	BCC-CSM1.1	BCC-CSM1.1	BCC-CSM1.1
BCC-CSM1.1(m)	BCC-CSM1.1(m)	BCC-CSM1.1(m)	BCC-CSM1.1(m)
BNU-ESM	BNU-ESM	CSIRO-Mk3.6.0	CSIRO-Mk3.6.0
CSIRO-Mk3.6.0	CNRM-CM5	GFDL-CM3	GFDL-CM3
CanESM2	CSIRO-Mk3.6.0	GFDL-ESM2G	GFDL-ESM2G
GFDL-CM3	CanESM2	GFDL-ESM2M	GFDL-ESM2M
GFDL-ESM2G	GFDL-CM3	HadGEM2-ES	GISS-E2-H
GFDL-ESM2M	GFDL-ESM2G	IPSL-CM5A-LR	GISS-E2-R
HadGEM2-ES	GFDL-ESM2M	IPSL-CM5A-MR	HadGEM2-ES
IPSL-CM5A-LR	GISS-E2-H	MIROC-ESM	IPSL-CM5A-LR
IPSL-CM5A-MR	GISS-E2-R	MIROC-ESM-CHEM	IPSL-CM5A-MR
MIROC-ESM	HadGEM2-ES	MIROC5	MIROC-ESM
MIROC-ESM-CHEM	IPSL-CM5A-LR	MRI-CGCM3	MIROC-ESM-CHEM
MIROC5	IPSL-CM5A-MR	NorESM1-M	MIROC5
MRI-CGCM3	MIROC-ESM		MRI-CGCM3
NorESM1-M	MIROC-ESM-CHEM		NorESM1-M
	MIROC5		
	MRI-CGCM3		
	NorESM1-M		
Number of models 16	**Number of models 19**	**Number of models 14**	**Number of models 16**

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