University of Zurich[UZH]

Past and future of managed retreat; a global overview

ESS 511 Master's Thesis

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1 Introduction

Rising sea levels, more frequent and more powerful storms, more intense heavy precipitation, more extreme and longer-lasting heat waves and droughts are among the effects of climate change that will continue to increase in the future (IPCC 2021). All of these factors may render areas that have previously been used for human habitation uninhabitable. Estimates suggest that climate change could force up to 200 million people to relocate by 2050 (Environmental Justice Foundation, 2009), and sea level rise alone threatens between 72 and 187 million people by 2100 (IPCC 2014 (search for more recent figures)). One way to address these processes is "managed retreat," in which vulnerable settlements and people are proactively relocated from high-risk areas. Managed retreat thus differs from resettlement, which is undertaken only in the aftermath of a natural disaster such as a flood. Between 1987 and 2017, managed retreat projects have already resettled 1.3 million people in 22 countries worldwide (Hino et al., 2017).

Here, managed retreat is defined as planned relocation that preemptively and permanently removes people and their assets away from hazards (Lawrence et al., 2020). Until now, retreat has mostly been carried out in the aftermath of a natural disaster, occurring reactively rather than preemptively (Collins et al., 2019). This suggests that such projects are politically easier to implement after a natural event has arrived and caused damage than proactively to prevent it from happening (Mortreux et al., 2018). There is also a difference between managed retreat and climate migration. While the latter is often uncoordinated and can be driven by climate change as well as ecological degradation from other causes or economic factors, managed retreat requires a planned and coordinated approach to permanently relocate people and property from vulnerable areas (Ajibade et al., 2020).

Managed retreat can be approached in a number of ways: Is it intended as a stand-alone project or integrated into a larger development plan (social / environmental...)? Is it implemented as an alternative to construction measures or as complementary to them? Is it reactive (after a disaster event has occurred) or proactive (to avoid an expected one)? Is its implementation voluntary or are forms of government coercion used? Is it financially supported by the authorities and in what form (compensation for property loss, compensation for relocation costs, provision of alternative housing, investment in new infrastructure, maintenance of cleared land)? Is only one tier of government involved or multiple (especially as it relates to funding) (Lawrence et al., 2020)?

However, the practical implementation of such projects is often decidedly difficult. For those resettled, managed retreat programs invariably entail severe social, economic, and cultural disruptions that often hit poorer populations or marginalized groups the hardest (Siders, 2019). Often managed retreat projects have also been reduced to financial cost-benefit considerations and imposed on the affected population by the relevant authorities (Maldonado, 2014., Blunkell, 2017., Paprocki, 2019). In this context, one also speaks of the "climate gap", the sometimes wide gap between the great international attention paid to climate change and the everyday needs of vulnerable communities, which manifests itself in adaptation strategies that bypass local cultural and structural realities and people's needs (Gaillard, 2012).

Although 1.3 million people in 22 countries have already had to relocate due to a wide variety of natural hazards between 1987 and 2017 (Hino et al., 2017), most of these relocations were retreats that were not preemptively planned (Neal et al., 2017). In the future, managed retreat will be inevitable as a proactive adaptation to climate change, especially in large river deltas and in cities that are already experiencing flooding today, such as Lagos, Jakarta, Mumbai, and Miami (Kulp and Strauss, 2019). However, there are also cases where managed retreats have been planned and funded by government and have already been implemented in its narrower, preventative sense, such as in the "Delta Program" in the Netherlands (Rijke et al., 2012) and "Twin Streams" in Auckland, New Zealand (Vandenbeld and MacDonald, 2013). In both cases, more space was created for the river.

One likely reason why retreat is so controversial and often strongly opposed is that it changes the status quo like no other adaptation strategy and can lead to large and irreversible losses. (Of course, it can also lead to large gains, but these are highly uncertain, compared to the certain losses (own comment)). Managed retreat also raises existential questions of justice, forcing people to confront inevitable change and make trade-offs about potential improvements and losses in their respective lives (Mach and Siders, 2021).

Structural or technological adjustments often have an easier time politically than retreat proposals. They are an expression of a technical optimism that "we can do it" with our ingenuity and inventiveness, and therefore lead to less concern with the possible dangers and other impacts of climate change. It can also create the impression in people's minds that these impacts will cause few fundamental changes in their daily lives (Gardezi and Arbuckle, 2020).

As Koslov (2016) writes, government officials who are empowered to plan retreat tend to avoid this option whenever possible. Retreat is often not seen as an actual adaptation strategy by them, but as a threatening scenario that must be prevented with investments in shelters or reductions in greenhouse gas emissions.

Unlike other forms of migration triggered by climate change, retreat involves not only the relocation of people, but also the permanent abandonment of previously used land. While millions of people have been relocated by governments around the world for countless infrastructure or development projects, it is this return of land to nature that seems to be stoking fears. Government officials in the U.S., for example, fear declining property tax revenues (due to fewer homeowners) and the cost of maintaining new open spaces. Yet these open spaces increase the value of surrounding properties and bring numerous other benefits to the economy and the health and well-being of surrounding residents, especially in densely populated areas (Active Living Research, 2010).

1.1 Aim of work

Natural disasters and climatic changes have led to the abandonment of settlements and entire areas many time in world history, either because the settlements were destroyed or the area became uninhabitable because the climatic conditions did no longer permit it. (Taklamakan desert) Whether these processes came gradually with decreasing precipitation - or suddenly with a storm surge (Rungholt), they always had in common that people could not estimate the future developments and a planned move away from future dangers would therefore hardly ever have been possible. This has changed with the steadily increasing amount of collected climate data and constantly improving climate models, whose forecasts are becoming more and more reliable. It is now possible to estimate clearly emerging trends in their temporal and spatial occurrence. From these forecasts, in turn, it is possible to identify where conditions will change so much in the future that it will be unavoidable to take measures to protect the population.

Depending on the situation in the individual case, it may make sense or even be unavoidable to abandon or relocate settlements in whole or in part. All measures to protect people, property, infrastructure and land incur costs and bring with them ecological, social and economic consequences. It is therefore sensible and of great importance, that states, regions and individuals concerned are aware of these developments and their potential consequences. In this way, appropriate measures can be discussed, planned and initiated at an early stage, even before the first damage occurs. The preventive resettlement of people represents a very large intervention in the livelihoods of those affected. To ensure that such projects run as smoothly as possible and result in as few negative impacts as possible, it is worth analyzing managed retreat projects that have been carried out in the past to see which specific measures have proved successful and which obstacles have arisen. In addition, it is important to look at cases where resettlement was requested but failed to be implemented in order to identify mistakes that were made or conditions that were not met, and what precautions should be taken to avoid these scenarios. In order to calculate the required resources for any planned resettlement as accurately as possible, it is important to know where they are likely to be needed most urgently and how many people are likely to be affected. In order to use them as efficiently and effectively as possible, lessons must be learned from past experience, promising approaches must be further developed and mistakes made elsewhere must be avoided. The aim of this thesis is therefore to identify the areas of the world where climatic changes are most likely to be severe enough to require measures to protect the population and to suggest what we can learn from past experience so that managed retreat can be planned and implemented on a sound basis.

2 Methods

This thesis is based on a review and synthesis of the literatures on managed retreat.

For the first part of the thesis a literary analysis was conducted to find scientifically accompanied or investigated cases of attempted and carried out managed retreats in the past. These are used to extract the various aspects that proved challenging during such a process. A literature review can provide important insights into how the managed retreat approach to climate change adaptation is being implemented in practice and what challenges may be encountered. For example, questions can be explored about how decisions to retreat from vulnerable areas are made, what political and social factors are involved, and how affected communities can be involved in the process. In addition, a literature review helps identify the different approaches and strategies that are being used in practice to protect communities and ecosystems from the impacts of climate change. Such an analysis also allows us to assess the effectiveness of these approaches and strategies and identify what factors contribute to their success. Literature reviews can help examine the impacts of managed retreat on the environment and affected communities on a much broader scope than an individual and localized case study and identify potential alternatives to this approach. Overall, a literature review can help develop a comprehensive understanding of managed retreat and its opportunities and challenges as they have been encountered in the past and thus are likely to be encountered again in the future. Gaining this understanding allows for informed reflection on the current state of research, the discussions surrounding it and the decisions that are being taken in this area and provide a foundation for further research and practice.

Literature was searched for on the scientific databases Mendeley, Google Scholar, Web of Science and Science Open. Other studies were found through the references provided in the literature on these databases. If available, further information on the scope and success of resettlements may be drawn from government sources or NGO's such as the United Nations refugee agency UNHCR. The focus lies on case studies concerning reallocation of people and infrastructure due to climate and weather effects. The search was conducted thematically as well as geographically. Thematical search terms included combinations of the terms "managed", "retreat", "relocation", "resettlement" and the four hazards sea level rise, river floods, desertification and extreme heat, the analysis is focused on. The geographical search combined the same terms with specific world regions such as "Southeast Asia" or "Africa" and aimed at finding studies from locations that may not have attracted as much research interest in the past as others and thus collect and provide insights from many diverse locations around the world.

The literature was then searched for findings on different approaches towards and effects of managed retreat which were divided into the categories "financial", "ethical / social", "ecological" and "legal / regulatory". Each of these categories was further split up into a section listing the challenges or negative observed or expected implications of relocation and a section outlining methods that have been observed to minimize these negative effects and proposed strategies to enhance chances for successful outcomes of managed retreat.

The results of the literature analysis were then used to develop a framework providing guidance for policy makers as to which measures should be put in place and which steps are to be taken in what order to increase chances of socially, ecologically and economically sustainable relocation process.

In addition to the literary analysis, publicly available databases have been consulted in a secondary data review to assess which regions of the planet are expected to experience changes that will increase the probability of a necessity to retreat. These may be due to climate change as in the case of rising sea levels, but also the result of land use or a combination of land use and climate change as can be expected in the case of desertification.

Conducting a secondary data analysis involving multiple online modeling tools in the field of managed retreat research can provide several benefits and insights. This approach provides access to a wide range of data. Online modeling tools often provide access to extensive datasets related to various aspects of managed retreat, such as sea level rise projections, estimated changes in precipitation and temperature patterns, demographic information, and land use patterns. By using multiple tools, it is possible to access different data sets and gain a comprehensive understanding of the factors that influence managed retreat. Different online modeling tools may use different methods, algorithms, and data sources. Using multiple tools allows for comparison of results and identification of commonalities and discrepancies. This comparative analysis can help validate results, identify patterns, and gain a better understanding of the research problem. Modeling tools often include inherent assumptions and uncertainties. Conducting secondary data analysis with multiple tools allows for cross-validation of results, ensuring reliability and accuracy. Research in managed retreat involves interdisciplinary considerations, including environmental science, demographics, urban planning, social science, and more. Online modeling tools from multiple disciplines can provide insights into the challenges and opportunities associated with managed retreat as a coping strategy. By integrating multiple tools, a more holistic understanding of the complex dynamics can be gained. Managed retreat is a relatively new field, and there are ongoing efforts to refine modeling techniques and improve the accuracy of predictions. By using a variety of online modeling tools, one can identify knowledge gaps, areas of uncertainty, and limitations of existing models. This analysis can guide further research and contribute to the ongoing development of more reliable and comprehensive models.

To make an assessment on how changes in the earth system translate in a need for relocation, certain thresholds are determined or taken from the literature, e.g. when does decreasing precipitation no longer allow for agriculture / at which point is sea level rise too severe to allow for coastal habitation etc. From the databases, relevant parameters for the assessment of future developments of different processes threatening livelihoods have been chosen.

Sources of the data that have been used are:

2.1.1.1 IPCC WGI Interactive Atlas: https://interactive-atlas.ipcc.ch/

The IPCC Interactive Atlas complements the IPCC's 6th Assessment Report (AR6) and allows to make changes in several important atmospheric and oceanic variables to be analyzed spatially and temporally while also including the influences of different development scenarios. It obtains the data incorporated into the models from several global and regional measurement and modeling data sets that underlie the AR6, which contains a complete listing of the underlying data and models (IPCC, 2021).

2.1.1.2 World Atlas of Desertification: https://wad.jrc.ec.europa.eu/

The Wold Atlas of Desertification (3rd Edition) is a tool of the Joint Research Centre of the European Commission. It focuses on the processes that contribute to land degradation with the aim of identifying where soils are under particular pressure, potentially threatening food security due to declining agricultural yields. It does this by collecting a variety of different factors that affect soil productivity and quality. Overlaying several of these climatic and anthropogenic influences reveals the regions where developments that negatively affect soils are converging. A convergence of evidence map for land degradation is thus created. The factors included on the bio-physical level are: aridity, water stress, decreasing land productivity, climate vegetation trends, fires and tree loss. At the socio-economic level, population density, increase in population density, Income level, built-up area change, low input agriculture (nitogen deficit), high input agriculture (nitrogen surplus), irrigation and livestock density were included in the map. The parameters were calculated from satellite data and population statistics and can be viewed in detail in the Atlas (Cherlet et al., 2018).

2.1.1.3 IPCC AR6 Sea Level Projection Tool: https://sealevel.nasa.gov/data_tools/17

Mit dem IPCC Sea Level Projection Tool lässt sich der Anstieg des Meeresspiegels in die Zukunft pojizieren. Dabei lassen sich für eine Vielzahl existierender Messstationen die bisher gemessenen und die zu erwartenden Pegelentwicklungen einsehen. Dadurch wird ersichtlich, wie unterschiedlich schnell der Meeresspiegelanstieg an den einzelnen Küstenabschnitten vor sich geht. Dabei können auch die verschiedenen SSP-Szenarien miteinbezogen und die Unterschiede sichtbar gemacht werden.

2.1.1.4 Coastal Risk Screening Tool: https://coastal.climatecentral.org/

Das Coastal Risk Screening Tool enthält eine Weltkarte, auf welcher die Flächen dargestellt werden, die bei einem bestimmten, zuvor ausgewählten Meeresspiegelanstieg überschwemmt werden, wenn keine Massnahmen dagegen ergriffen werden. Im Unterschied zum IPCC Sea Level Projection Tool lässt sich hier somit nur ein global uniformer Anstieg des Meeresspiegels simulieren und nicht nach unterschiedlichen Klimaszenarien differenzieren. Damit lässt sich aber erkennen welche Regionen aufgrund ihrer topografischen Gegebenheiten besonders stark von einem Steigenden Meeresspiegel bedroht sind. Mithilfe dieses Tools wurden die Küstenabschnitte auf der Karte in Abbildung … ausgewählt, wo mit besonders grossflächigen Überflutungen gerechnet werden muss.

Selected maps and excerpts from these sites were chose to exemplify the expected effects on affected areas in various locations around the planet that have been deemed to be of particular interest.

These datasets are compiled into world maps, showing likely affected areas of all four analyzed hazards, thereby highlighting where risk areas of different hazards overlap. As the topic of desertification

The derived maps and data are compared with other available data such as population density to derive an estimated number of the affected population and area.

Most of the utilized tools provide their modeling outcomes via ScenarioMIP, the part of the international Coupled Model Intercomparison Project 6 (CMIP6) of the World Climate Research Programme (WCRP) that comprises scenario runs for the 21st century. The modeled scenarios form the concept of the Shared Socioeconomic Pathways (SSPs). The SSPs are a set of potential development pathways developed by the Intergovernmental Panel on Climate Change (IPCC) that represent different scenarios of future socioeconomic conditions. Based on these scenarios, assumed human impacts are input into climate models to identify the potential impacts of climate change, ways to mitigate them, and adaptation strategies.

Each SSP is a combination of socio-economic developments and climate policies and includes different challenges and opportunities that a future society might face. Each SSP is linked to a set of climatic consequences and provides the basis for assessing the impacts of different actions in terms of greenhouse gas emissions, energy use, land use and other relevant factors.

This thesis focuses on the two scenarios SSP2 and SSP3. SSP2 is also called the "Middle of the Road" - Scenario and describes a world with moderate challenges and opportunities, where current trends continue. It represents a future where economic development, population growth, and technological progress follow historical patterns. It assumes a balance between fossil fuels and renewable energy sources and leads to intermediate greenhouse gas emissions and temperature increases.

The SSP3 pathway is called "Regional Rivalry" and depicts a fragmented world with high regional competition and limited global cooperation. It assumes a focus on national interests, decreasing Investments in education and technological progress, and slow economic development. SSP3 projects a future with higher greenhouse gas emissions and significant climate change impacts.

Additionally, ScenarioMIP assigns a specific increase in radiative forcing by the year 2100 to some SSPs, based on the expected greenhouse gas emissions in a certain scenario. SSP2-4.5 assumes an additional radiative forcing of 4.5 W/m² by the year 2100 and represents the medium pathway of future greenhouse gas emissions. This scenario assumes that climate protection measures are being taken. SSP3-7.0 estimates an increase of 7 W/m² by the year 2100. This scenario is in the upper-middle part of the full range of scenarios.

The two pathways this thesis focuses on were chosen as they do not represent the extremes and are therefore expected to agree with real developments as time goes by. Nevertheless, they diverge enough form each other as to produce significant differences in modeled outcomes, thereby illustrating the effect human action or inaction can have on the climate system.

Different papers use different metrics for extreme heat events. (Mean Annual Temperature MAT, Wet Bulb globe temperature, WB(g)T, MMT...). Although these metrics generally correlate well with each other, they are often not directly comparable, as they include or omit different factors. Also, different authors use different thresholds for the point at which heat decisively affects human health or performance. This (and the differences in the climate models used) results in differences in the maps based on these data and the calculated or estimated number of people affected.

3 Results

3.1 Climatic developments

Der Klimawandel

3.1.1 Sea level rise

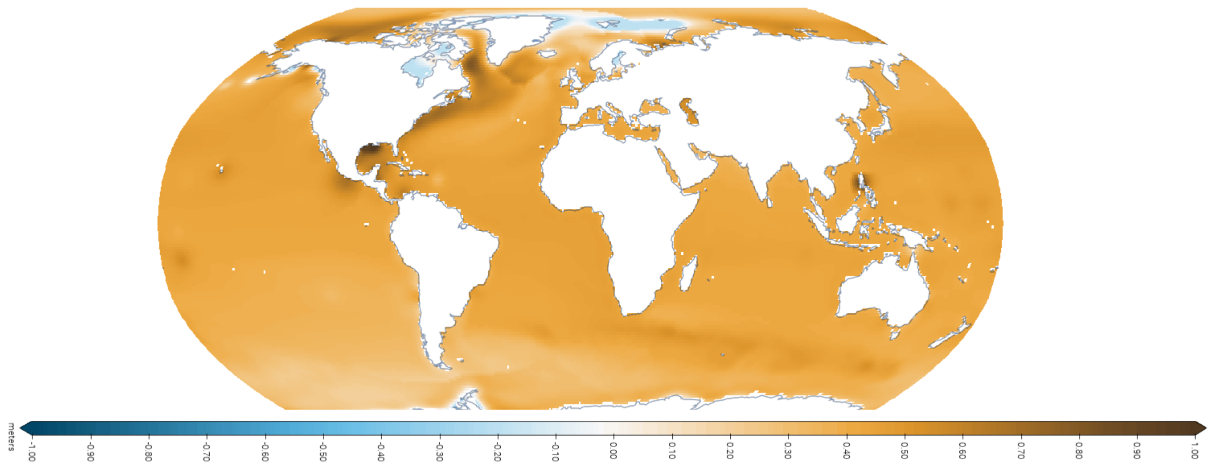


Figure 1: Change in sea level in meters for the 2081-2100 period under the SSP1-2.6 scenario (interactive-atlas.ipcc.com)

The rise in sea level under the auspices of climate change comes about through two different processes. On the one hand, the ice masses bound in the Greenland and Antarctic ice sheets and the mountain glaciers are melting. Second, the water in the oceans expands as the water temperature rises.

As can be seen in Figure 1, sea level is not rising uniformly all over the world, but in some areas much faster than in others. Some areas in the Arctic Ocean, in the Hudson Bay area in Canada, and in the Gulf of Finland will experience a slight decrease in sea level in the future, as is already the case today. This is because these areas are still in uplift since the melting of the large ice sheets after the end of the last ice age due to the process of isostasy. In all other areas, sea level is rising. This process is occurring most rapidly in the Caribbean, the North American Atlantic coast, around the Philippine island of Luzon, in a section of the Mexican Pacific coast, and in parts of the Arctic Ocean. Under the SSP2-4.5 scenario, most areas of the world are expected to experience an increase between 0.4 m and 0.6 m (interactive-atlas.ipcc.com).

This value increases to 0.5 to 0.7 in the SSP3-7.0 scenario.

These values are a major problem, especially for low-lying, flat areas such as those found in the estuaries of large rivers. It should also be remembered that sea levels may continue to rise for centuries even if greenhouse gas emissions are halted.

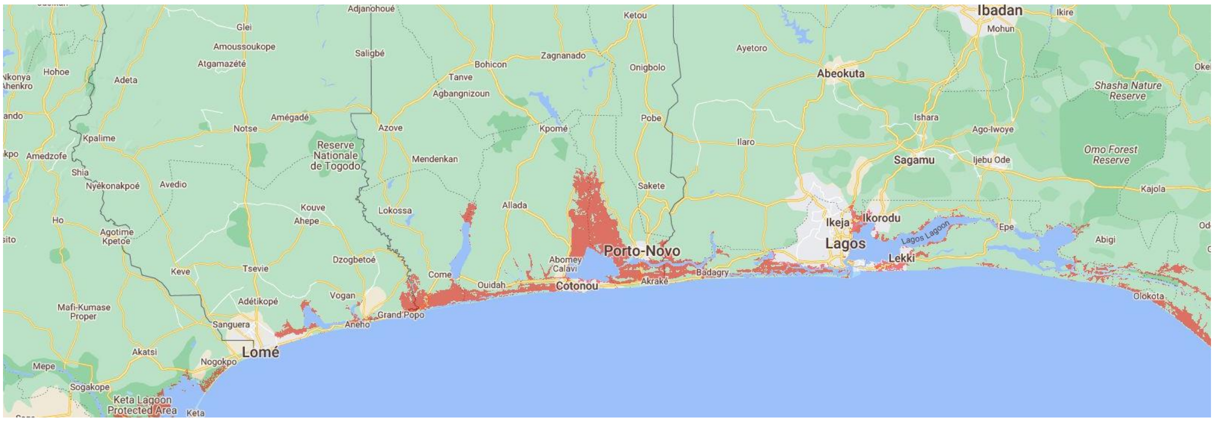


Figure 2: Expeced flooding area at 1m increase in sea level, gulf of Guinea coast

The northern coast of the Gulf of Guinea is the location of the largest cities of the bordering countries, such as Lomé in Togo, Porto-Novo in Benin and Lagos in Nigeria. These and numerous other cities are located on lagoons or partly on flat islands offshore from the mainland, areas that rise only slightly above the current sea level. The areas affected here are also projected to experience tremendous population growth this century; for example, the United Nations projects that the population of Togo will increase from 9 million today to 27 million, that of Benin from 13 million to 47 million, and that of Nigeria from 219 million to 546 million people (UN WPP, 2022). A large part of this growth is likely to affect the large cities on the coasts.

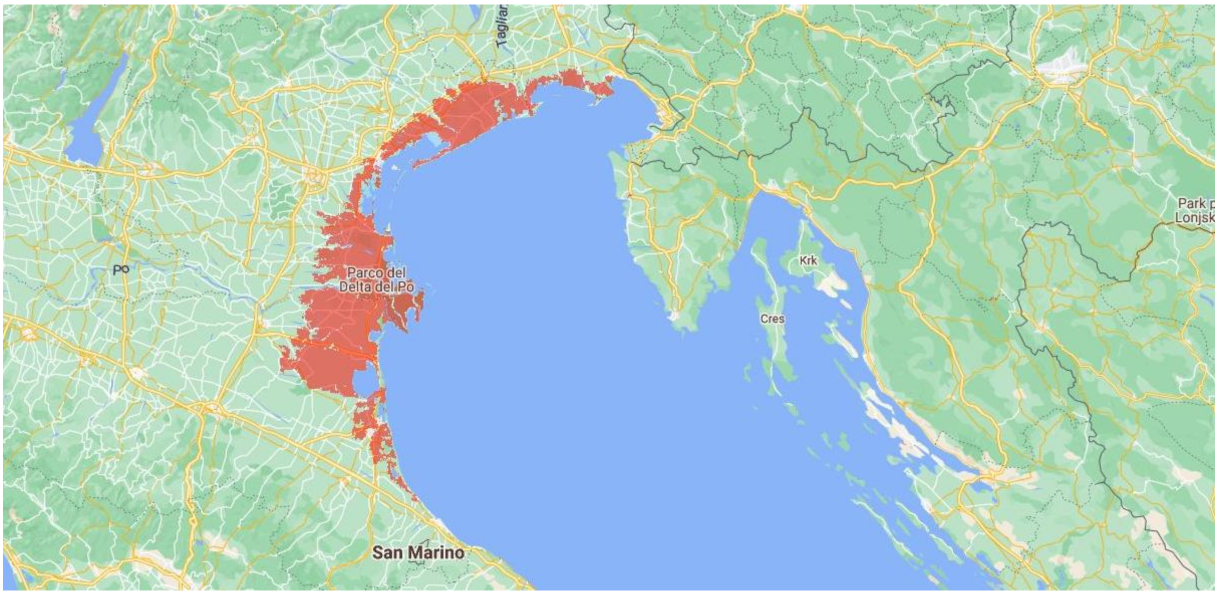


Figure 3: Expeced flooding area at 1m increase in sea level, northern Adriatic Sea (https://coastal.climatecentral.org)

Similar to the Gulf of Guinea, along the northern Italian Adriatic coast there are lagoons and shallow islands, like those surrounding the UNESCO World Heritage city of Venice. In addition, there is the Po Delta, where important agricultural areas are also located, as well as large ports and industrial areas around the city of Mestre.

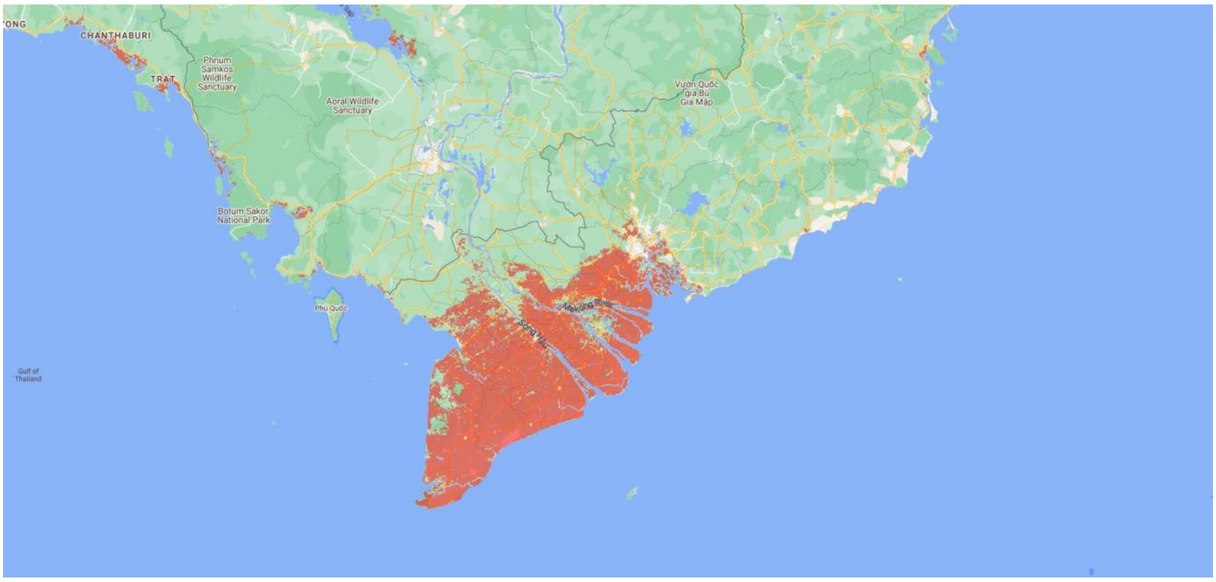


Figure 4: Expeced flooding area at 1m increase in sea level, Mekong delta, Vietnam (https://coastal.climatecentral.org)

As shown in Figure 4, a sea level rise of one meter would flood almost the entire Mekong Delta. The adjacent city of Ho Chi Minh City in the center of the picture would also be severely affected. The delta measures about 39,000 km2, is inhabited by about 18 million people and produces about 16 million tons of rice per year in three harvests. Thus, in addition to the flooding of numerous settlements, extremely productive agricultural land would be lost (Oppenheimer et al., 2019).

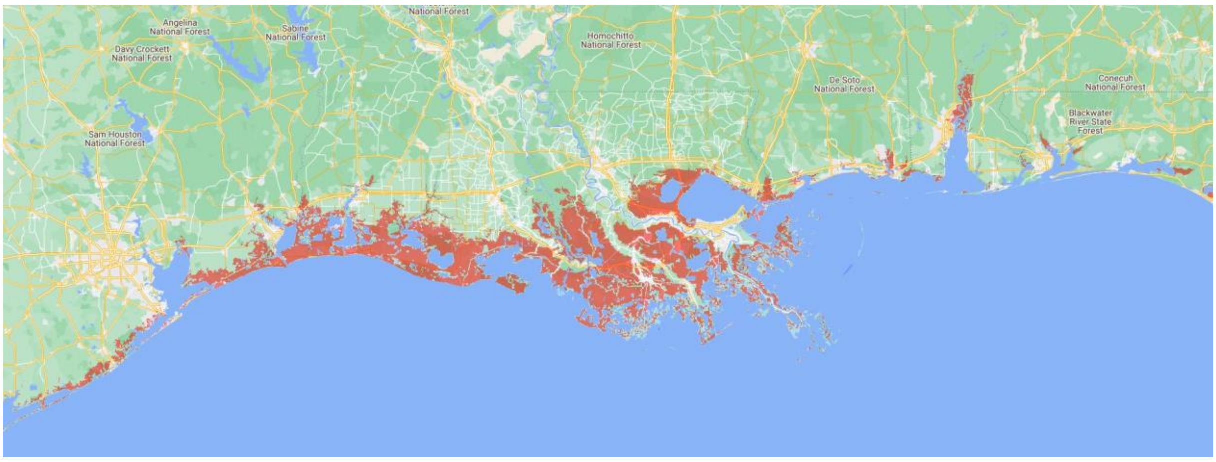


Figure 5: Expeced flooding area at 1m increase in sea level, Mississippi delta, Louisiana, USA (https://coastal.climatecentral.org)

At the northern edge of the Gulf of Mexico, in the area of the Mississippi Delta, sea level rise is proceeding particularly rapidly, as a considerable subsidence of the land can also be observed here. Therefore, unlike the previously mentioned examples, sea level in this area is expected to have already exceeded the one meter rise mark by the end of the century. Increased sea level also increases the risk of flooding during storm surges in areas protected by levees, as happened in New Orleans in 2005 during Hurricane Katrina, which flooded large areas of the city that were already below sea level at the time.

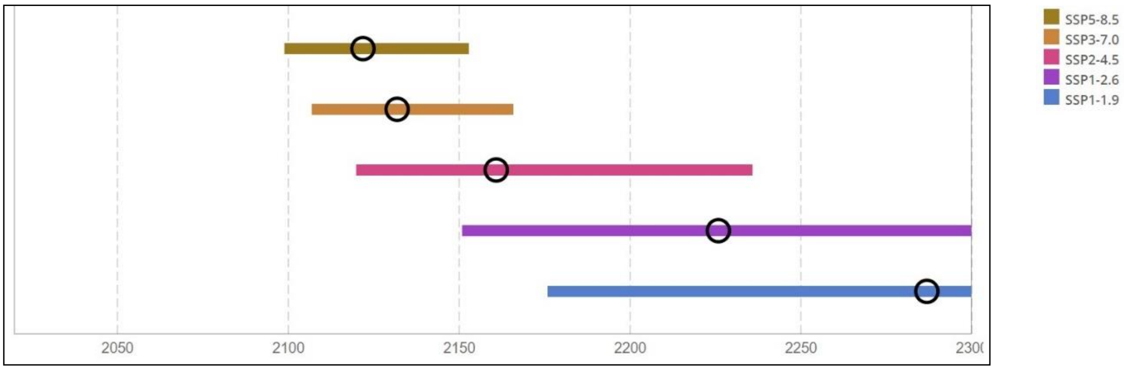


Figure 6: Year by which rise of 1 m above 1995-2014 is expected (www.sealevel.nasa.gov)

As can be seen in Figure 7, the different development paths of the SSP scenarios have a large influence on the speed of sea level rise.

Locally, however, there can be large differences in the rate of rise, mainly due to land subsidence caused by natural tectonic processes or anthropogenic processes such as oil extraction or groundwater pumping (Oppenheimer et al., 2019).

3.1.2 Extreme precipitation events

The CMIP6 modelings shows an increase in the intensity of heavy precipitation events over most of the Earth's surface and almost over the entirety of dry land. Decreases are only to be expected in the southern region of the Pacific off the coast of South America and in the Atlantic between the Caribbean and North Africa and between southern Brazil and South Africa with high agreement of the models. The intensity increases of precipitation are particularly intense in the two polar regions as well as over central and eastern Africa, the southern Arabian Peninsula, parts of southern, central, and eastern Asia, the southeast asian islands, and the Pacific coast of South America near the equator. The intensity increase of events with a duration of less than 24 hours is generally greater than that of events with a duration of up to 5 days. However, both modeled time horizons lead to particularly strong intensity increases in the same areas.

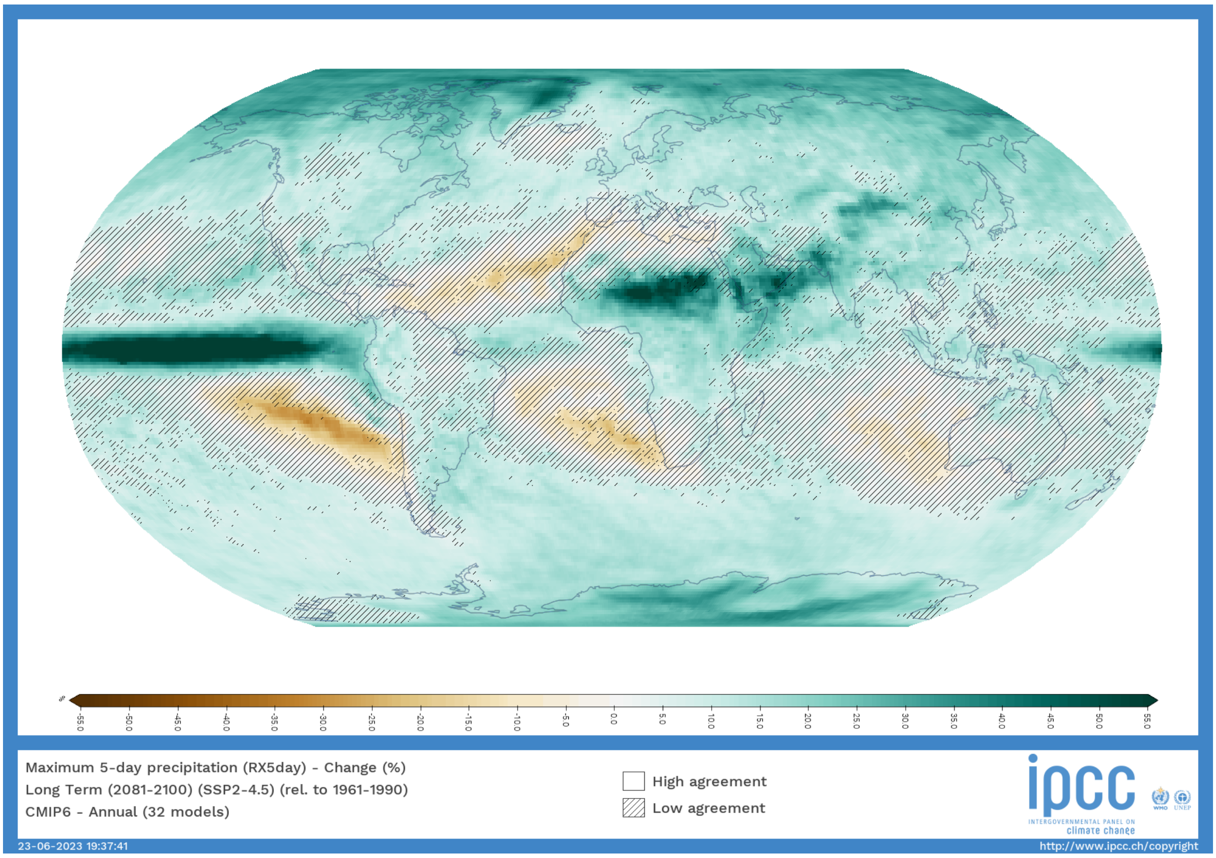


Figure 7: Increase in maximum 5-day precipitation by 2100, SSP2-4.5

Increase in maximum 5-day precipitation by 2100, SSP2-4.5

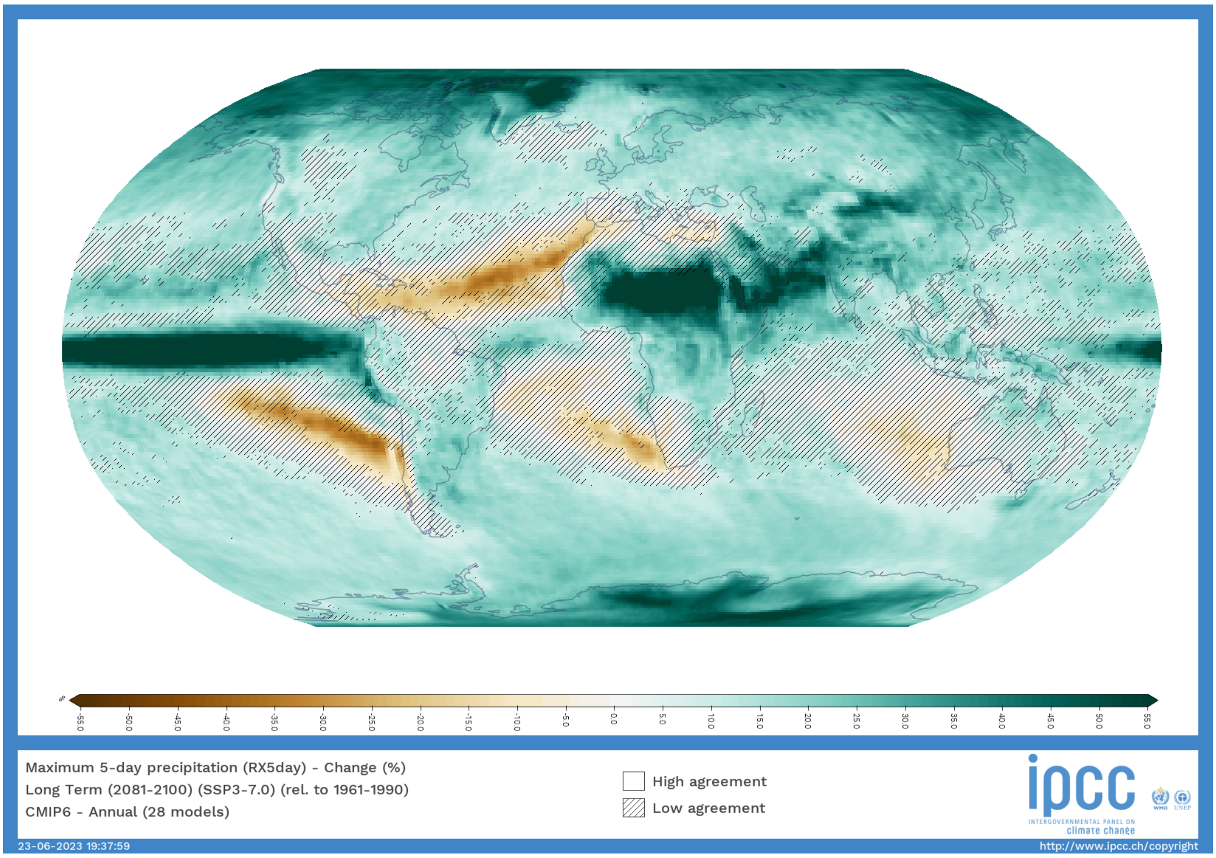


Figure 8: Increase in maximum 5-day precipitation by 2100, SSP3-7.0

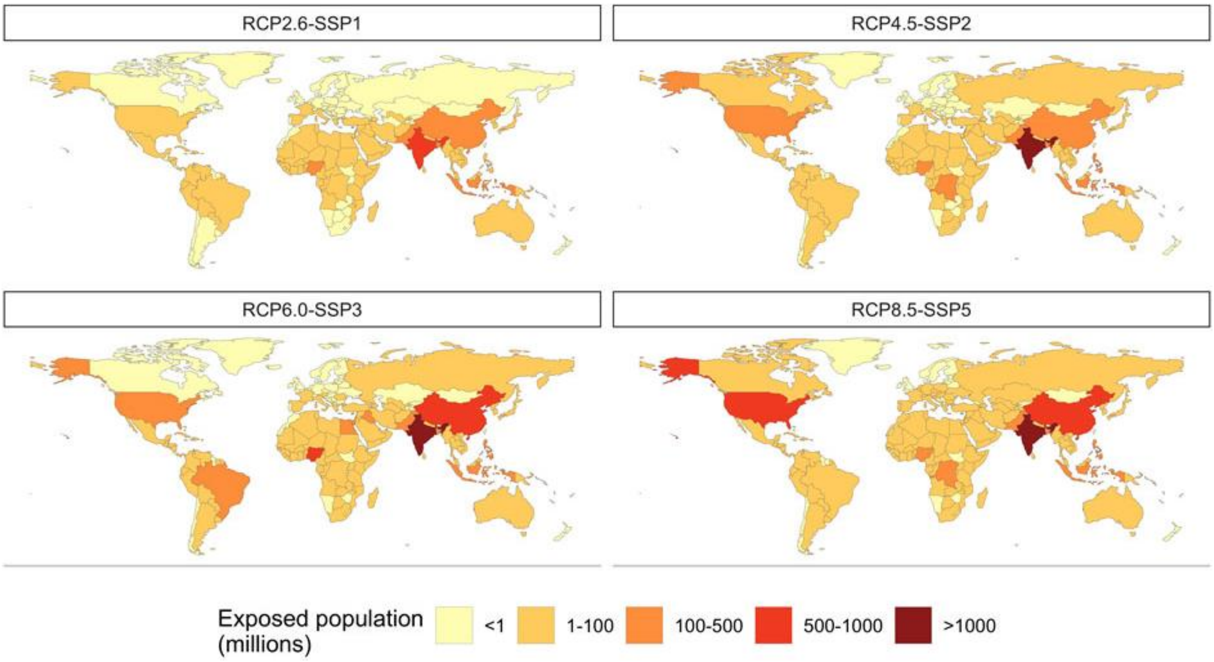


Figure 9: Exposed national urban populations to 15-day heatwaves >42°C in the period of 2070-2099 (Marcotullio et al., 2022)

3.1.3 Extreme heat

Heat waves are known to lead to thermal stress for humans, leading to increased hospitalization and death tolls especially in the elderly. On the whole earth more than one billion people are affected by extreme heat each year (Nguyen et al., 2022). The combination of extreme heat with high humidity is especially detrimental to the health as it reduces the body's capability to cool itself by sweating. Such conditions are likely to increase with ongoing climate change and make one-third of the world difficult to live in (Xu et al., 2020).

Relative Humidity \ Temperature	27°C	28°C	29°C	30°C	31°C	32°C	33°C	34°C	35°C	36°C	37°C	38°C	39°C	40°C	41°C	42°C	43°C
40%	24.5	24.7	25.1	25.5	25.9	26.4	27.0	27.6	28.2	28.9	29.7	30.5	31.3	32.2	33.2	34.2	35.2
45%	24.5	24.9	25.3	25.7	26.2	26.8	27.4	28.1	28.8	29.6	30.4	31.3	32.3	33.3	34.4	35.6	36.8
50%	24.7	25.0	25.5	26.0	26.5	27.2	27.9	28.6	29.5	30.4	31.3	32.3	33.4	34.6	35.8	37.1	38.4
55%	24.8	25.2	25.7	26.3	26.9	27.6	28.4	29.3	30.2	31.2	32.3	33.4	34.7	35.9	37.3	38.7	40.2
60%	24.9	25.4	26.0	26.6	27.4	28.2	29.0	30.0	31.1	32.2	33.4	34.7	36.0	37.4	38.9	40.5	42.2
65%	25.0	25.6	26.3	27.0	27.8	28.7	29.7	30.8	32.0	33.2	34.6	36.0	37.5	39.1	40.7	42.5	44.3
70%	25.2	25.8	26.6	27.4	28.3	29.4	30.5	31.7	33.0	34.4	35.8	37.4	39.0	40.8	42.6	44.6	46.6
75%	25.3	26.1	26.9	27.9	28.9	30.1	31.3	32.6	34.1	35.6	37.2	38.9	40.7	42.7	44.7	46.8	49.0
80%	25.5	26.4	27.3	28.4	29.5	30.8	32.2	33.7	35.2	36.9	38.7	40.6	42.6	44.6	46.8	49.1	51.5
85%	25.7	26.6	27.7	28.9	30.2	31.6	33.1	34.7	36.5	38.3	40.3	42.3	44.5	46.8	49.1	51.6	54.2
90%	25.9	27.0	28.2	29.5	30.9	32.5	34.1	35.9	38.8	39.8	41.9	44.2	46.5	49.0	51.6	54.3	57.1
95%	26.1	27.3	28.6	30.1	31.7	33.4	35.2	37.2	39.2	41.4	43.7	46.1	48.7	51.4	54.2	57.1	60.1
100%	26.3	27.6	29.1	30.7	32.5	34.4	36.4	38.5	40.7	43.1	45.6	48.2	51.0	53.9	56.9	60.0	63.2

Normal (WBGT ≤ 27.7°C)
Caution (WBGT 27.8 - 29.3°C)
Extreme Caution (WBGT 29.4 - 31.0°C)
Danger (WBGT 31.1 - 32.2°C)
Extreme Danger (WBGT > 32.2°C)

Figure 10: Wet bulb globe temperature diagram for a study in Thailand (Paengkaew et al., 2020)

Even in the more moderate SSP2-4.5 scenario, the models predict that a significant portion of the tropics and subtropics will experience mean annual temperatures above 29°C. These now include large parts of Africa between the equator and the Sahara, large coastal parts of the Red Sea and Persian Gulf, the Indus Valley, and many coastal areas on the Indian subcontinent. Temperatures are also expected to be as high over the sea around the Southeast Asian islands. In the models, the larger islands themselves appear to be below the 29°C limit. How densely populated coastal areas will be affected in this context is not directly evident from the models, so they often appear to be on the threshold of these 29°C annual mean temperatures. In addition, extensive areas of northern Australia, large areas of the Amazon basin, and parts of the Central and South American Caribbean and Pacific coasts are now also affected.

Under the SSP3-7.0 scenario, this warming trend continues. In this scenario, extreme annual mean temperatures affect almost all coastal areas of the tropics and many subtropical regions. The Indian subcontinent is now mostly in this zone and in Southeast Asia the coastal areas of the larger islands and especially the very populous island of Java are now completely in the zone with more than 29°C annual mean temperature. Likewise, the equatorial coasts of West and East Africa, which are also highly populated, and most coastal sections of the Caribbean are now affected.

Under current climatic conditions (ERA5 data for the years 1980-2015), only a few regions are affected by a mean annual temperature of 29°C or more. These are almost exclusively in Africa at the southern edge of the Sahara. A small area is also found on the Arabian Peninsula in the border region of Oman, Saudi Arabia and the United Arab Emirates, and at the mouth of the Amazon in Brazil.

The maps show a clear difference between the scenarios SSP2-4.5 and SSP3-7.0. While in the former only a narrow area in western Africa experienced an increase of more than 90 days with 40°C maximum temperature or more compared to the reference period 1961-1990, under the latter scenario this already affects large parts of the Sahara and the adjacent areas to the south, as well as first areas on the Arabian Peninsula and in the Amazon Basin.

Under the SSP3-7.0 scenario, maximum temperatures of over 40°C are expected in the dark-colored areas on more than 150 days per year. This mainly affects the southern Saharan regions and the Sahel as well as the Arabian Peninsula and the Thar Desert in the Pakistan-India border region. In addition, a first area in northwestern Australia must expect these conditions in this scenario.

With the exception of the Persian Gulf, these extreme temperatures are not to be expected directly on the coast, but somewhat further inland.

3.1.4 Desertification

The World Atlas of Desertification (WAD) provides a world map showing the risk of land degradation. The WAD estimates include both climatic factors such as temperature and precipitation development, as well as anthropogenic developments such as population growth or the intensity and type of land use. The color gradations result from the accumulation of various of these factors.

Only areas that are not already deserts today are shown in color. Regions with ten or more indicators of land degradation are considered most at risk. An example of such a map can be seen in figure 11 .

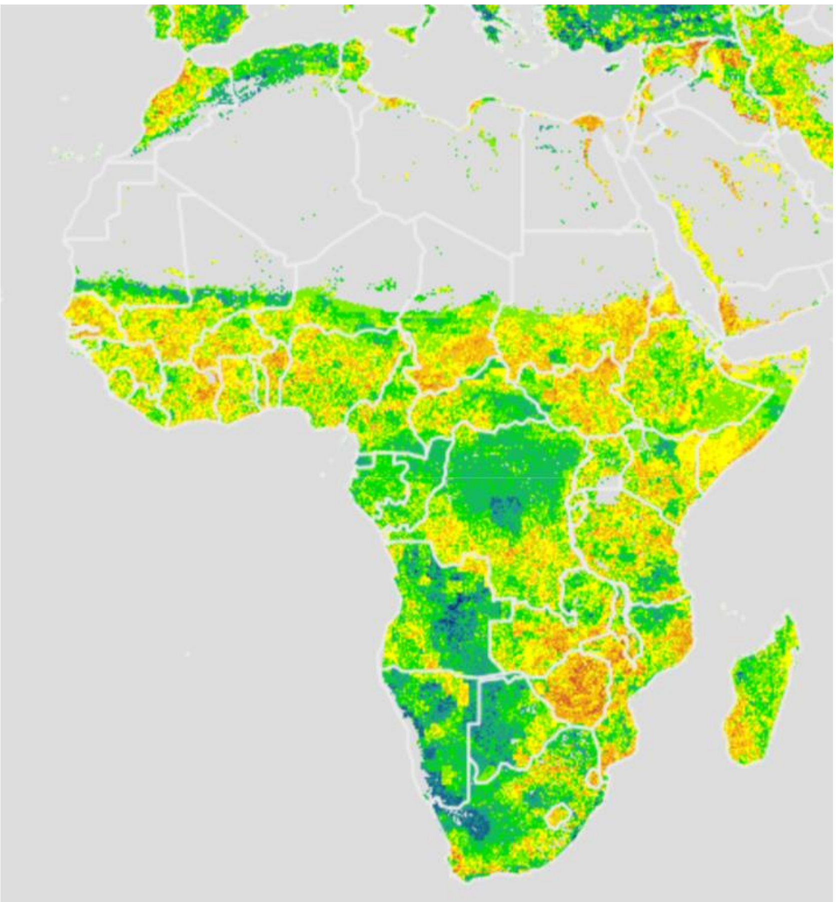
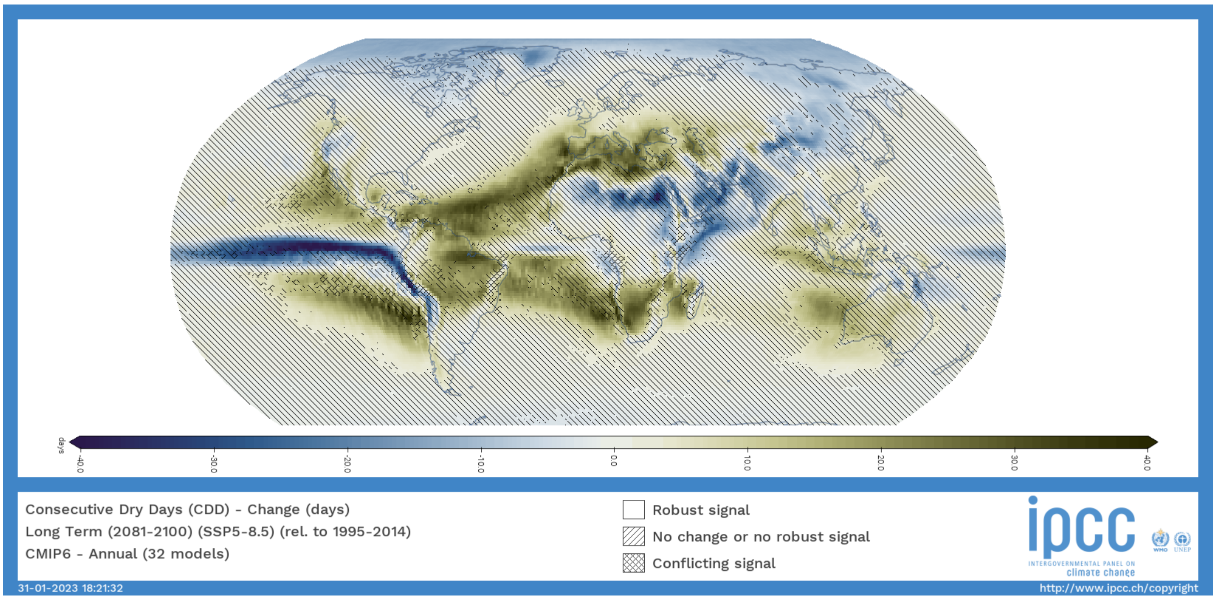


Figure 11: Africa as seen in the World Atlas of Desertification. Blue and Colors stand for few factors enhancing soil degradation, yellow and red mean high risk of degradation

Unlike the other selected metrics, the AoD maps are not forecasts for a selected time period or a specific development scenario. Rather, they depict current trends and show particularly vulnerable areas without predicting exact development.

The World Atlas of Desertification is not designed to show a shift in climatic zones caused by changes in rainfall or rainfall distribution and evapotranspiration, although these developments are also included in the atlas. Rather, it aims to show where current climatic as well as anthropogenic trends are present that can degrade soils, reducing their ability to be productive to the same extent as before. The presence of such factors does not necessarily lead to actual degradation, but the greater the number of negative trends found in an area, the greater the risk that degradation of soil properties will occur. This is referred to in WoD as Convergence of Evidence.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Consecutive Dry Days (CDD) - Change (days)
Long Term (2081-2100) (SSP5-8.5) (rel. to 1995-2014)
CMIP6 - Annual (32 models)
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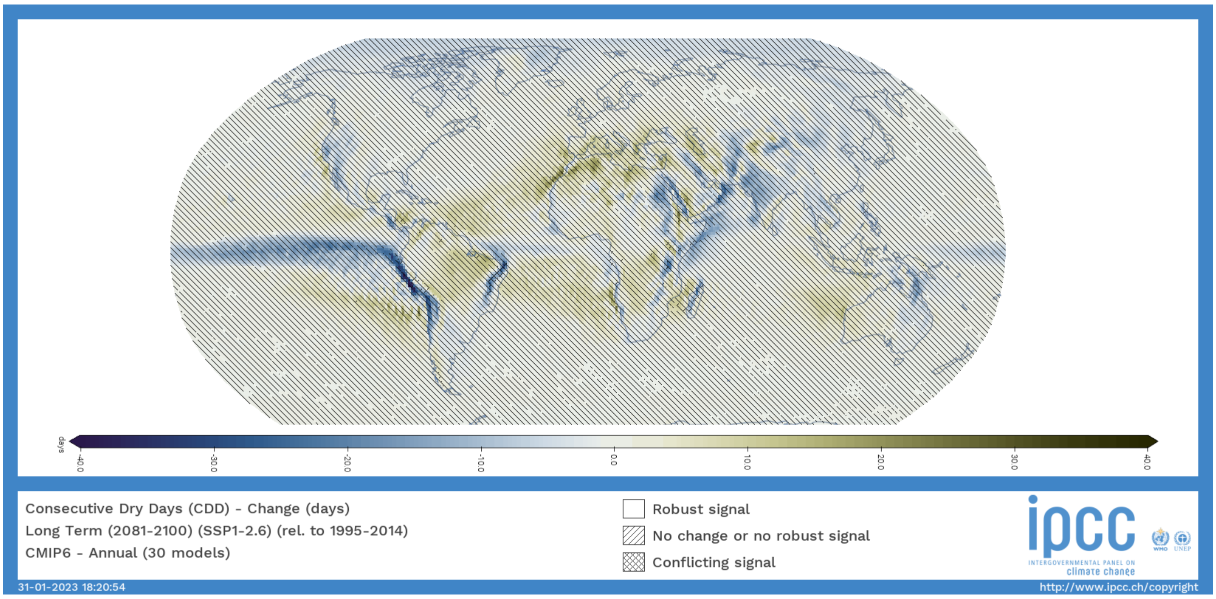
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Long Term (2081-2100) (SSP1-2.6) (rel. to 1995-2014)
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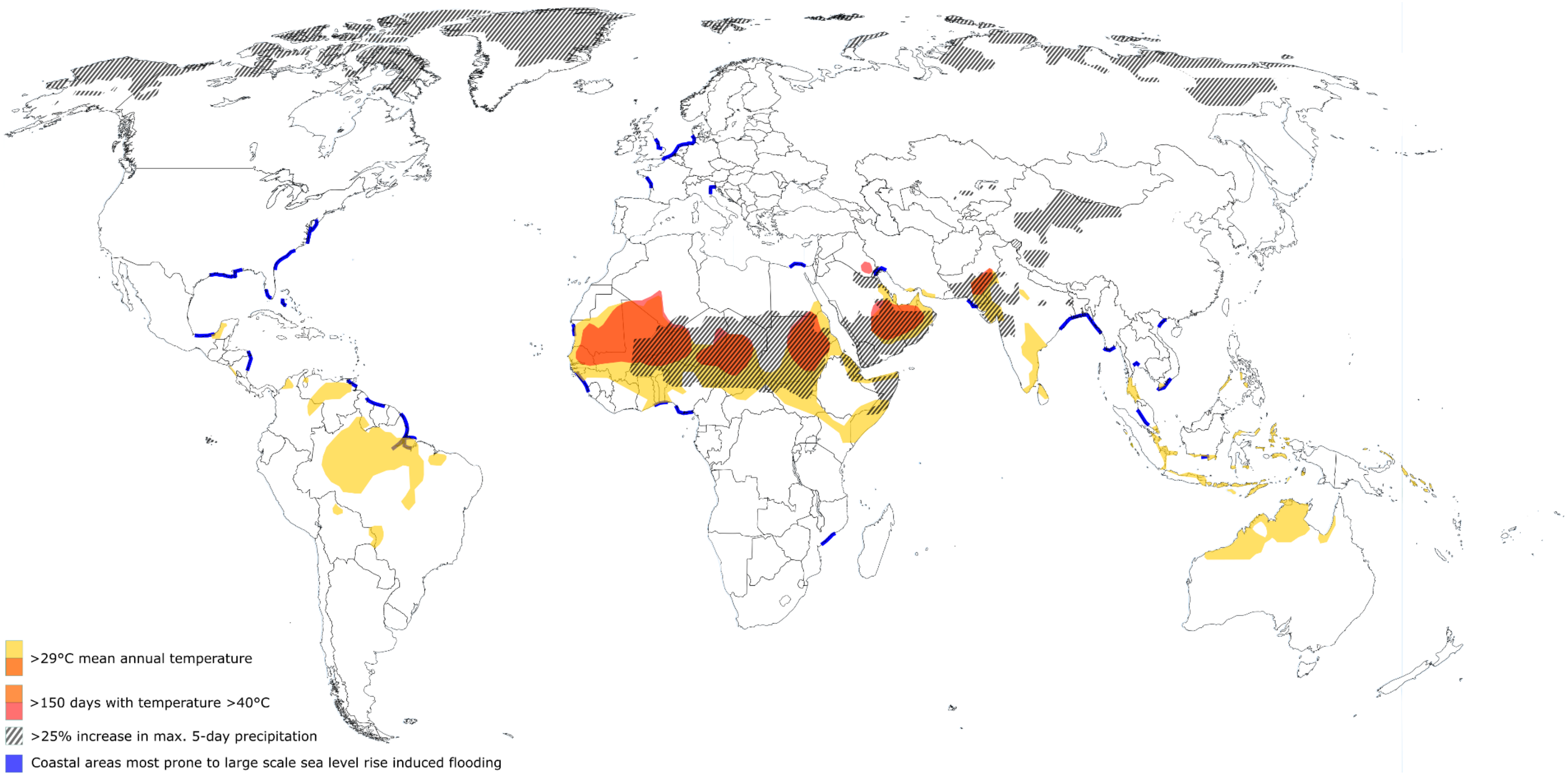
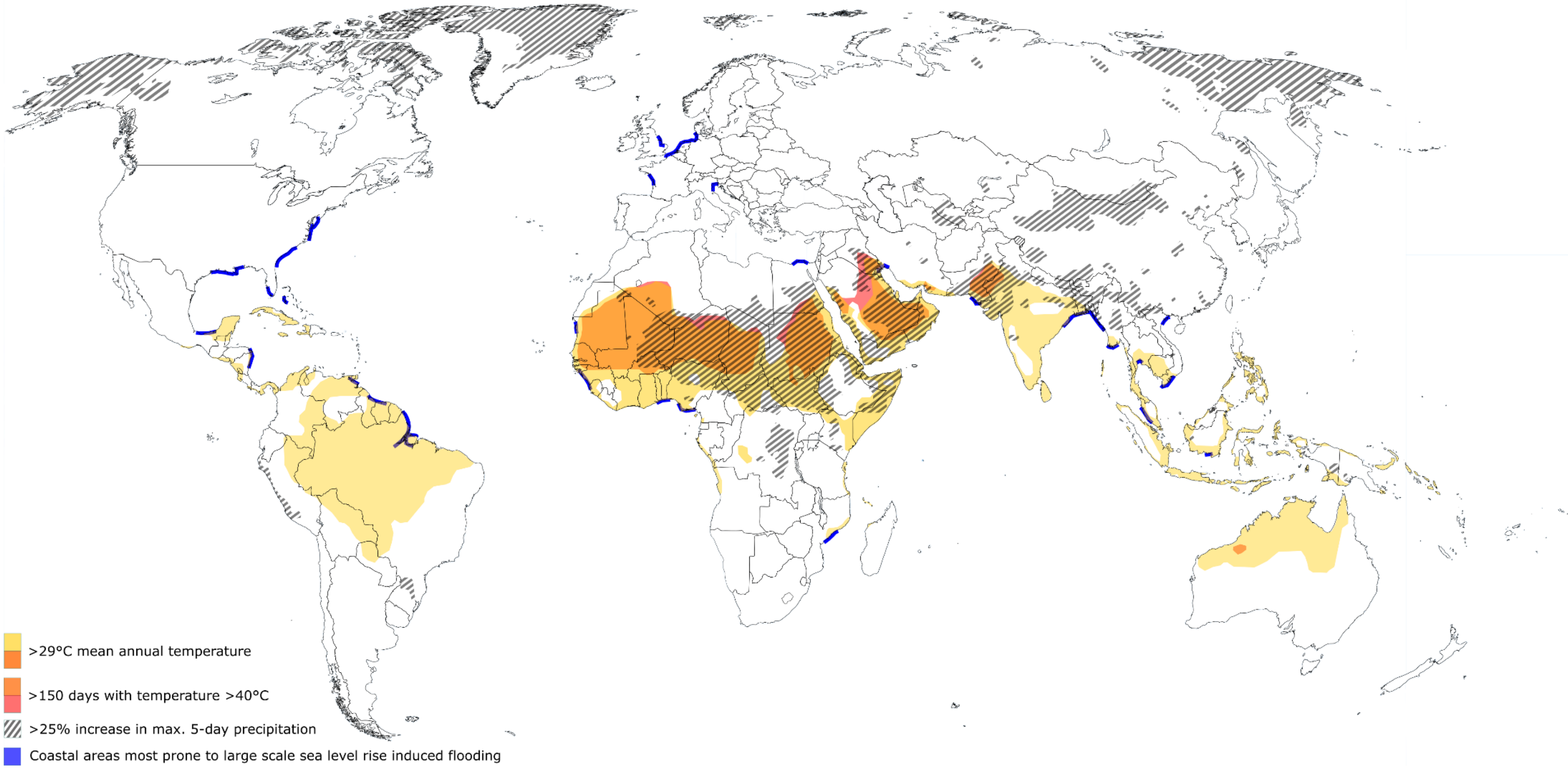
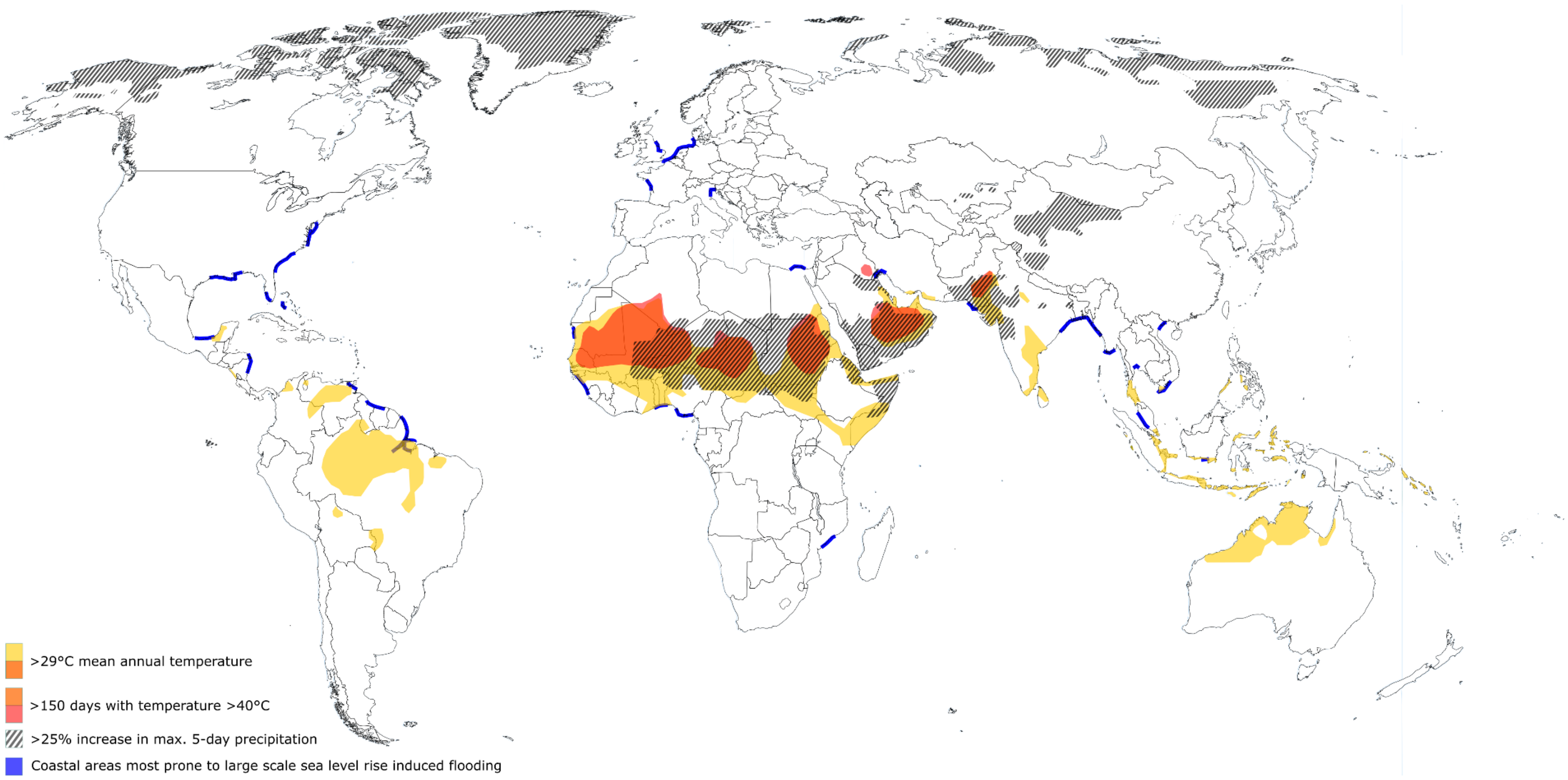
Areas at high risk under scenario 2-4.5 in 2100



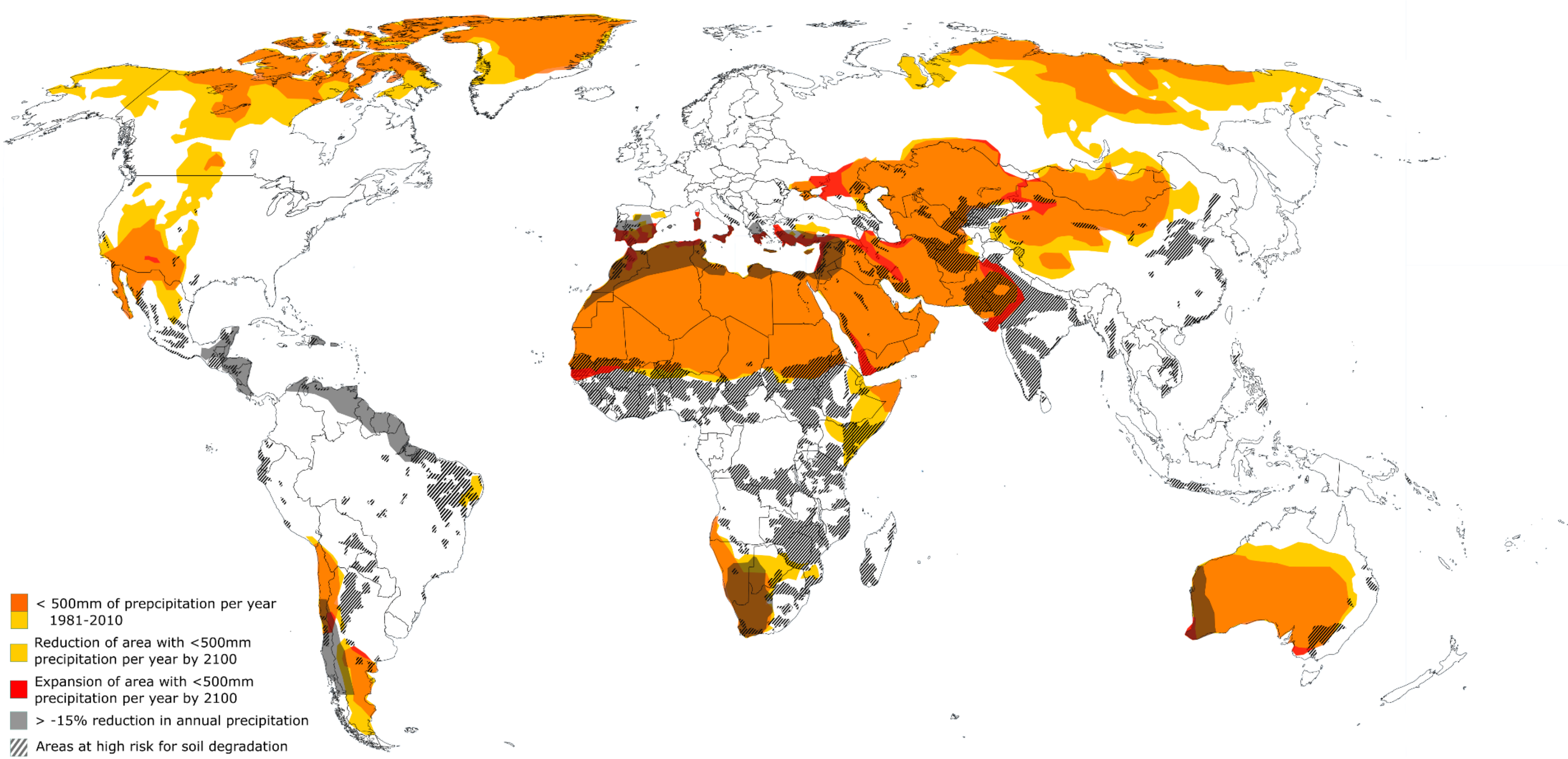
Areas at high risk under scenario SSP 3-7.0 in 2100



Desertification risk under scenario SSP2-4.5 in 2100



Desertification risk under scenario SSP3-7.0 in 2100



4 Learning from the past

4.1 Challenges for managed retreat projects

4.1.1 Legal and regulatory implications

Currently, most countries lack functional financial models to deal with managed retreat. The most obvious weaknesses are that funds are not set aside to address the expected impacts of climate change, that the focus of financial assistance is too often on resettlement after environmental disasters rather than preventive retreat, and that funds are generally inconsistently and unsystematically disbursed (Boston and Lawrence, 2018). Often, structural measures that are effective in the short term, such as dikes and levees, are also prioritized in the allocation of financial resources, rather than focusing on long-term minimization of risk exposure. This can create a sense of false security among residents, the so-called "levee effect" (Tobin, 1995), which allows ongoing development to proceed, thereby steadily increasing residual risk. It also increases public demand for protection through such construcitons in other locations, even where their technical feasibility, cost-effectiveness, and long-term benefits are questionable (Lawrence et al., 2020). Retreat as risk management has also been very unpopular because the main goal has been to prevent transformation and change and to allow people to continue living as they do now, as much as possible. However, if the climate is no longer within the bounds of past experiences, a profound transformation of time-honored systems will likely become inevitable in some places (Dupuy et al., 2020; Storlazzi et al., 2018; Hauer et al., 2020; Lincke and Hinkel, 2018).

Lack of coordination among different government agencies has led to situations in the U.S. in the past where infrastructure projects were planned or implemented even though the affected neighborhoods were to be relocated (Siders, 2019). Raising the necessary funds for managed retreat is also hindered by the fact that the costs involved are very high, the timeframes extend well beyond the legislative terms of decision makers, and cross-level policy coordination is complex (Lawrence et al., 2020). There is furthermore the possibility of people relocating because of natural hazards to other, equally vulnerable areas. If this decision is made solely by those affected, or by the property market, and a strategy is lacking, i.e., the retreat is unmanaged (Loughran and Elliott, 2019). Long-term, socioeconomic challenges and issues arising from retreat are often not adequately addressed. Instead, the responsibility for solving them is assigned to the community, or the individual affected, potentially exacerbating the problem (Tubridy and Lennon, 2021).

Currently, UK climate policy places responsibility on individual citizens, portraying them as adaptive subjects capable of tactically responding to man-made changes in the world and leaving them to provide for their own safety by moving (Felli and Castree (2021).

Bronen (2011) and Ferris (2012) found that currently no framework does exist anywhere in the world to assess the impacts of climate change and determine at what point residents of certain areas can no longer be protected locally. This lack of a legal and administrative framework impairs the ability of local, regional, and state authorities to respond appropriately to climate change (Bronen, 2015). Bronen (2015) notes that no institutional mechanisms exist with respect to preventive withdrawal; neither to determine when it should occur, nor who should make that decision or how that decision should come about.

International law states that governments of nations must protect citizens within their national borders from the effects of climate change (ICISS 2001). This responsibility is derived from the concept of sovereignty, which implies that the protection of the population is the responsibility of governments (ICISS, 2001). Following this line of reasoning, the European Court of Human Rights. The court ruled that the authorities had failed to take risk-minimizing spatial planning measures and to develop emergency evacuation protocols in advance and were therefore co-responsible for the deaths of these eight people (Kälin, 2011). This responsibility to protect the population could also lead governments to forcibly relocate citizens from at-risk areas as part of precautionary relocations (Ferris, 2012). Such relocations have been implemented in the past primarily in the context of infrastructure projects - particularly dams - which displaced an estimated 280 to 300 million people between 1990 and 2010 (Ferris, 2012). However, officially mandated forced relocations have almost invariably had devastating consequences for those affected (Bronen, 2015).

While agencies in the U.S. have a variety of options for protecting their citizens, including managed retreat of smaller areas, their scope for moving entire communities is very limited, severely compromising the ability to respond dynamically and effectively to climate change (Bronen, 2015). Past practice has been to protect existing structures along coasts and rivers using engineering methods such as sea walls (Lewis, 2012). However, these measures are problematic because they are not only expensive and time-consuming to maintain, but also lead to more erosion in adjacent sections of shoreline and encourage development in vulnerable areas (Grannis, 2011; Lewis, 2012). The common approach in the aftermath of environmental disasters has been to restore pre-event conditions where possible, and to rebuild buildings and infrastructure in place, and restore livelihoods (Bronen, 2011). Research by Raleigh and Jordan (2010) found that peoples need to remain in place is very strong even in the aftermath of an event, and only 30% of those affected subsequently move away and of those over 90% do return later, leaving less than 3% actually leaving the area. Dauphin Island in the US state of Alabama was hit by hurricanes ten times between 1975 and 2015, destroying homes and infrastructure. During this time, the population received $80 million in federal reconstruction assistance (Which equates to more than $60,000 per resident) and $72 million from federal flood insurance payments (Siders, 2013). Residents paid approximately $9.3 million for insurance premiums (Siders, 2013).

Managed retreat can take the form of buyouts or setbacks, among other forms. In the latter, a boundary is drawn beyond which building is prohibited (Grannis, 2011). In acquisition programs, landowners who decide to leave their endangered property are compensated for doing so by the government with public funds (Lewis, 2012). Thus, such programs usually take place at the level of individual households and depend on the decisions of individuals. The U.S. Federal Emergency Management Agency (FEMA) is reluctant to apply this measure to entire communities, although a few have gone this route (Bronen and Chapin, 2013).

The ability of governments to proactively implement managed retreat depends heavily on stakeholders being aware of the danger they and their properties are in (Bronen, 2015). Government decisions that affect property rights also have legal implications. For example, landowners can assert their rights to be protected in situ and fight land use restrictions and construction bans (Siders, 2013). Such legal standards can cause delays in the resettlement process (Bronen, 2015). Current laws are not designed to address climate-induced changes in the environment, which were established with an eye toward responding to extreme weather events, flooding, and erosion (Bronen, 2015). Restricting land use and buying up properties may be sufficient on some coastlines, but these tools will not be enough to adequately respond to the complexities caused by masses of displaced people needing new homes, infrastructure, and livelihoods in new places (Bronen, 2015). Decision makers in the future will need to weigh many factors, such as the degree of risk to people and property, the cost of protection infrastructure, the value of properties and infrastructure at risk, long-term maintenance costs, and the physical condition of the land, when deciding whether to protect or resettle people in place (Grannis, 2011).

Bronen (2015) studied the situation of villages in Alaska that have requested help to relocate their settlements due to thawing permafrost, coastal erosion due to dwindling sea ice, and extreme weather events. Although all of these requests were known to the U.S. Government Accountability Office by 2009, not a single resettlement had occurred as of 2015 (Bronen, 2015). The local and tribal governments of the Kivalina, Shishmarev, and Newtok communities on the west coast of Alaska, for example, found, based on observations of environmental change over several decades, that only relocation of the communities could ensure their safety in the long term. Instead, $15.5 million were invested by the U.S. national government in Kivalina between 2006 and 2009 to build seawalls that are expected to last 10-15 years (Bronen and Chapin, 2013).

For governments, one-time payments to buy out properties at risk are far less expensive than building and maintaining protective structures that may become obsolete as flooding becomes more intense and sea levels continue to rise. The levee effect also causes more people to settle in the supposedly safe area protected by these measures, increasing the risk to life and property. Thus, hard defenses increase the potential for damage and increase the cost of flooding. Apart from this, such structures can also cause significant ecological damage and divert water to adjacent areas (Tobin, 1995). Although managed retreat brings financial savings and long-term opportunities, many decision makers rate abandoning land and removing it from the market as riskier than remaining in place, which is more uncertain and short-term (Jacob, 2015; Polefka, 2013).

4.1.2 Financial implications

Different states have developed very different approaches to the financial challenges of retreat. In the United Kingdom, compensation has typically not been paid for property lost or devalued due to unprotected shorelines (Esteves, 2014; Blunkell, 2017; Storey, 2019). In contrast, managed retreat in the United States typically occurs as part of property buyout programs, in which responsible agencies purchase and relocate or demolish properties at risk (Bronen, 2015). Such programs have so far usually been launched in the aftermath of a flood event, but the property prices paid have been based on the pre-event market price (Koslov, 2016). Such financial compensation has repeatedly attracted criticism as it has been perceived as a redistribution of resources from the general public to private coastal residents who have chosen this exposed residential location themselves (Cooper and McKenna, 2008, p.299). On the other hand, De Vries and Fraser (2017) argue that disadvantaged and low-income communities in particular are less free than others to choose where to live, and to some degree more exposed to natural hazards. Thus, depending on the context, exposure to natural hazards can result from both historical processes such as segregation and discrimination and personal housing preferences (Smith, 2005). Market-rate property buyouts inevitably result in the largest financial sums flowing to those who own the most expensive properties (Marino, 2018). Canada is therefore testing an adjusted buyout program in which the compensation paid cannot exceed a set maximum amount (Flavelle, 2019).

Few countries today have the legal, planning, and financial frameworks in place to implement the kind of efficient retreat programs that projected climate change will require (Lawrence et al., 2020). Some, such as the Netherlands, Singapore, New Zealand, and the United Kingdom, have worked in recent years on improved risk management strategies, new legal frameworks, optimized spatial planning regulations, and insurance settings. But only a few countries, such as the Netherlands, have already built national, systematic and targeted policy frameworks that define how to deal with the costs of adaptation to climate change (Lawrence et al., 2020).

There is enormous variation among different countries on whether - and if so, to what extent - resettlement beneficiaries should be compensated. Approaches range from paying the full market price of the property, to providing an equivalent house or apartment in a protected location, to little or no financial assistance, such as in the United Kingdom (Climate Change Committee, 2018). In the United States, where extensive and established compensation programs are in place, the prevailing view is that citizens who will suffer an inevitable loss should be helped by the public sector so that they can continue their lives in adequate housing circumstances (Lawrence et al, 2020). However, where financial assistance is provided, it is often co-funded by various national and sub-national agencies, increasing the administrative complexity of retreat programs. This can lead to delays in the process and also to inequities between different parts of the country, as different sub-national government agencies often have different financial resources (Freudenberg et al., 2016). Local governments are often reluctant to dispense financial aid because their funds are often limited anyway. As residents move away, their tax revenues decrease, this raises thorny political debates about who should pay for whom, and they do not want to set a precedent that forces them to pay more and more aid as the negative impacts of climate change increase (Lawrence et al., 2020).

4.1.3 Ethical /Social implications

Regardless of financial compensation, relocation can have diverse negative impacts on the lives of those affected. These include loss of relationships with friends and loved ones, difficulties finding adequate alternative housing, and strains on physical and mental health (Lynn, 2017; Dannenberg et al., 2019). Particularly in the global south, resettlement has repeatedly resulted in loss of livelihoods when, for example, unofficially constructed neighborhoods have been demolished or affected populations loose access to coastal resources they were depending on (Greiving et al., 2018; Ajibade, 2019; Scott and Lennon, 2020). Psychological impacts can include grief over the loss of a home, nostalgia, disorientation, and a sense of foreignness in the new place of residence (Agyeman et al., 2009), phenomena that have been documented to be more prevalent among minority and low-income populations (De Vries and Frasier, 2012, Siders, 2019b), and particularly impact indigenous communities whose culture may be extremely strongly associated with particular places (Maldonado, 2014).

Different populations exert varying degrees of influence on the decision to and implementation of managed retreat. For example, there are examples of forced conversions, such as to create "buffer zones" after the 2004 Indian Ocean tsunami or in the dissolution of informal settlements (Ajibade, 2019; Scott and Lennon, 2020). Such measures are often carried out undemocratically without involving the affected population and are sometimes used to implement previously planned large-scale development projects (Paprocki, 2019). Forms of pressure on the population can also be observed in the global north. These can be harsh measures, such as a compulsory sale, but also more subtle measures, such as a flood insurance requirement (Paprocki et al., 2019) or structural measures to protect properties from flooding that must be met (Gibbs, 2016). Such requirements are often difficult to implement for low-income strata and are therefore very likely to lead to above-average relocation of these same populations (Tubridy et al., 2021). Although the UK provides for a certain degree of consultation with the resident population, stakeholder participation in coastal management has generally been limited to institutional actors, while those directly affected have not been involved. (Mcglashan and Williams, 2003).

Blunkell (2017) finds that in the UK those with more money, time, and political savvy were able to attract the attention of decision makers and avert proposed retreat projects much more than more resource-poor communities. Similarly, in New Zealand, it has been documented that the community consultation processes used sometimes favored financially strong homeowners rather than ensuring the fairness of the planning process (Hayward, 2008). In the opposite case of communities seeking government assistance for a managed retreat, Koslov (2019) finds for the U.S. that relatively wealthy, white, and politically influential neighborhoods in New York have relatively easy access to the desired buyout program. Contrast this with the case of indigenous communities in Alaska, where complex administrative hurdles prevented access to resettlement assistance (Shearer, 2012).

Seemingly objective approaches such as cost-benefit analysis have also proven problematic in determining where managed retreat programs should be implemented (De Vries and Fraser, 2017; Lynn, 2017; Siders, 2019b). In particular, it is emphasized that programs based on cost-benefit analysis are disproportionately applied in low-income neighborhoods because the lower land prices allow for greater risk reduction for a given amount of money. In countries such as the U.S., where income, and housing location is often linked to ethnicity, this has historically led primarily to buyouts in majority black neighborhoods.

Cost-benefit analyses are also usually limited to easily quantifiable, financial impacts and cannot account for other factors such as mental stress that, for example, fishing families suffer when they move inland and have to give up their way of life (Maldonado, 2014). This can lead to inadequate resettlement services that cannot address people's social needs (Siders, 2019b). These problems are referred to in the literature as the "incommensurability" of market and non-market values. This expresses that social and environmental values cannot be reduced to a monetary price and their weights should be determined by other, more democratic methods (Martinez-Alier et al., 1998).

Another weakness in the interaction between decision-makers and the population is the so-called climate gap. This term refers to the oftentimes deep chasm that exists between affected communities and experts when it comes to determine how big certain risks are, where the greatest vulnerabilities exist, and in which areas adjustments should be prioritized (Gaillard, 2012). Gaillard (2012) cites an example from Kiribati, where international experts focused exclusively on the direct physical and biological impacts of climate change, bypassed local democratic governance structures, and presented proposed solutions that disregarded as more urgently perceived local problems, such as health and education, and diverted resources and attention away from them. In the case of sea level rise, experts often place a much higher value on understanding the physical, economic, and ecological impacts of flooding than those on the daily lives of coastal residents (Hardy et al., 2017). This reduces the complex, socio-ecological phenomenon of rising sea levels to a technical problem. According to Hardy et al. (2017), the climate gap results from underrepresentation of underprivileged, marginalized, and vulnerable populations, both in the global scientific community and government circles as well as locally in public meetings. Marginalized communities are often vulnerable to climate hazards themselves as well as to inappropriate adaptation strategies (Tubridy et al., 2021).

Planning and managing resettlement is also important because unmanaged retreat has lead to climate gentrification in the past. In these cases, increasing demand for housing protected from natural hazards raised prices in such locations and displaced the resident population (Kaswan, 2019).

Cases have also been documented where land vacated through managed retreat was being repurposed for profit-oriented projects (Koslov, 2016, Ajibde, 2019).

Compensation for the loss suffered is seen as an important requirement for managed retreat projects (Few et al., 2007a), but it has also been noted that financial losses are often not the most drastic impact of such programs (Binder et al., 2019).

Protective structures such as levees can fundamentally alter the basic appearance of a neighborhood or impede access to public spaces and cause residents to perceive their home differently. Such impacts, however, receive little consideration in the planning process of protective structures, while they are addressed more thoroughly in retreat (Clarke et al., 2018). Similarly, perservation in a place that is increasingly degrading can be emotionally stressful (Albrecht, 2020).

The Isle de Jean Charles Band in the Mississippi Delta, belonging to the Biloxi-Chitimacha-Choctaw tribe has largely disappeared in recent decades due to erosion of its shores, and its inhabitants have been referred to in the media as the first climate refugees of the United States (Davenport and Robertson, 2016). In the process, however, questions of equity, justice, and rights have been raised (Bennet et al., 2019; See and Wilmsen, 2020), as rising sea levels are only one reason for the island's shrinking. The other is oil and gas development offshore, which significantly accelerated the rate of erosion because the Army Corps of Engineers did not consider it cost-effective to protect the island from it with a levee (King, 2017; Palinkas, 2020).

4.1.4 Ecological implications

According to the United Nations Environment Programme (UNEP, 2016), positive co-benefits for the natural environment occur in the context of managed retreat, such as an increase in biodiversity, improved ecosystem services such as increases in water quality, and benefits to tourism and local recreation through the creation or restoration of natural or semi-natural spaces.

Managed retreat was originally understood primarily in an ecological context and applied in agricultural areas along coasts. For example, coastal defenses were deconstructed and agricultural land was abandoned to give more space to the sea and allow beach line movements rather than prevent them. The motivation behind this has mostly been to create new wetlands and salt marshes either as restoration of previously drained habitats or as mitigation areas for development projects elsewhere along the coast (Milligan et al., 2009). However, these habitats can also serve a protective function by absorbing incoming water during floods or by providing a "buffer" between the coast and populated areas.

4.2 Possible solutions to adverse impacts

Although the challenges and the social implications of managed retreat are enormous, the literature suggests concepts and presents examples which could minimize harmful impacts or even result in overall benefits for the affected.

Blunkell (2017) notes that communities themselves should have control over important decisions about whether to retreat or be protected in situ. According to De Vries and Fraser (2012), buyouts should always be completely voluntary and worked out in a dialogue between authorities and the population - marginalized groups included. Maldonado (2014) suggests that resettlements should be financed and supported by the state, but the implementation should be organized by the affected population. Examples of such retreats with initiation or large participation by local people have been documented in New York in the aftermath of Hurricane Sandy, where people made a high-profile case for resettlement (Koslov, 2016; 2019), as well as in the Philippine capital of Manila, where intensive discourse with residents led to resettlement that addressed both social and environmental considerations (Ajibade, 2019), and in Alaska, where the community of the village of Shishmaref democratically voted to resettle (Agyeman, 2009).

Core to managed retreat projects are adequate new housing and employment (Lynn, 2017), Ajibade (2019) and the co-creation of the entire resettlement process by those affected (Maldonado, 2014). Managed retreat therefore involves not only escaping imminent danger, but also (re)building and developing social and economic structures (Love, 2019).

It is also important to increase knowledge and understanding of natural hazards and the potential impacts of climate change among populations so that they are able to make informed decisions about their future in a particular location (Tubridy et al., 2021). In addition, frameworks and mechanisms need to be developed to help governments and institutions identify where and when biophysical as well as social risks become so great that resettlement should be undertaken (Bronen, 2015; Greiving et al., 2018).

Armitage et al., (2011) as well as Tubridy et al, (2021) call for a coproduction approach to managed retreat by which they mean the inclusion of all the different stakeholders to increase the sources and types of knowledge and thereby facilitate a more informed planning, decision making and implementation of the retreat program. Armitage (2011, p. 966) calls it a "collaborative process of bringing a plurality of knowledge sources and types together" to address complex challenges that cannot be overcome by either science or local knowledge alone. This requires meaningful participation in the decision making process, particularly by low-income or marginalized communities. Examples for such a process are the Baan Mankong (Secure Housing) project in Thailand was actually created as a program to resettle illegally built neighborhoods, but in some cases also helps with managed retreat Greiving et al., 2018) and has been able to improve the housing situation of 104,000 households (although it was not shown how many of these are managed retreat) (Boonyabancha and Kerr, 2018). In this process, the authorities provide financial resources and technical assistance to the communities, while planning, implementation, and control over finances are primarily the responsibility of the local community (Boonyabancha and Kerr, 2018). The community is supported by members of academia, technical experts and NGOs, without having to relinquish their leading role. This project can also serve as an example of how existing spatial development programs can both address managed retreat concerns and engage diverse stakeholders.

Another example is the Oplan-LIKAS program in Manila, which involved the relocation of up to 120,000 households from flood-prone areas from 2011 to 2016. According to Galuszka (2019), in this case, the population won a far-reaching say from the local government and won the right to independently plan the nature and form of their new communities and negotiate implementation. What has been negatively striking in this context however is the entrenched bureaucratic and political machinery that was not attuned to a coproduction approach (Galuszka, 2019).

Basic prerequisites for coproducion are the inclusion of the concerns of the affected communities, both those who are moving, those where the move is taking place, and the broader population (Tubridy et al., 2021). According to Siders (2019), a strategy by authorities that minimizes conflicts with environmental and social goals and discourages, for example, climate gentrification or relocation to other vulnerable locations is important in this regard.

Olufson (2019) compiled the various elements and located them chronologically in the process of managed retreat, providing a planning overview from the beginning to the end of the process. Community engagement begins at the very beginning of the process and should continue until the end. Agencies that engage in intensive collaboration with the community through meetings, workshops, and dissemination forums enable collaborative development of adaptation strategies and can better advocate for the need for and benefits of managed retreat to be understood and accepted by the community. Planning and preparation involve identifying and weighing different adaptation strategies and how best to implement them. This will require establishing thresholds that, when reached, will trigger implementation of the strategies developed and monitoring programs to track these thresholds. In addition, rezoning and building restrictions must be implemented quickly in the affected area. Enabling investments to be made in the event of an emergency includes buying up properties, and/or compensation programs, developing alternative settlement areas, investing in new infrastructure while reducing spending on infrastructure in the risk area. Active retreat includes relocation, demolition, or abandonment of private and public buildings, and relocation of needed infrastructure, such as water, electricity, and transportation systems. This step is dependent on the previous three elements of the process having established the mandate and supporting framework for the managed retreat to occur efficiently. This is followed by cleanup and repurposing of the vacated space. This includes demolition of the remaining buildings and infrastructure, remediation of the land, e.g., by disposing of contaminated soils in a landfill or reforesting with appropriate vegetation, and enhancement and maintenance of the new public land for community use.

In order to ensure efficient adaptation to climate change, an equitable burden sharing and a minimization of costs in the long term must be pursued. This would require efforts to reduce investments in short-term measures, such as filling beaches or building dams, in favor of long-term ones, such as managed retreat, and to avoid shifting the costs to other actors. (Lawrence et al., 2020). One way to distribute costs more equitably could be to prefund them, as some states have done in retirement planning. In this way, the burden could be gradually spread over several generations

(Kunreuther and Pauly, 2018; Siders, 2019). In many countries, taxpayers will have to bear the cost of managed retreat. However, not all countries have the financial resources necessary to compensate private individuals for their losses suffered in managed retreat programs. For example, some of the world's poorest countries in Africa and Asia are particularly vulnerable to sea-level rise because they have large, extremely shallow river deltas (Boston and Lawrence, 2018).

To date, managed retreat has mostly been considered a last resort and interpreted as a failure, hindering the implementation of this strategy in places where resettlement will be inevitable. However, when managed retreat is integrated into a country's long-term development goals and implemented in an evidence-based, context-specific manner, it can contribute to the achievement of larger societal goals such as sustainability, resilience, equity, and community revitalization (Siders et al., 2019).

Using public resources to fund private losses is a controversial topic, but there are some good reasons to do so: The construction and maintenance of physical protection measures is also paid for by the public purse. If the same is not true for other adaptations to climate change, this will lead to an increasing call for more protective structures among the population, even if they are not cost-effective. As a result, there will be additional costs in the end. The actual implementation of managed retreat will, at least in some cases, also require the compulsory purchase of land. In such cases, governments are usually required to compensate owners. In addition, private insurance is often unavailable or prohibitively expensive for those affected. Without compensation, some communities would suffer large losses that are likely to disproportionately affect the poorest residents, with negative social and economic impacts on society. Therefore, there is a need to establish frameworks for funding managed retreat that are broad-based and meet transparent criteria (Lawrence et al. 2020).

Most upheavals triggered by climate change will consist of different measures that are combined with each other. Thus, in many cases, managed retreat will not be applied in isolation, but together with protective structures and other measures (Mach and Siders, 2021). Mach and Siders (2021) present a range of possible forms that retreat could take in the future. For example, in some places it could be small-scale, such as clearing individual, selected parcels to create retention ponds. In some cases, individual outer neighborhoods, or the core of the settlement, could be relocated while the settlement as such remains in place. In other cases, however, retreat might necessitate the abandonment of entire towns, or the conversion of their road networks into canals and waterways, and the conversion of conventional agricultural land to aquaculture (Mach and Siders (2021).

How retreat is implemented depends on the particular natural hazard being escaped, its return period, how it varies in time and space, its intensity, and what other adaptation options are available (Dupuy et al., 2020; Mach et al., 2019; Kitzberger et al., 2017). To date, most retreat programs have lacked a holistic plan to integrate protection from risk into larger development strategies (Greiving et al., 2018; Mach et al., 2019). It has mainly been aimed at reducing risks and economic losses or, in the case of ecologically motivated retreat, at creating new habitats, often in isolation from higher goals such as strengthening the cultural or community unity of society, improving livelihoods, or housing security (Ajibade, 2019). However, it is the integration into more extensive strategies and the involvement of more stakeholders at the local, regional, and national levels that must find their way into managed retreat strategies in the future in order for them to be implemented successfully and with added value for society (Greiving et al., 2018, Siders, 2019).

In terms of future managed retreat, it is also important to keep social justice in mind. Managed retreat is always a very political endeavor, and without an awareness of past and existing social factors, there is a risk that past injustices will be exacerbated by the process (McNamara et al., 2018; Oppenheimer et al. 2019; Ajibade, 2019). For example, marginalized groups, such as indigenous communities, have been forcibly relocated and inadequately served by governments for decades. A strategic managed retreat of such communities threatened by climate change, which they plan and lead in a self-determined manner with the support of authorities and experts, could be a step toward recognizing historical wrongs and making amends (Mach and Siders, 2021).

For reforms that make approaches like retreat more feasible and easier to implement to gain traction, it would be helpful if managed retreat were understood not as a regrettable fate to be avoided, but as a desirable opportunity for adaptation (Siders, 2019; Lawrence et al., 2020). However, how such a shift in thinking would be achieved in society and among decision makers is an open question (Mach and Siders, 2021).

Establishing the need for managed retreat in the future requires the incorporation of climate science that addresses complex risks; studies of dynamic socioeconomic development and migration; techno-economic assessment of structural-engineering solutions; and analysis of sociocultural, psychological, political, institutional, and financial factors central to the feasibility of protecting societies on the ground in the face of increasing climate risks (Hauer et al., 2020; Clarke et al., 2018 set almost 1:1 from Mach and Siders, still to be rephrased).

Retreat always simultaneously creates both opportunities and losses. It is therefore important to approach managed retreat in a way that maximizes the opportunities created and minimizes the losses (McNamara et al., 2018). It is also important to recognize that some losses cannot be compensated for and that addressing them is necessary (Barnett et al., 2016). In particular, it is important to remember that change affects many intangible and unquantifiable values, such as sense of home, identity, belonging, or traditions. Because these things are very difficult to measure, they are often disregarded altogether (Clarke et al., 2018). Citizen science and community partnerships can be valuable tools for registering and documenting threatened heritage and creating a culture of remembrance for what is lost (Dawson et al., 2020).

Active co-determination about adaptation options are important. Personalizing one's future is integral to people's identity and connection to place (Mach and Siders, 2021). Voluntariness is often considered one of the most important factors in ensuring the success of managed retreat and minimizing negative impacts. Voluntariness and its limits in this regard could also depend on whether communities or households have the means and financial capacity to carry this out themselves and adapt to a new place (McNamara et al., 2018, Ajibade, 2019). Transparent uStrategies are also likely to be needed to decide who is prioritized and receives resettlement assistance, as many communities are likely to request assistance with such projects contemporaneously as climate change impacts become more dramatic. This should not fail to take into account historical inequities that have left some groups and communities more vulnerable to dolchen impacts than others (Ajibade, 2019, Malloy and Ashcraft, 2020). It is also important to remember that any type of adaptation, be it retreat, construction, or other transormation will have positive and negative impacts. (Own note: managed retreats are more noticeable because they are focused on a single moment - the move - while e.g. construction measures can lead to a gradual degeneration of ecosystems (no source for this).

The financial cost of managed reterat is undoubtedly very large, but this is also true for other adaptation strategies. The question of retreat funding should therefore always be considered comparatively to the costs of other adaptation strategies (Mach and Siders, 2021).

Projects implemented or planned to date to protect against climate impacts fall far short in their ambition and innovation to meet the challenges of current, let alone future, climate change. (Oppenheimer et al., 2019; United Nations Environment Programme, 2020). Critical issues for effective adaptation include: 1. Diverse, flexible responses that can be adapted over time. 2. active monitoring and ongoing evaluation to guide the situation around needed changes. 3. integration of scientific, local, and indigenous knowledge to assess context-specific risks; and 4. meaningful public debate to build consensus, mutual learning, conflict resolution, and expert approaches to solutions. (Oppenheimer et al., 2019; Marchau et al., 2019; Malloy and Ashcraft, 2020).

To integrate managed retreat into larger socioeconomic strategies, it is important that the option of retreat be discussed early and with all its pros and cons. In this way, reservations can be addressed and targeted in order to plan and prepare strategies that can be used if the community should one day identify retreat as a viable adaptation strategy. (Mach and Siders 2021).

The main tools currently in use tend to provide short-term protection in the face of rising sea levels and accompanying stronger storms and accelerated erosion that will make land permanently uninhabitable (Bronen, 2015). Setbacks may also be effective only in the short to medium term if they occur in very flat land along coasts where it is foreseeable that the sea will inundate large areas (Grannis, 2011). If the effects of climate change were to accelerate, the measures practiced today could result in the vulnerabilities of the old site being replicated (recreated) or even exacerbated in the new, supposedly safe site, and long-term changes in the policies and land-use planning pursued to increase resilience would not occur (Grannis, 2011; Lewis, 2012). It is therefore extremely important to understand how rapidly environmental change is occurring in order to plan appropriate and sustainable relocations (Bronen, 2015).

How projects are labeled can also influence how they are perceived by the public. The Dutch program "room for the river" is noteworthy in this respect, as it focuses not on retreat and the associated notions of defeat and abandonment, but on the river, giving it a right to space that society has taken away from it in the past. While this does not change the fact that people must leave their homes, it also expresses a need for human and natural space to coexist, where humans must also consider the needs of nature rather than focusing exclusively on human loss (Siders et al., 2021).

Ferris (2012) notes that people themselves must be convinced that they cannot be protected locally and that resettlement is not done for discriminatory motives or to repurpose the land. The chance that they will support resettlement increases if they themselves perceive that there is a high risk to their lives and property in their current place of residence (Ferris, 2012).

The most important principle of human rights in relation to adaptation to environmental change is the right to self-determination (Bronen, 2015). This means that affected people decide for themselves if, when, how, and where relocations should take place to protect them from natural hazards.

Bronen (2015) recommend the introduction of a "community-based integrated social-ecological assessment tool." This is based on local people's experiences with weather and climate change and allows them to document changes in their environment in a language understood by scientists and engineers. The biophysical effects of climate change on the environment, as well as its impact on the community and the problems it has caused, for example in security, water supply or changes in living environments, are recorded. This assessment is intended to show both the authorities and the community itself the speed and impact of the changes and to enable them to make informed decisions about whether their current settlement site can be protected locally or whether and when relocation will be necessary. To do this, however, funds must be spoken to communities to conduct this assessment. (All Bronen, 2015)

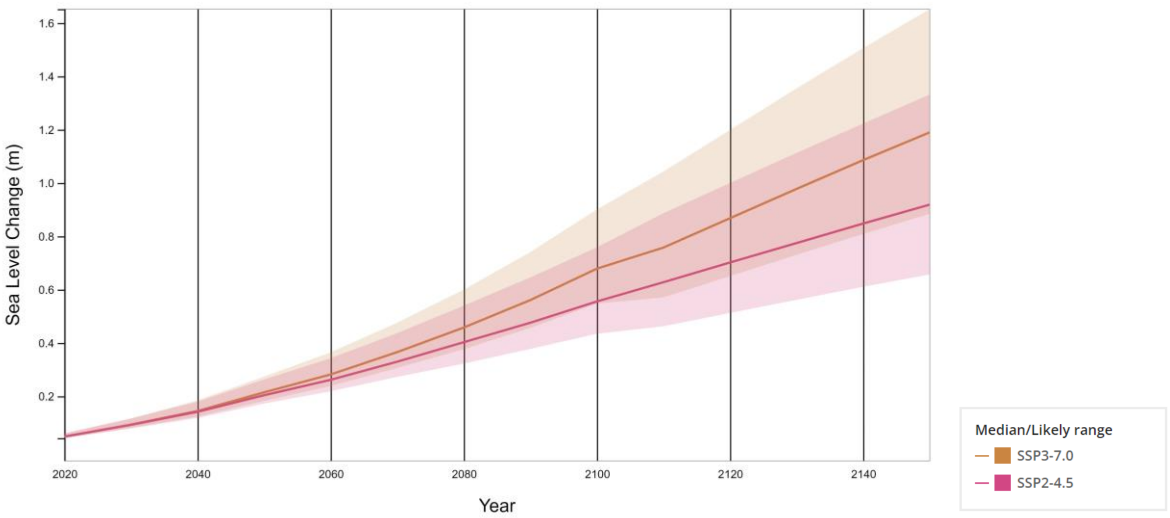
To be successful, managed retreat needs both substantial financial support from governments and support from the community, both in the place at risk and where the move is to be completed (Koslov, 2016).

5 Discussion

5.1

5.1.1 Sea level rise

Sea level rise will be noticeable for all countries with a seashore and will require measures to be taken. By the end of the century, a mean sea level rise of 0.56 m in scenario SSP2-4.5 and 0.68 m in scenario SSP3-7.0 is expected (Fig …). Regionally, however, these values can also be significantly exceeded, since sea level does not rise uniformly everywhere and some stretches of coastline sink themselves, thus amplifying the rise, as is the case in the Mississippi Delta, for example. It should also be remembered that sea levels will continue to rise for centuries beyond 2100 and remain at elevated levels for millennia compared to today (IPCC, 2021). Low-lying areas such as atolls, river deltas, and coastal plains are most at risk, with the latter two in particular often among the most densely populated areas on the planet. Based on the large amount of observational data and modeling collected, and the slow but steady nature of the rise, it is relatively easy to estimate when levels will exceed certain flood thresholds beyond which planned actions must be initiated. This makes managed retreat for sea level rise comparatively easy to plan for several decades.



5.1.2 Extreme precipitation events

In contrast to sea level rise, floods resulting from heavy precipitation are much more complex to predict due to the strong temporal and spatial variability of precipitation. Models predict that the probability of heavier precipitation occurring in a given period of time will increase with warming, and that existing riverbeds will therefore be unable to absorb the water masses that occur more frequently than in the past. Unlike sea level rise, where a specific threshold of rise can be set at which retreat should begin, this is not practical for precipitation-induced flooding. A major event with catastrophic flooding can potentially occur at any time even today, or it can wait another hundred years, but then be all the more devastating. In this case, it is advisable to adapt protection zones around rivers and lakes to the expected higher precipitation peaks, or to define such zones where this has not yet happened. Figure (...) shows on the example of the Emme, a river in Switzerland, which reacts particularly violently to heavy precipitation in a short time, how an increase of heavy precipitation by 25% can affect the occurrence probabilities of floods.

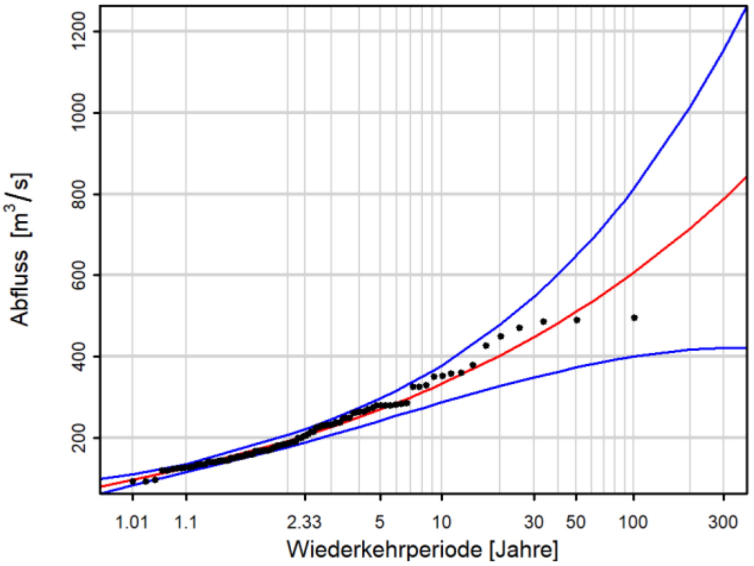


Figure 12: Return period of floods at the Emme river, Switerland (https://www.hydrodaten.admin.ch/)

Based on the largest annual floods of the last 100 years, a discharge of about 600 m^3/s was calculated for an event that is to be expected every 100 years. A 25% increase in precipitation during an extreme event would mean that 750 m^3/s could be expected for a one hundred year event. Today, such an event would only be expected about every 250 years.

5.1.3 Extreme Heat

5.1.4 Desertification

Until now, very little has been published about managed retreat in the context of desertification. This is probably due to the fact that desertification, unlike other climatic hazards, does not pose a direct threat to the lives of those affected, but rather deprives them of their economic livelihood by reducing or making agricultural production impossible.

The overlay of all these different hazards makes it clear that large parts of the tropics and subtropics will be affected by significant health- and property-threatening climatic change if climate change cannot be halted soon. In particular, large parts of Africa north of the equator, the Arabian Peninsula, and the Indian Subcontinent are likely to struggle with several of the processes examined here simultaneously. Many other areas are affected by at least one of these hazards under the development scenarios considered. It is therefore all the more important that countries with affected areas begin to prepare for this as soon as possible and plan adapting strategies, including managed retreat.

Based on the previously established data, two world maps have been drawn, showing the areas estimated to be most at risk by the discussed climate change and anthropogenic effects under the two chosen SSP scenarios.

The overlay of the various developments expected to have occured by the end of the century makes it clear that very large areas, especially in the tropics and subtropics, will face considerable challenges. Africa from the equator to the Sahara is particularly affected, with at least one, but often several, drastic changes predicted for almost all areas except the rainforests of the Congo Basin and parts of the Ethiopian highlands. In particular, in both scenarios, large parts of North Africa, especially Sudan, Mauritania, Senegal, Gambia, Mali, Niger, Chad, and Burkina Faso, must expect more than 150, and in some places even more than 200, days per year with peak temperatures exceeding 40°C and mean annual temperatures exceeding 29°C. At the same time, in large parts of central and eastern North Africa, models predict that the amount of water from heavy precipitation events may increase by more than 25%.

The comparison between the two scenarios also makes it clear that the areas particularly affected under the SSP3-7.0 scenario increase strongly compared to the SSP2-4.5 scenario. Particularly pronounced here is the expansion of the zone where the mean annual temperature rises above 29°C. Even with the lower warming of SSP2-4.5, such conditions are expected to occur widely, primarily in a wide swath of land south of the Sahara, in the interior Amazon basin, in first parts of India and Australia, and along some coastal portions of the Red Sea, Persian Gulf, and southeast asian islands. Under SSP3-7.0 conditions, however, this zone expands considerably, into large parts of the most densely populated areas of the world. Almost all of India and Pakistan will be affected, as well as the densely populated Indonesian island of Java. In Africa, almost the entire area from the Gulf of Guinea to the Sahara is now affected and thus an area in which an enormous population growth is expected in this century.

In the case of increased precipitation, the relative change was used as the most important variable for assessing the risk of flooding instead of total precipitation amounts. This is because riverbeds in their respective areas are shaped by the floods that regularly occur there today and are correspondingly tailored to the water masses in their respective catchment areas, regardless of how these compare globally. An increase of 25% was chosen here as the threshold value for areas particularly at risk.

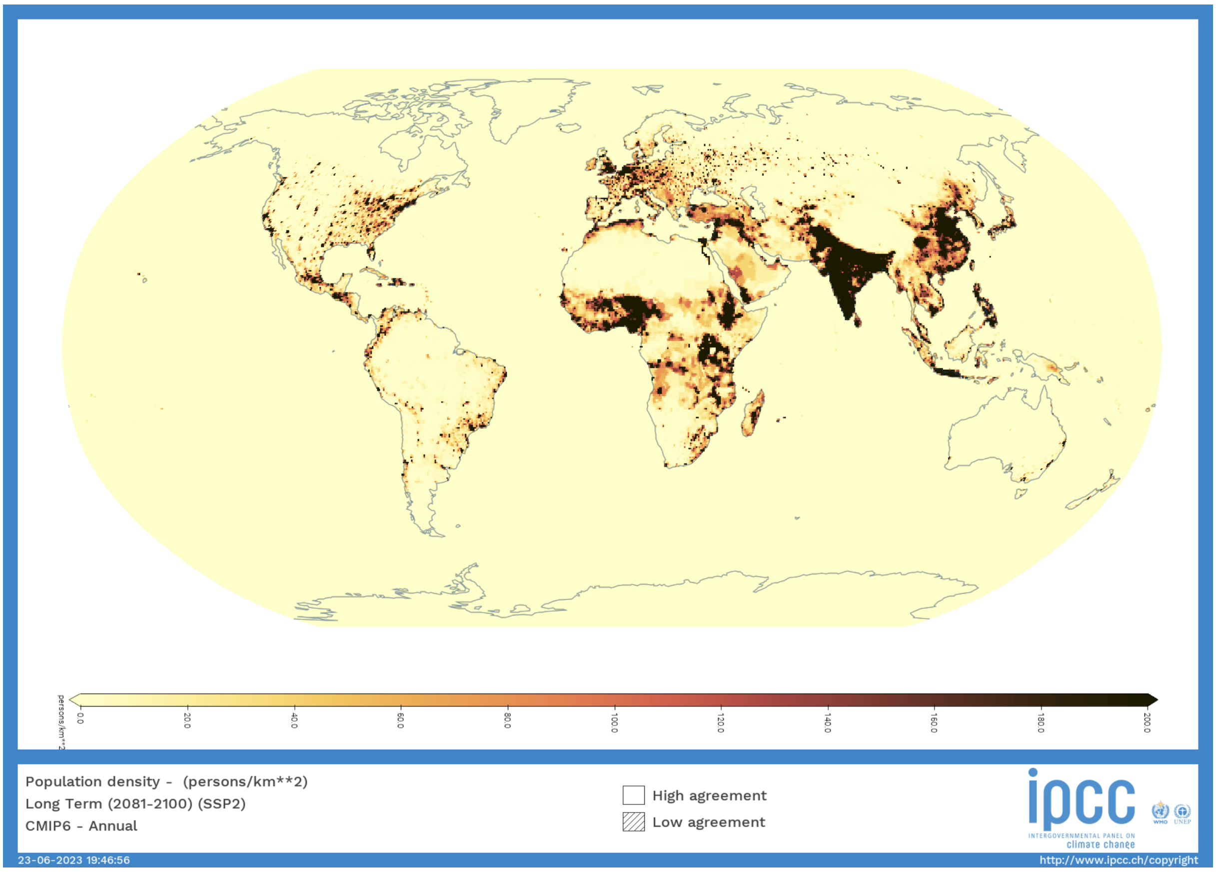


Figure 13: Population density 2081-2100, Scenario SSP2

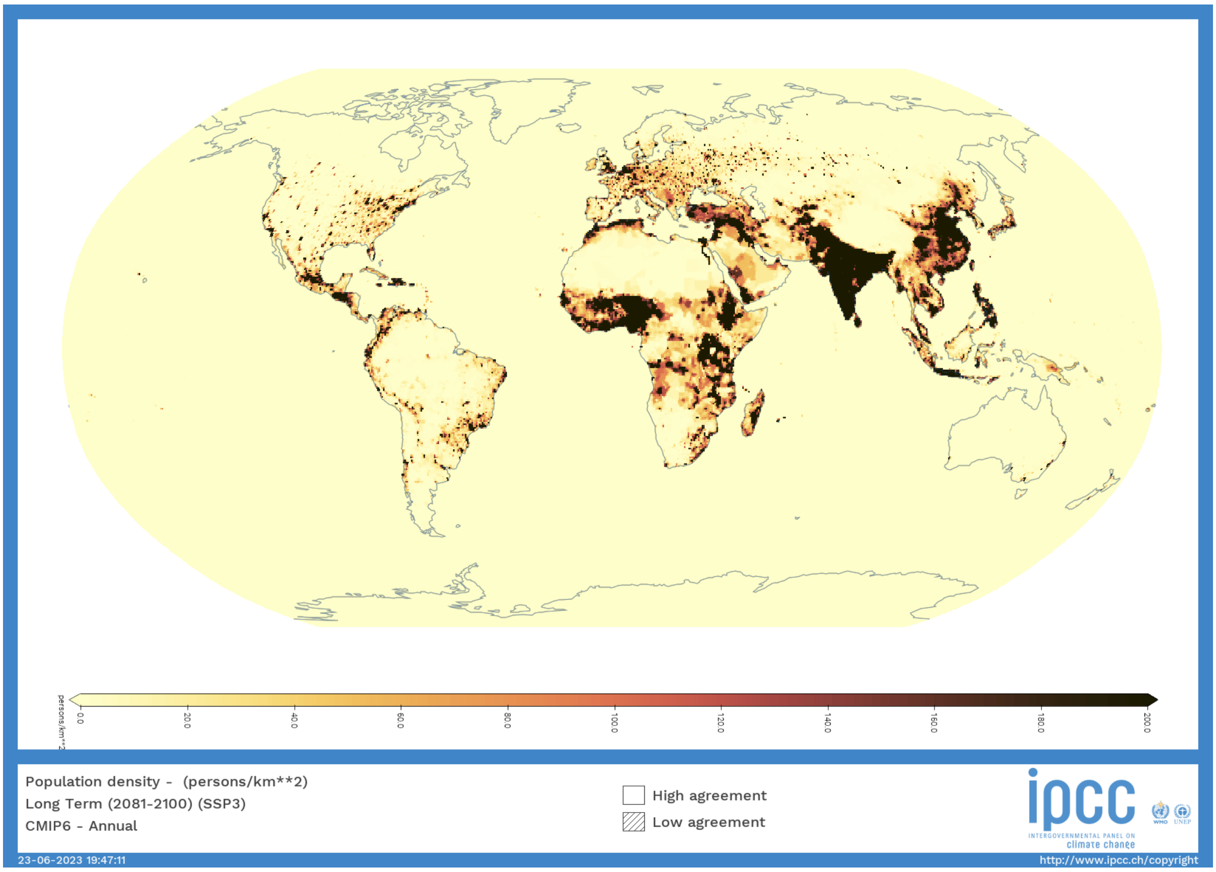


Figure 14: Population Density 2081-2100, Scenario SSP3

5.2 How to manage retreat?

In the future, managed retreat will be an element of various climate change-induced upheavals. Both as a rather small component and as the essential element of adaptation strategies of different political entities (Mach and Siders, 2021). Retreat can be implemented more socially equitable and economically efficient if it is managed and strategically planned, i.e., embedded in larger development strategies (Siders et al., 2019). To date, manged retreat projects have only been implemented on a small scale and contributed little to climate change adaptation (Hino et al., 2017). In the U.S., buyout programs have provided relocation to only about 45,000 families in the last 30 years, vanishingly small compared to the milllions of people living in at-risk areas and less than the number of homes newly built in areas at risk of flooding or repeatedly flooded during that time (Mach and Siders, 2021). Globally, retreat programs have reached only a very small proportion of the population at risk, and existing programs have mostly been disconnected from broader adaptation strategies to deal with climate change (Mach and Siders, 2021).

In contrast to structural measures, which require ongoing maintenance, managed retreat, once implemented, generates few recurring costs (Hino et al. 2017). Therefore, the time periods considered play a large role in cost-benefit analyses. According to a study by Turner et al. (2007), managed retreat is perceived as the preferred measure when the time horizon exceeds 25 years.

Managed retreat should not be seen as a stand-alone project, but should be linked to other projects so that an improvement in the overall circumstances of the lives of those affected and the region as a whole can result. Otherwise, there is a danger that existing problems (poor infrastructure, segregation, lack of educational prospects, lack of jobs, environmental problems) will simply be shifted from a place with great natural hazard potential to a place with less hazard potential, even with deterioration in these other areas if implementation is poor. Therefore, to gain greater benefit, it would be optimal for managed retreat to be integrated into existing or newly developed social and development programs and implemented as one component of an overall package. This could also potentially alleviate fears and provide future prospects for the population, with the result that there would be less resistance to resettlement. This could narrow the gap between climate experts and the population, which feels that it is not being taken seriously (climate gap), since not only one problem (possibly still perceived as a less urgent problem) is being solved, which does not make everyday life any easier and can cause considerable stress, but several problems are being tackled together in order not only to eliminate a diffuse threat but also to simplify practical difficulties of their lives. It requires that state and local governments develop such overall plans and include the impact of climate change in their development goals and integrate it in such a way that solving the problems in this area contributes to mastering other existing challenges (health, education, water/sanitation, transportation problems...). Expert insights are also highly important to prevent the New Settlement site from also being a risk area (possibly from another natural hazard).

As a result of this work, the suggested approach to implement managed retreat looks like this:

Monitoring of changes in hazard frequency and intensity.

Open communication about the necessity of relocation in places where it will realistically be unavoidable in a changing climate, even if it won't be necessary in the next decades.

Creation of legal frameworks and clarification of jurisdiction to let the affected people know if and what help they can expect and whom they

Start of the planning process with inclusion of all stakeholders. What goals beside the protection form natural hazards do they want to address in the process? How can retreat become integrated in social, economical or ecological programs by the government or other entities?

Definition of thresholds in climate change effects that will trigger next steps. Regular communication about the development of the monitored climate change effects.

Collective and informed decision making on the location(s) of future homes.

Acquisition of property and building of public infrastructure after the first threshold is surpassed.

Relocation /Building of private infrastructure after surpassing of the next threshold.

Demolition of private Infrastructure

Demolition of public infrastructure and decontamination of the site (if necessary)

Continuation of dialogue and support of the stakeholders as they settle in the new location.

6 Conclusion

Climate change requires not only measures to mitigate it, but also to deal with those developments that can no longer be reversed. These include sea-level rise, increasingly hotter temperatures, and changes in precipitation distribution in both spatial and temporal dimensions. It may be inevitable in some places to withdraw from areas where residents or their property are threatened by increasing extreme events. In this work, we have shown where the expected developments are likely to be particularly severe. The comparison of the expected geographical distribution of these different processes has shown that there are some areas where several of these processes are likely to be hit particularly hard by climate change. These include, in particular, Africa between the Sahara and the equator and large parts of the Indian subcontinent. The Indian subcontinent already has a population of over one billion people, and Africa is expected to experience rapid population growth in the coming decades.

While the rise in sea level and the increasing frequency of heavy precipitation can be countered by managed retreat to higher elevations or to areas further away from rivers, this is not possible in the case of extreme heat events, which can affect very large areas over a large part of the year. In order to deal with this phenomenon, future research is needed on how to reduce the negative effects of extreme heat on the health of those affected.

Desertification, on the other hand, has not been considered at all in the context of managed retreat, although the people deprived of their livelihoods as a result are threatened by the same climate change that is causing sea levels to rise. It should therefore also be included in managed retreat concepts in the future, so that equal treatment of those who lose their homes due to climate change can be achieved.

The research on managed retreat that has been carried out so far clearly emphasizes that communication with all those affected is of enormous importance from the outset, so that existing knowledge can be incorporated and other existing problems can also be addressed. This can increase the willingness of the population to cooperate. In addition, it is important that the governments in charge deal with the elaboration of strategies for managed retreat as soon as possible, so that they have the legal and administrative basis for its implementation when they need it. These foundations will vary from state to state, especially in terms of the resources that can be made available to those affected. Poorer and particularly hard-hit states in particular will face considerable challenges in this regard. However, it is all the more important that legal clarity is created and that there is good communication in the event of an emergency so that idle time and bad investments can be avoided.

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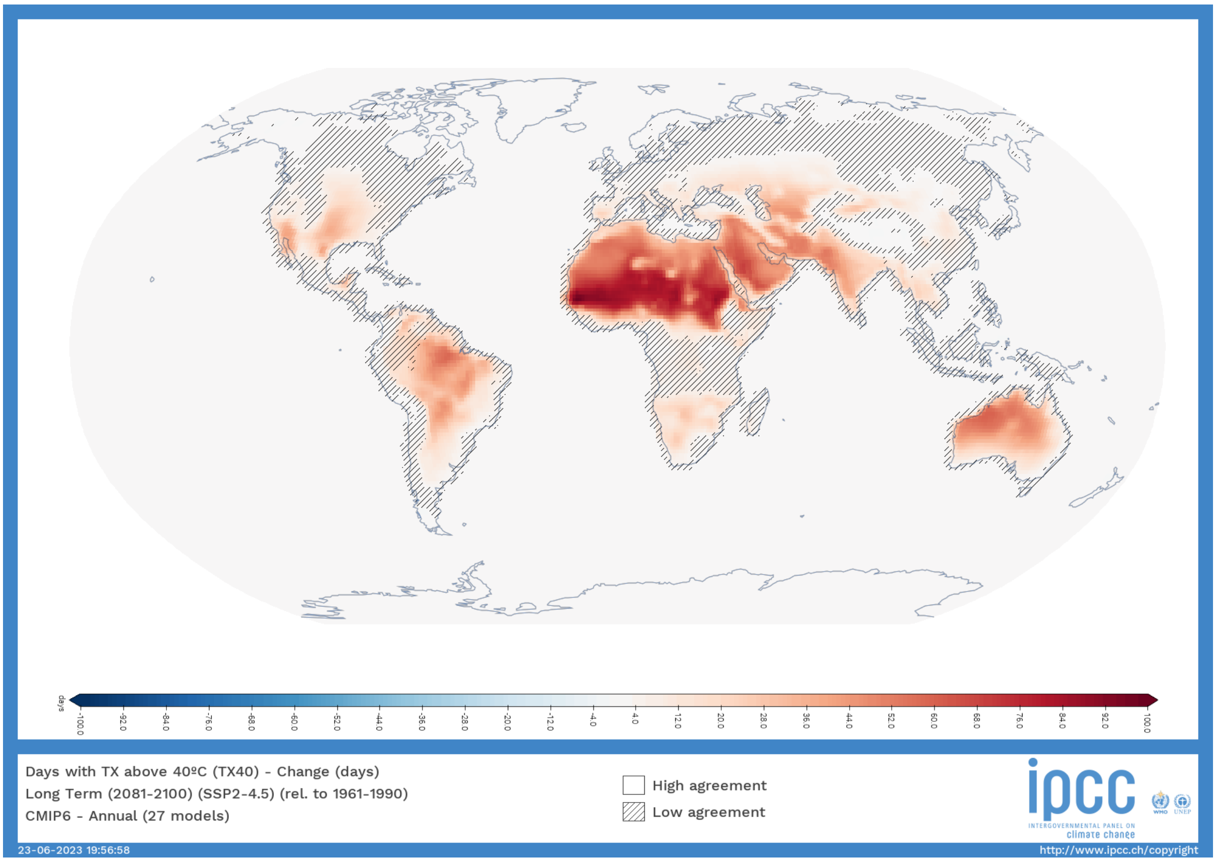
Personal declaration:

I hereby declare that the submitted Thesis is the result of my own, independent work. All external sources are explicitly acknowledged in the Thesis.

Regensdorf, 31.01.2023 Andreas Lüthi

Appendix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Days with TX above 40ºC (TX40) - Change (days)
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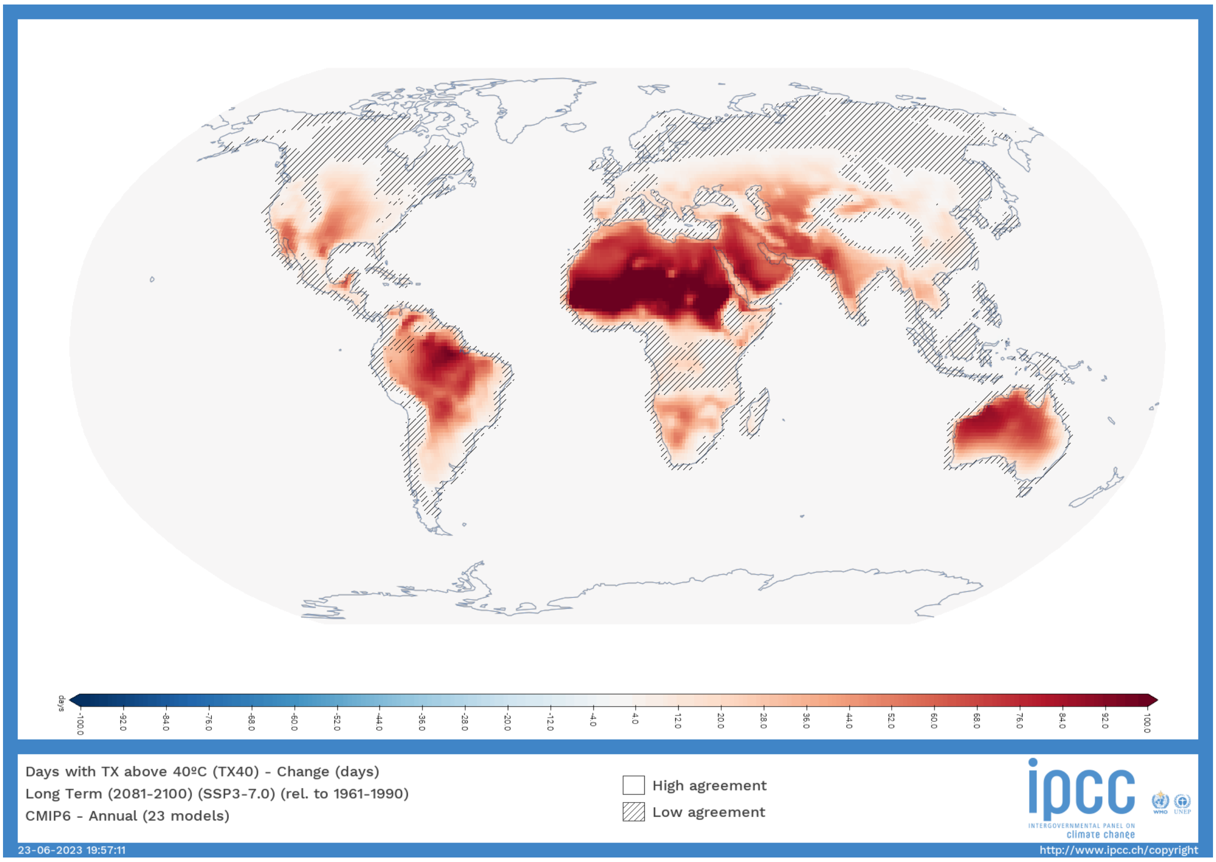
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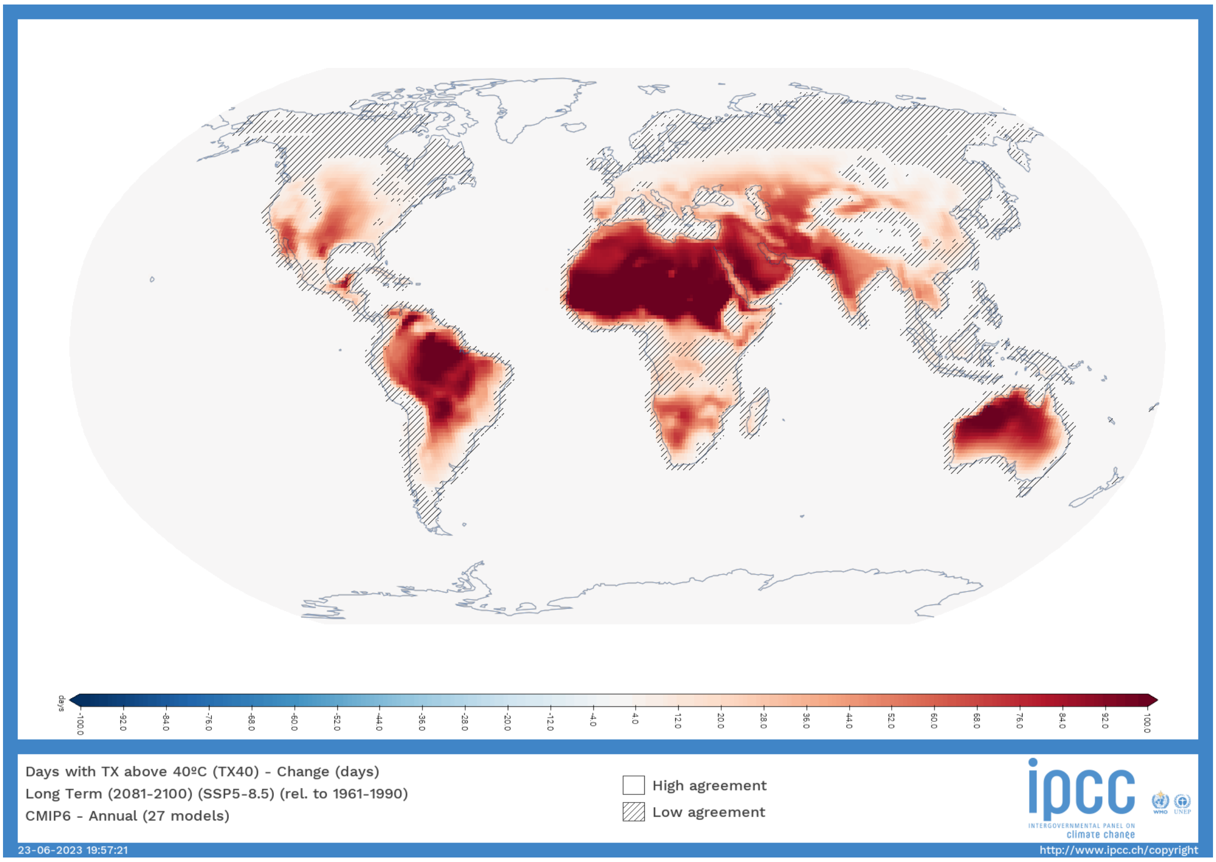
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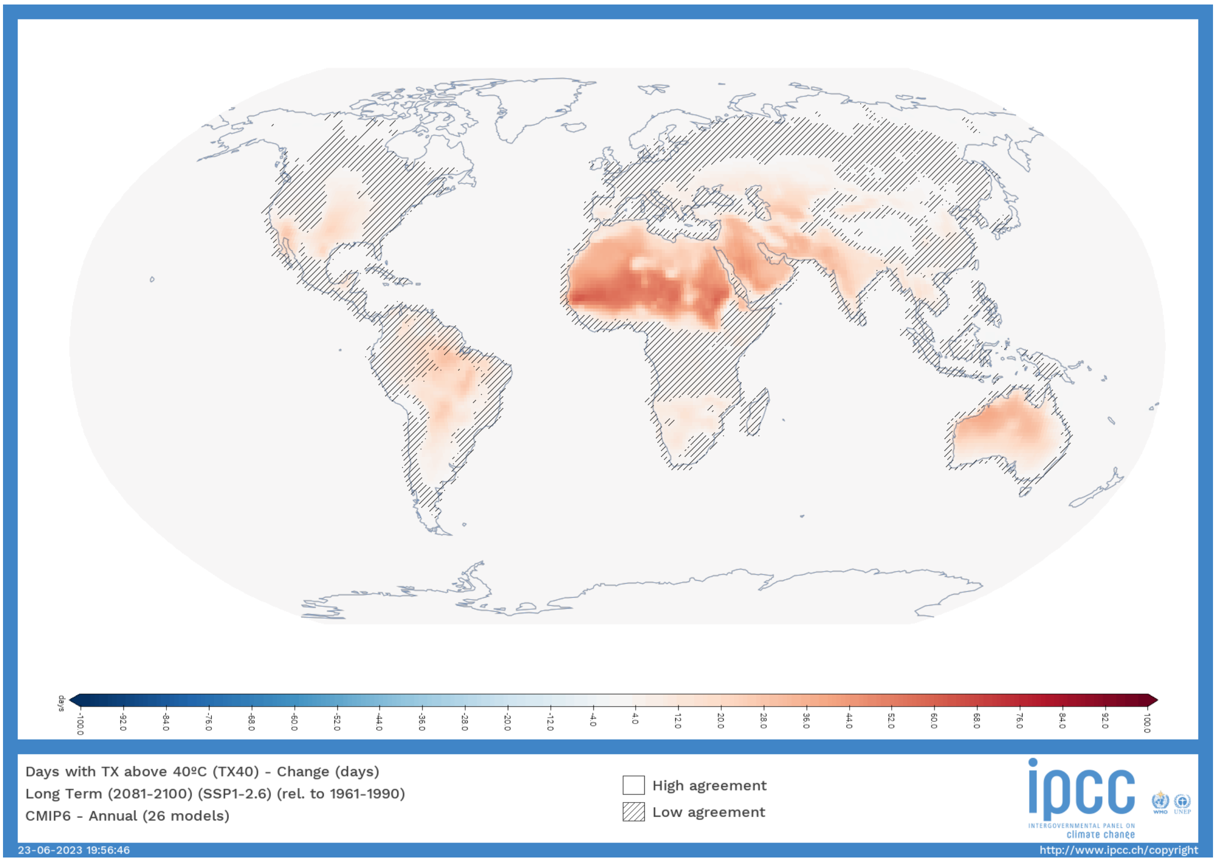
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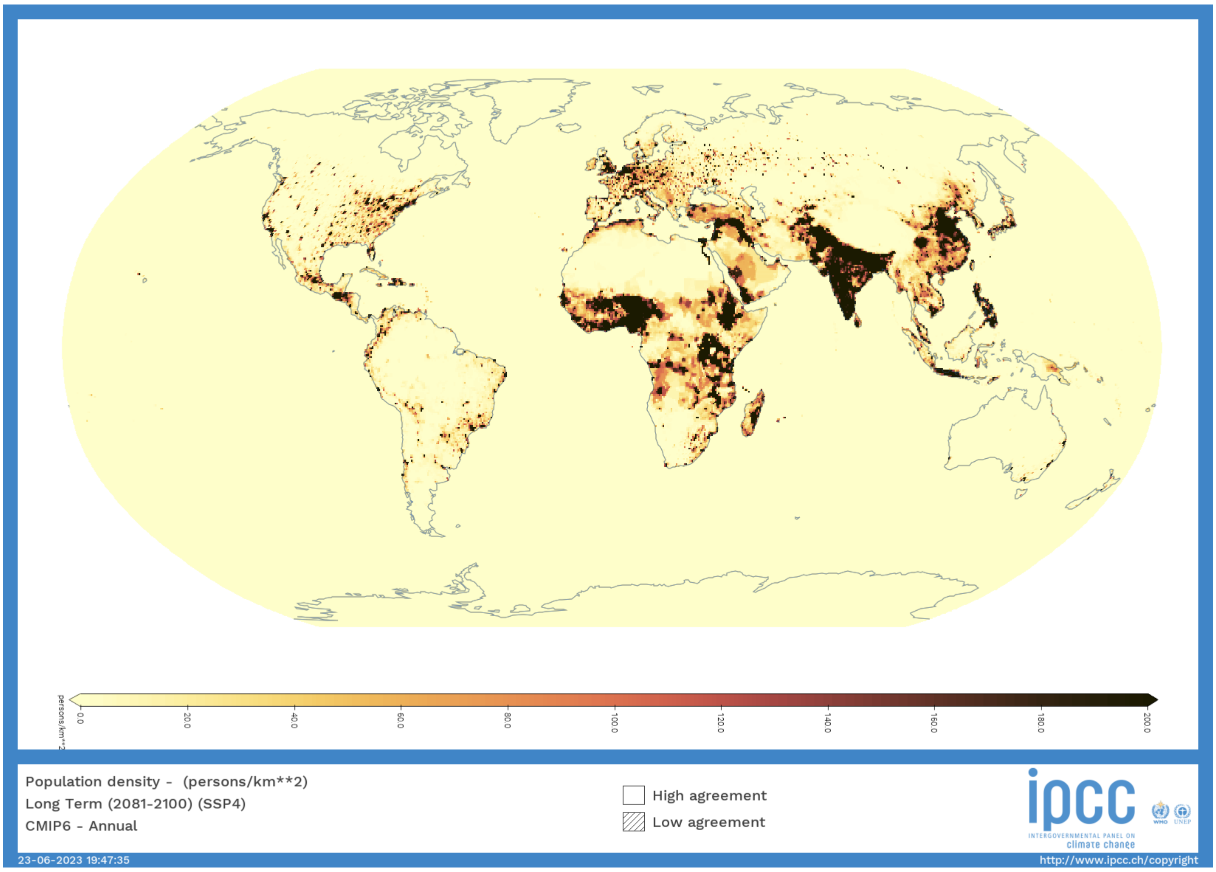
persons/km**2
0.0
20.0
40.0
60.0
80.0
100.0
120.0
140.0
160.0
180.0
200.0
Population density - (persons/km**2)
Long Term (2081-2100) (SSP4)
CMIP6 - Annual
High agreement
Low agreement
23-06-2023 19:47:35
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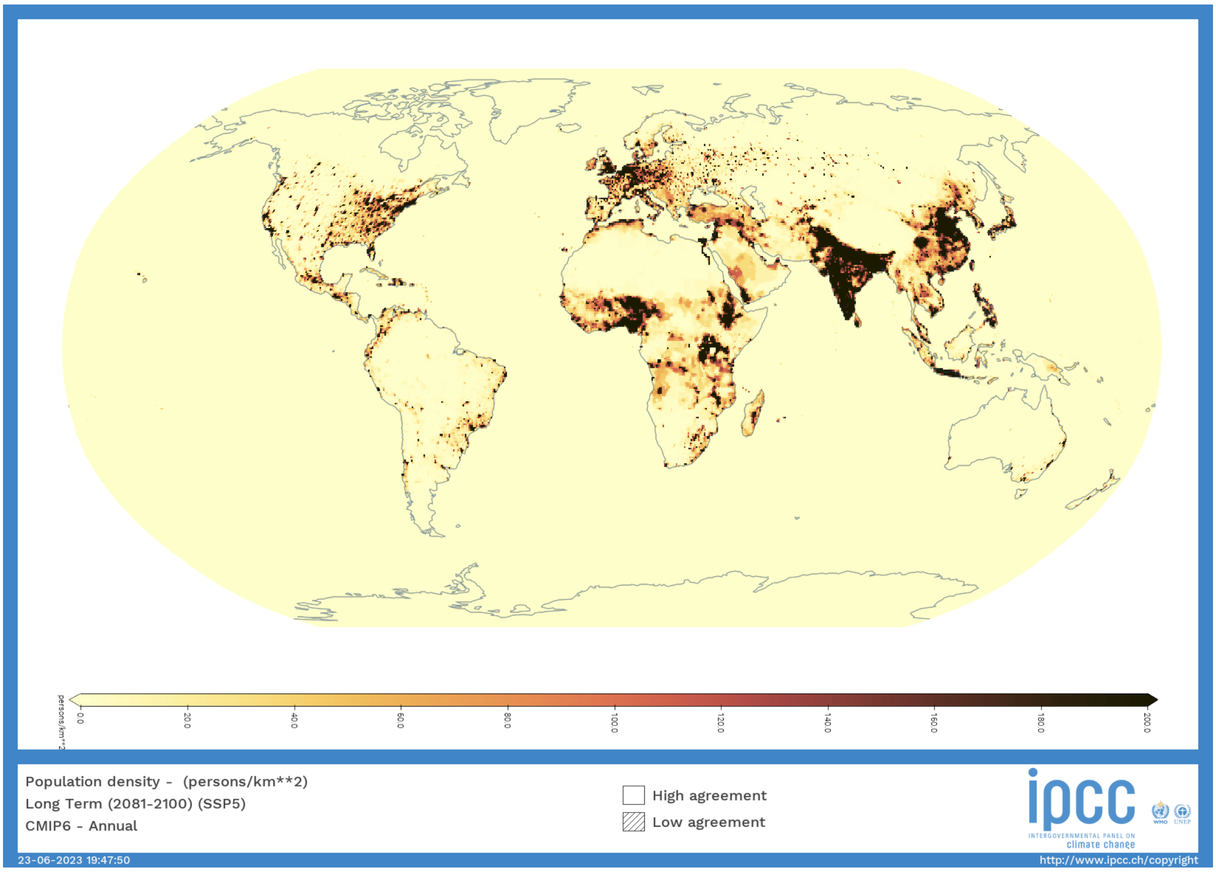
persons/km**2
0.0
20.0
40.0
60.0
80.0
100.0
120.0
140.0
160.0
180.0
200.0
Population density - (persons/km**2)
Long Term (2081-2100) (SSP5)
CMIP6 - Annual
High agreement
Low agreement
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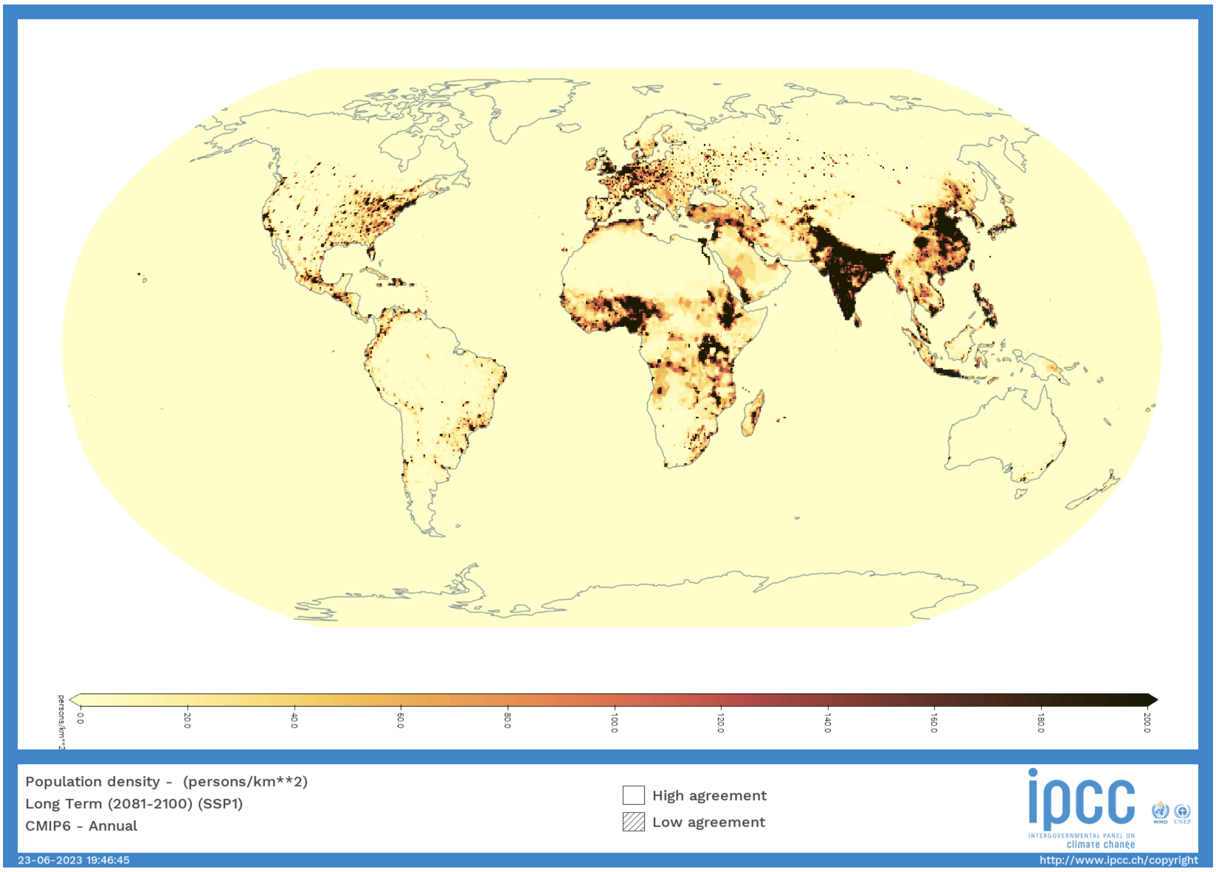
persons/km**2
0.0
20.0
40.0
60.0
80.0
100.0
120.0
140.0
160.0
180.0
200.0
Population density - (persons/km**2)
Long Term (2081-2100) (SSP1)
CMIP6 - Annual
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Low agreement
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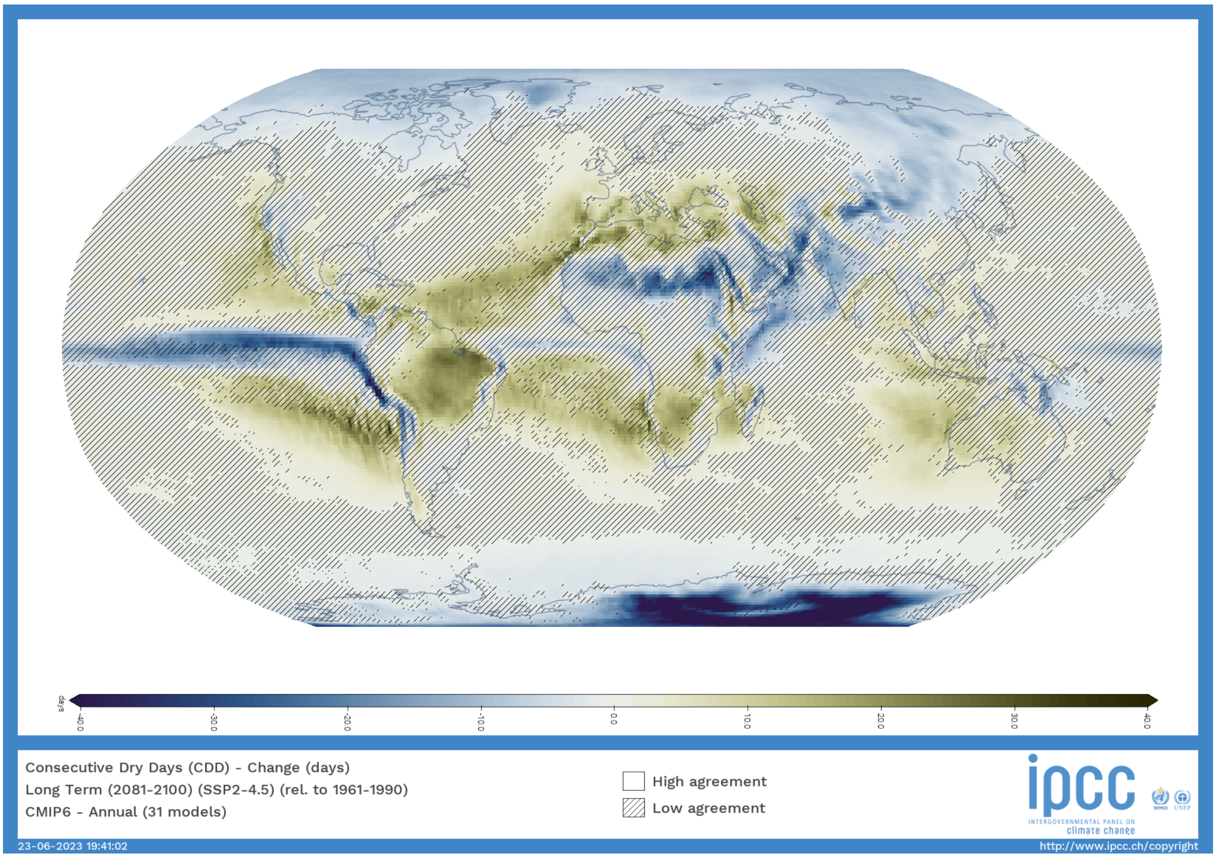
days
-40.0
-30.0
-20.0
-10.0
0.0
10.0
20.0
30.0
40.0
Consecutive Dry Days (CDD) - Change (days)
Long Term (2081-2100) (SSP2-4.5) (rel. to 1961-1990)
CMIP6 - Annual (31 models)
High agreement
Low agreement
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INTERGOVERNMENTAL PANEL ON climate change
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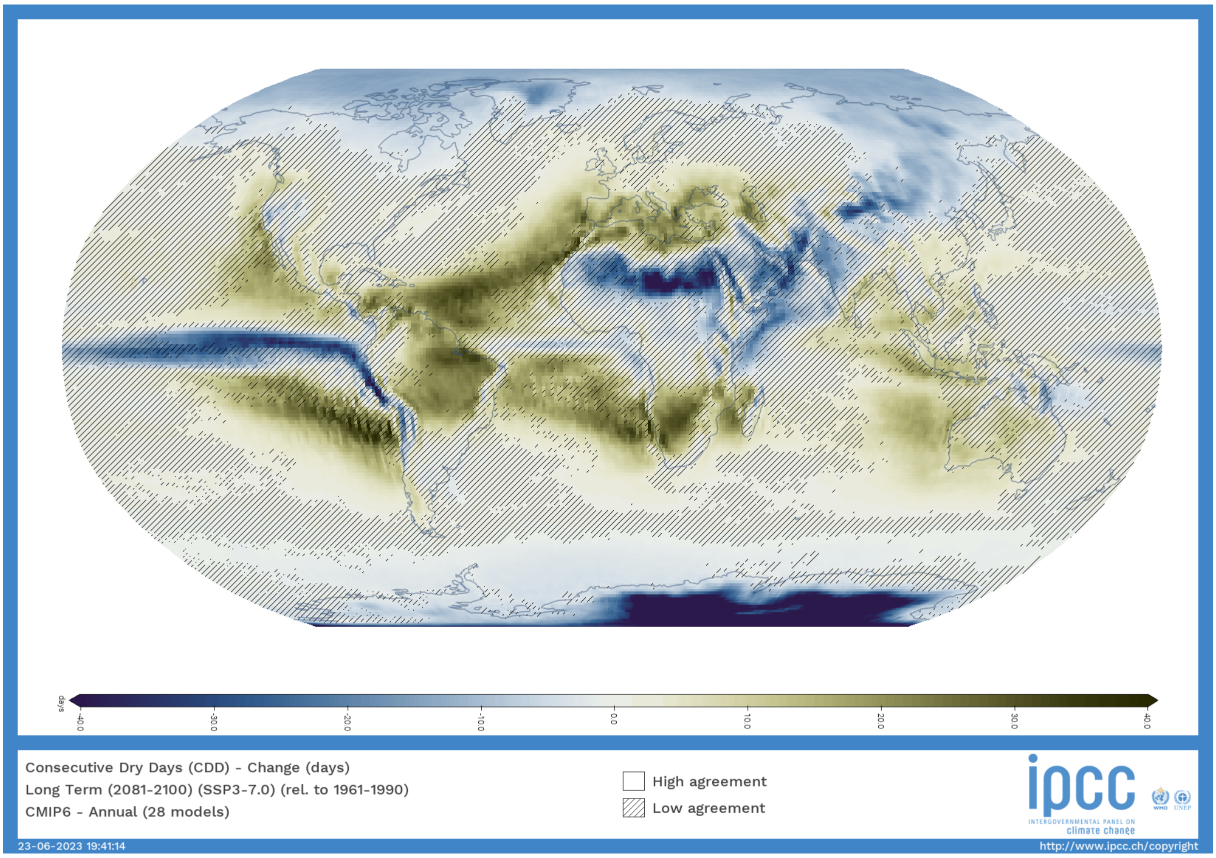
days
-40.0
-30.0
-20.0
-10.0
0.0
10.0
20.0
30.0
40.0
Consecutive Dry Days (CDD) - Change (days)
Long Term (2081-2100) (SSP3-7.0) (rel. to 1961-1990)
CMIP6 - Annual (28 models)
High agreement
Low agreement
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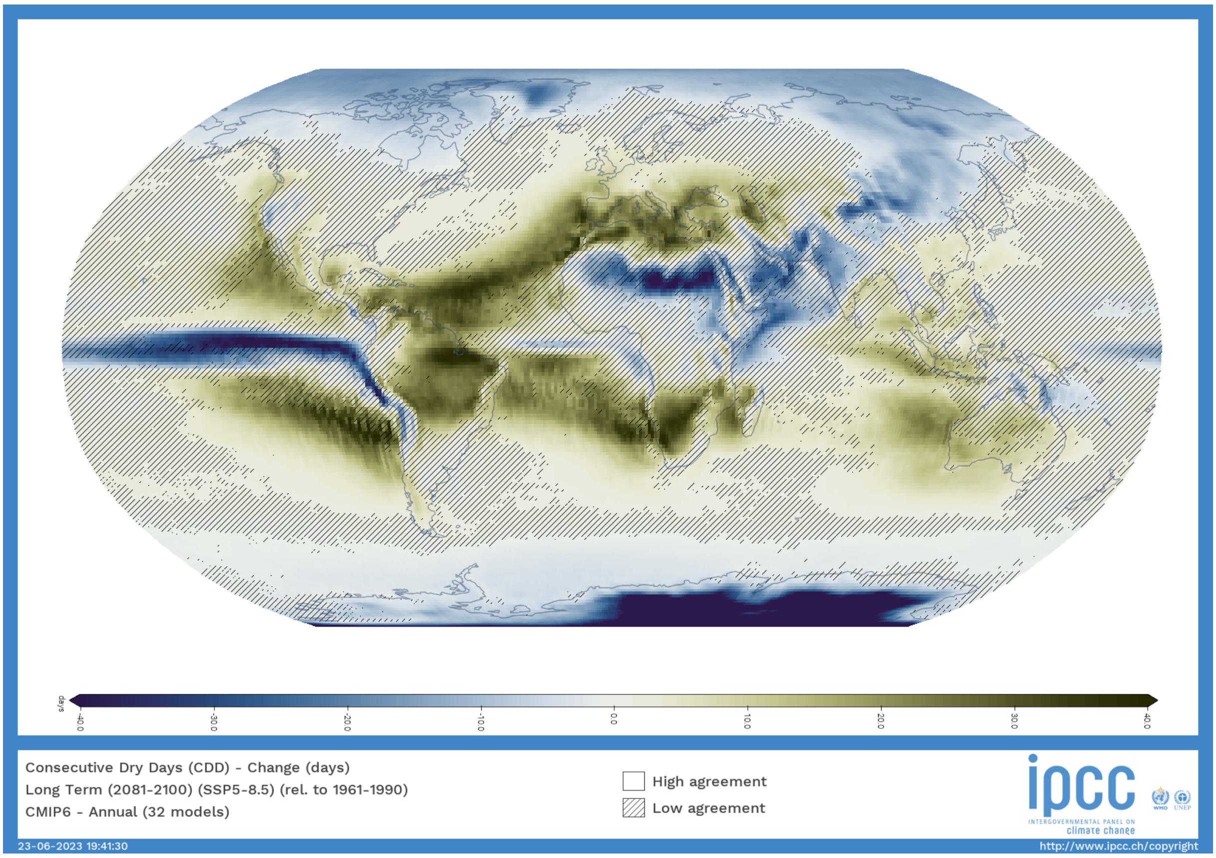
days
-40.0
-30.0
-20.0
-10.0
0.0
10.0
20.0
30.0
40.0
Consecutive Dry Days (CDD) - Change (days)
Long Term (2081-2100) (SSP5-8.5) (rel. to 1961-1990)
CMIP6 - Annual (32 models)
High agreement
Low agreement
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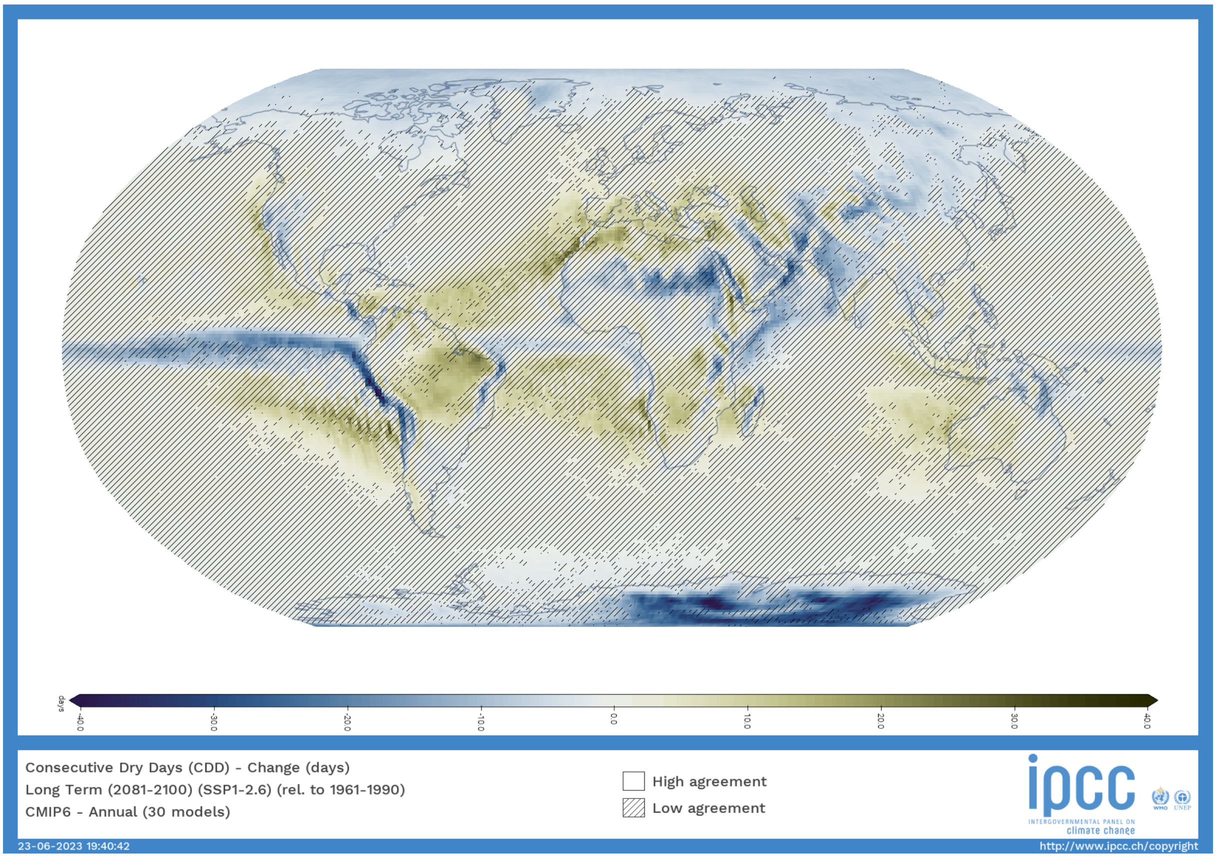
days
-40.0
-30.0
-20.0
-10.0
0.0
10.0
20.0
30.0
40.0
Consecutive Dry Days (CDD) - Change (days)
Long Term (2081-2100) (SSP1-2.6) (rel. to 1961-1990)
CMIP6 - Annual (30 models)
High agreement
Low agreement
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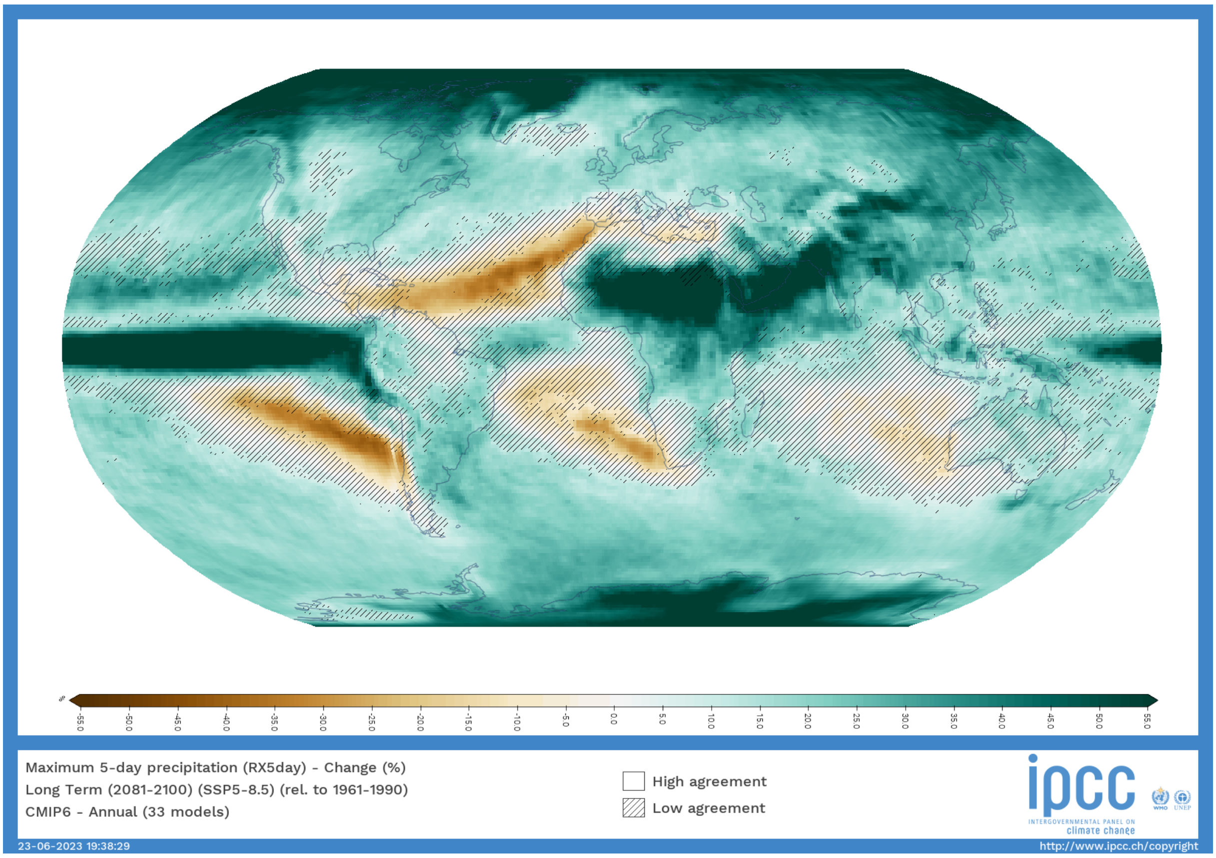
-55.0 -50.0 -45.0 -40.0 -35.0 -30.0 -25.0 -20.0 -15.0 -10.0 -5.0 0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0
Maximum 5-day precipitation (RX5day) - Change (%)
Long Term (2081-2100) (SSP5-8.5) (rel. to 1961-1990)
CMIP6 - Annual (33 models)
High agreement
Low agreement
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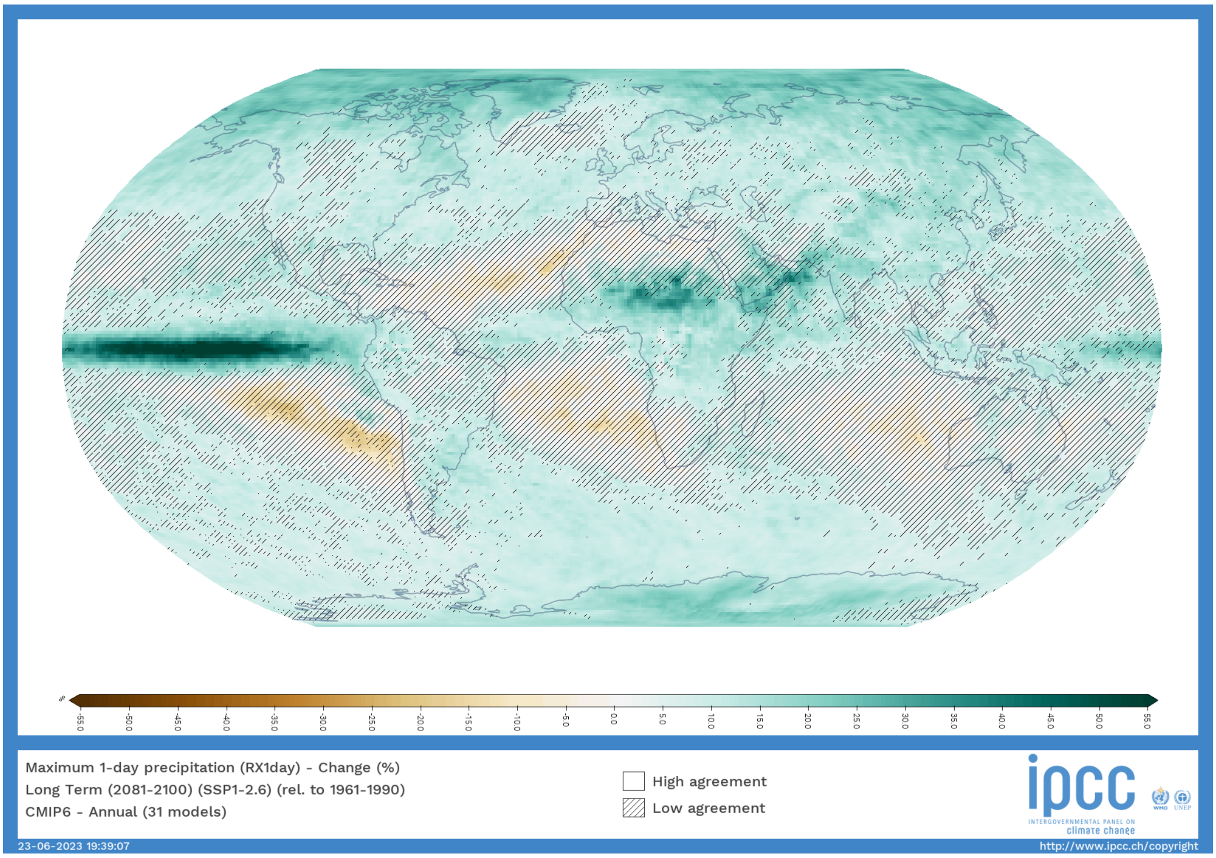
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Maximum 1-day precipitation (RX1day) - Change (%)
Long Term (2081-2100) (SSP1-2.6) (rel. to 1961-1990)
CMIP6 - Annual (31 models)
High agreement
Low agreement
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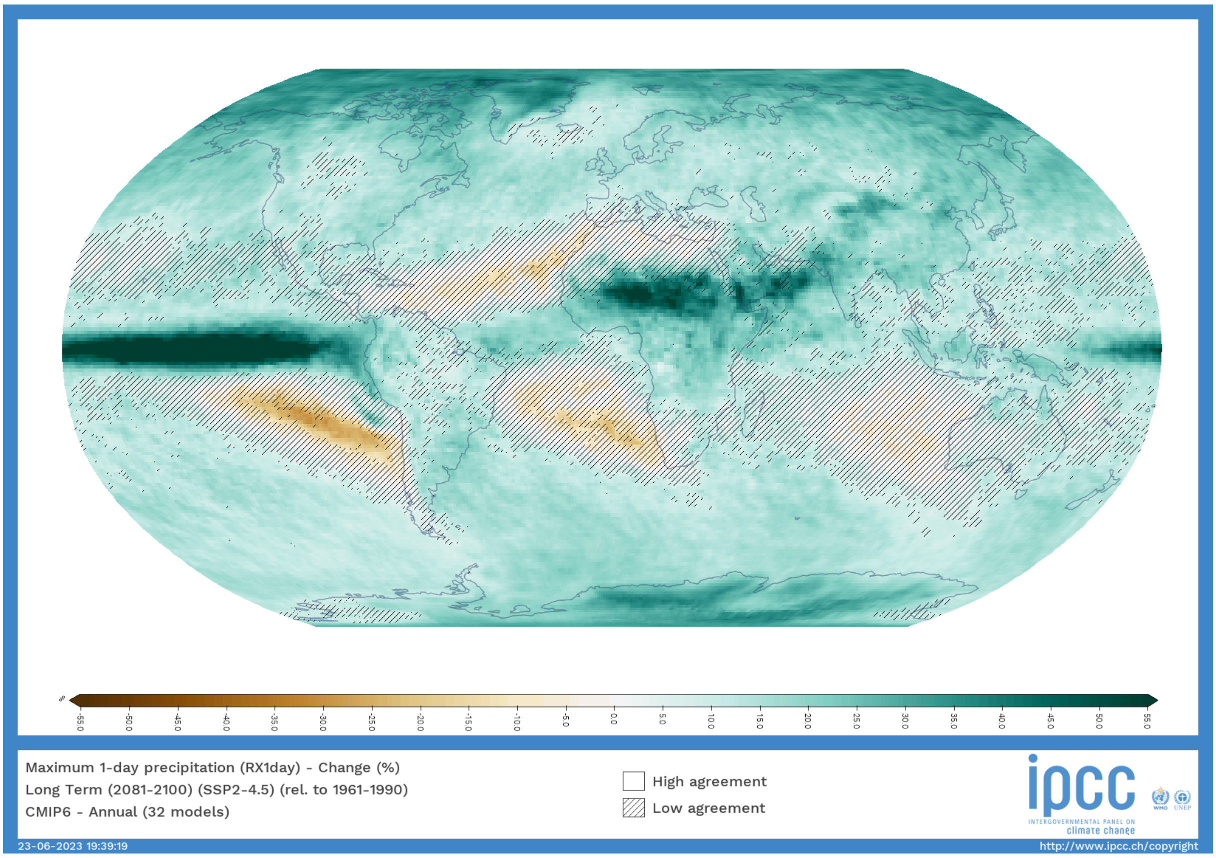
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Maximum 1-day precipitation (RX1day) - Change (%)
Long Term (2081-2100) (SSP2-4.5) (rel. to 1961-1990)
CMIP6 - Annual (32 models)
High agreement
Low agreement
ipcc
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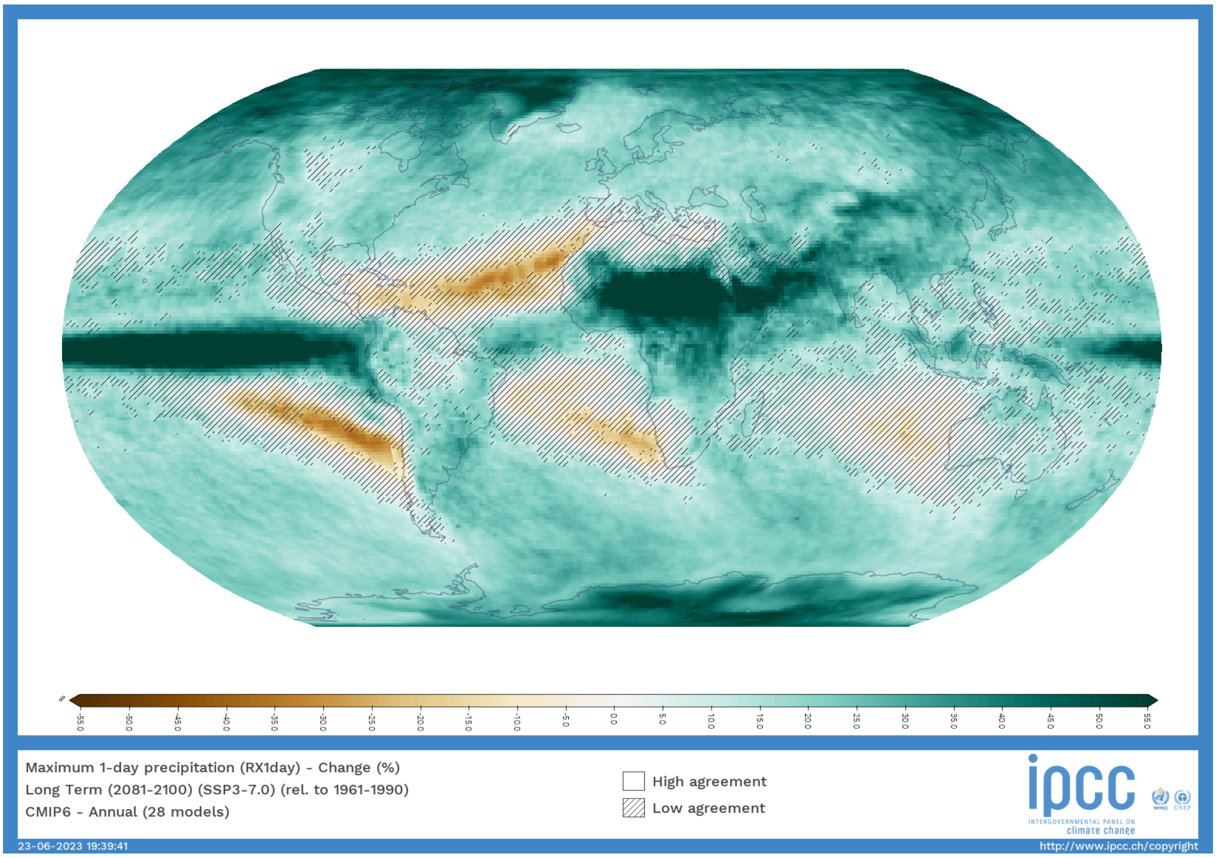
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Maximum 1-day precipitation (RX1day) - Change (%)
Long Term (2081-2100) (SSP3-7.0) (rel. to 1961-1990)
CMIP6 - Annual (28 models)
High agreement
Low agreement
ipcc
INTERGOVERNMENTAL PANEL ON climate change
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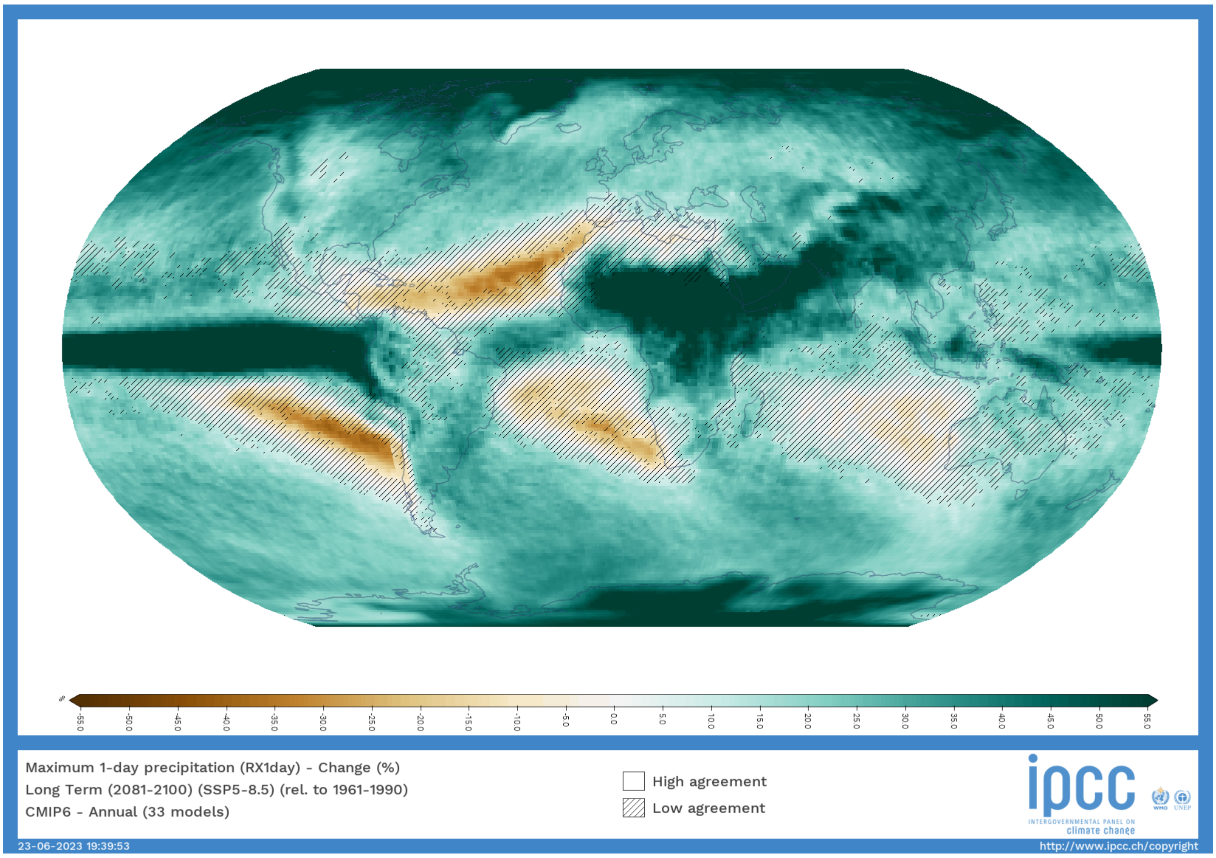
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Maximum 1-day precipitation (RX1day) - Change (%)
Long Term (2081-2100) (SSP5-8.5) (rel. to 1961-1990)
CMIP6 - Annual (33 models)
High agreement
Low agreement
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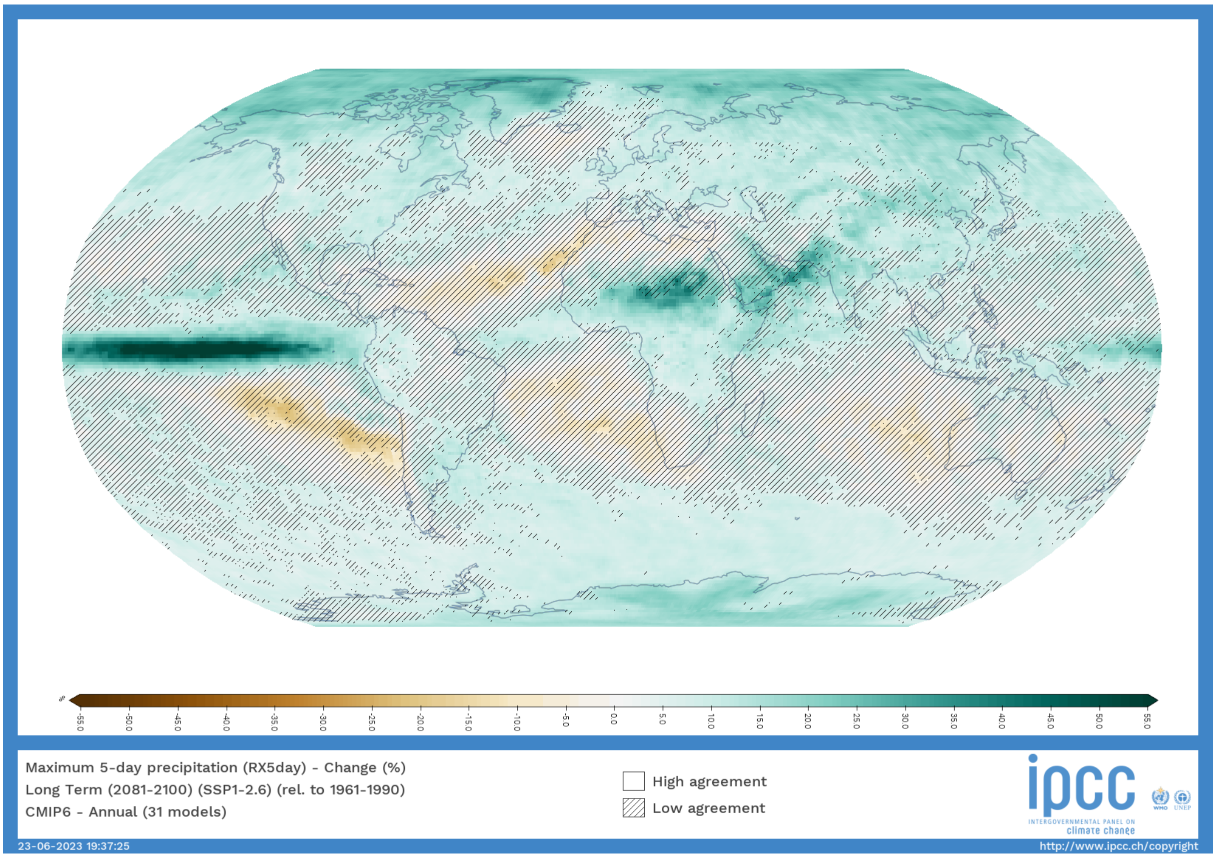
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Maximum 5-day precipitation (RX5day) - Change (%)
Long Term (2081-2100) (SSP1-2.6) (rel. to 1961-1990)
CMIP6 - Annual (31 models)
High agreement
Low agreement
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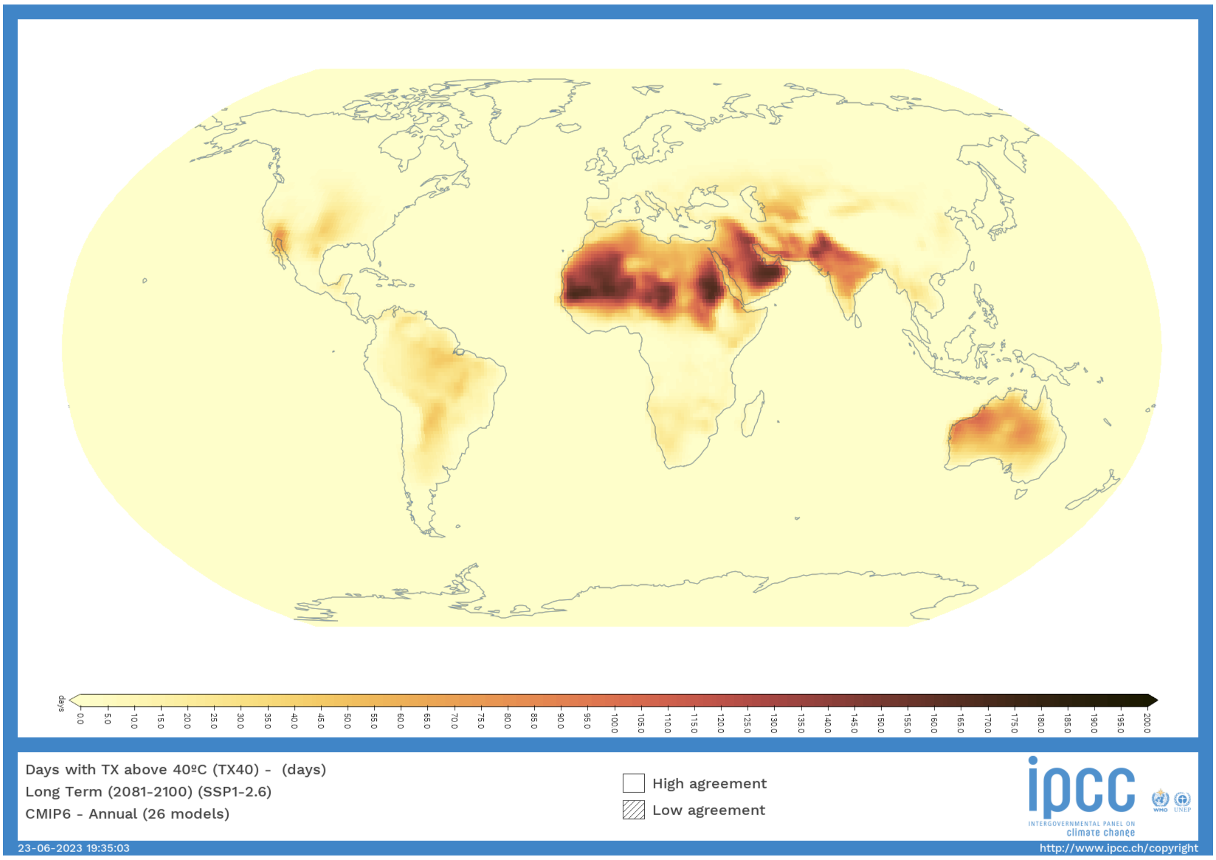
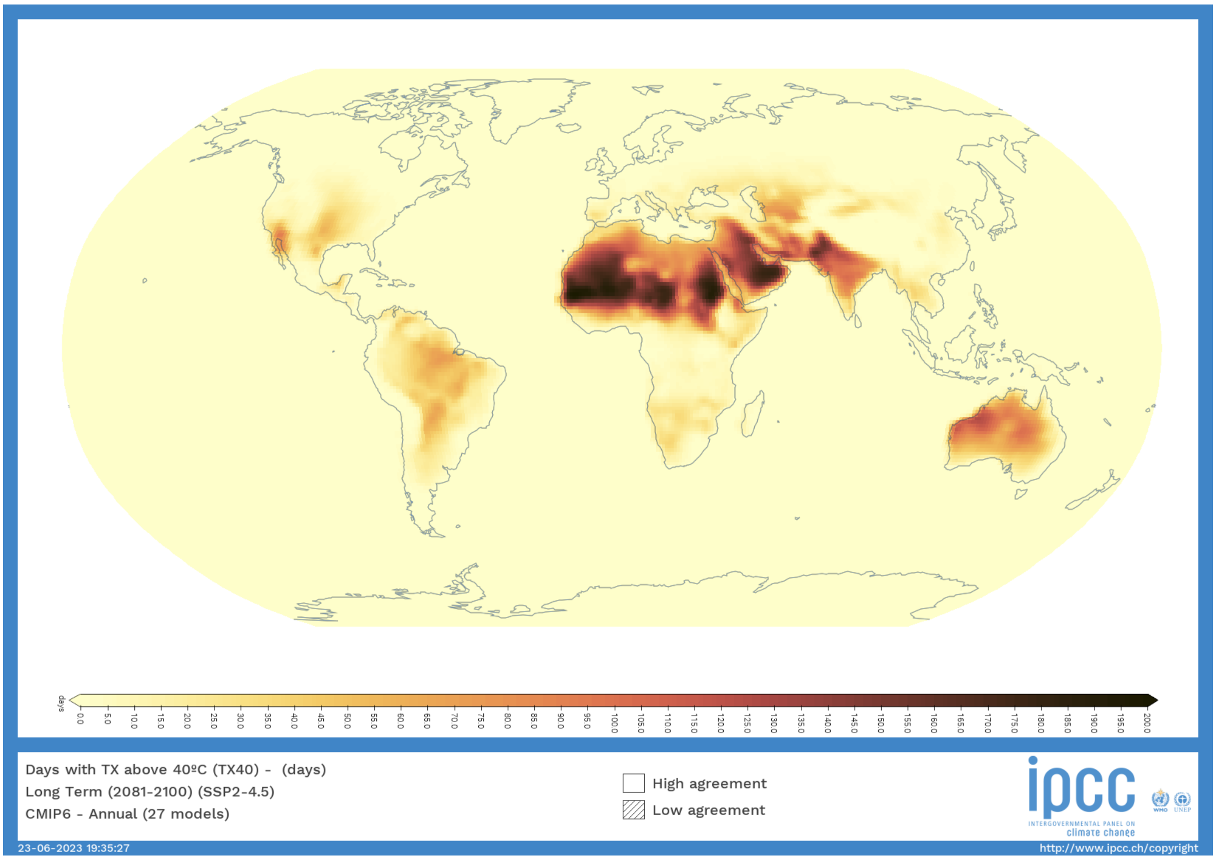

Days with TX above 40ºC (TX40) - (days)
Long Term (2081-2100) (SSP1-2.6)
CMIP6 - Annual (26 models)
High agreement
Low agreement
ipcc
23-06-2023 19:35:03
http://www.ipcc.ch/copyright


Days with TX above 40ºC (TX40) - (days)
Long Term (2081-2100) (SSP2-4.5)
CMIP6 - Annual (27 models)
High agreement
Low agreement
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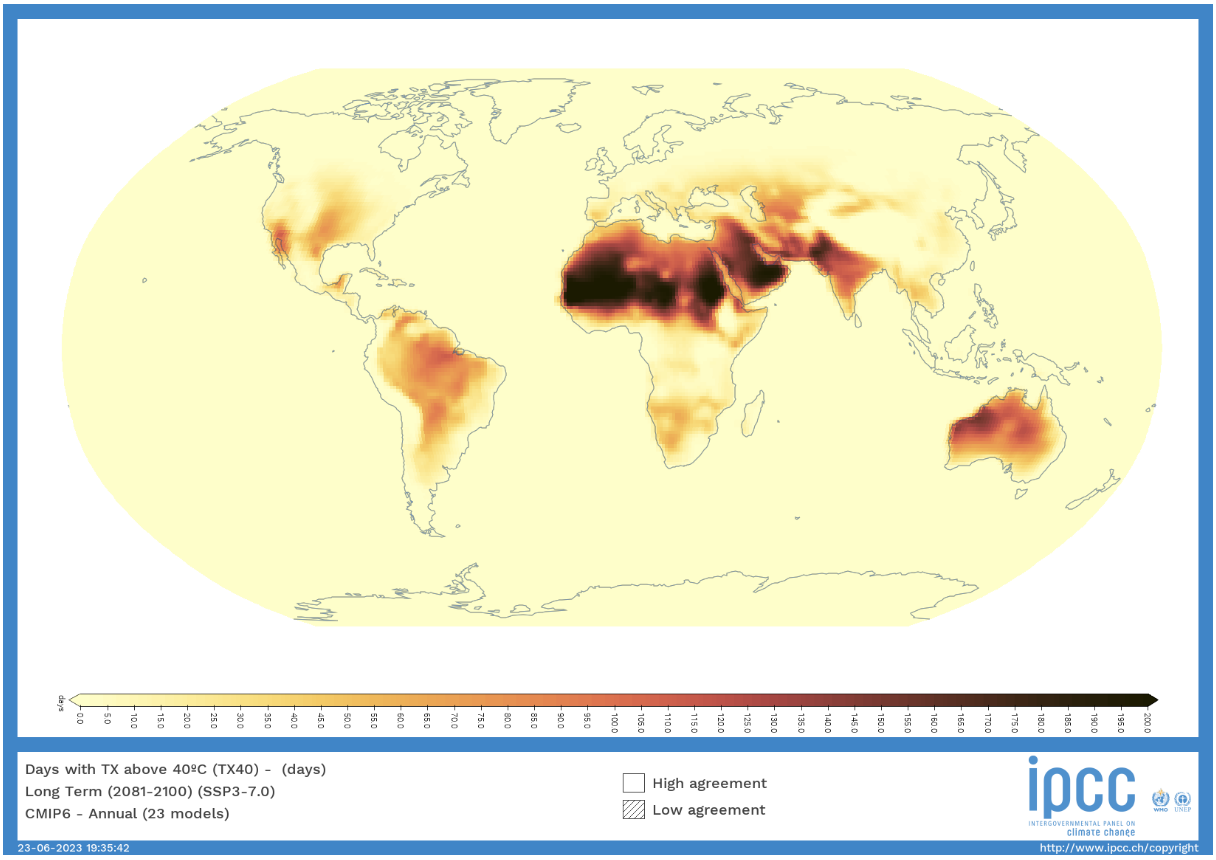
days
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0 65.0 70.0 75.0 80.0 85.0 90.0 95.0 100.0 105.0 110.0 115.0 120.0 125.0 130.0 135.0 140.0 145.0 150.0 155.0 160.0 165.0 170.0 175.0 180.0 185.0 190.0 195.0 200.0
Days with TX above 40ºC (TX40) - (days)
Long Term (2081-2100) (SSP3-7.0)
CMIP6 - Annual (23 models)
High agreement
Low agreement
ipcc
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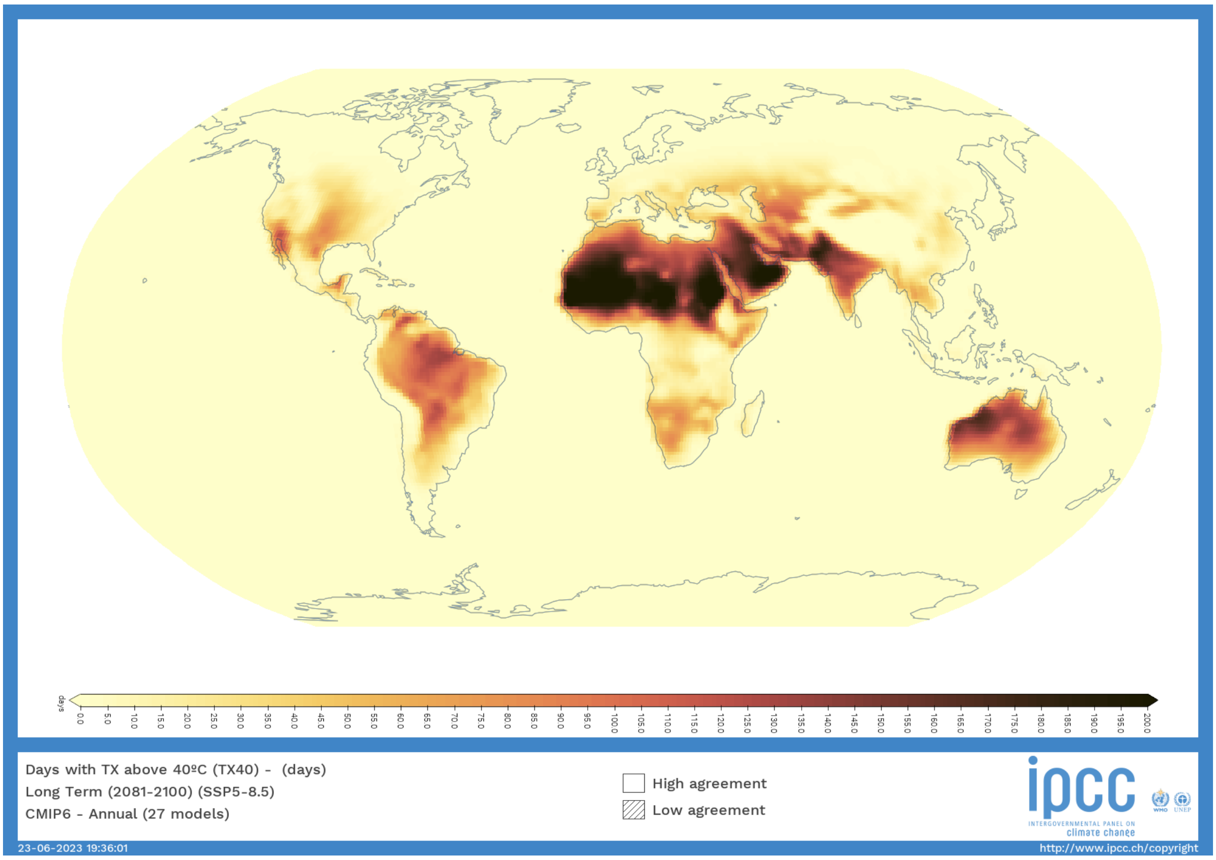
http://www.ipcc.ch/copyright


days
0.0 5.0 10.0 15.0 20.0 25.0 30.0 35.0 40.0 45.0 50.0 55.0 60.0 65.0 70.0 75.0 80.0 85.0 90.0 95.0 100.0 105.0 110.0 115.0 120.0 125.0 130.0 135.0 140.0 145.0 150.0 155.0 160.0 165.0 170.0 175.0 180.0 185.0 190.0 195.0 200.0
Days with TX above 40ºC (TX40) - (days)
Long Term (2081-2100) (SSP5-8.5)
CMIP6 - Annual (27 models)
High agreement
Low agreement
ipcc
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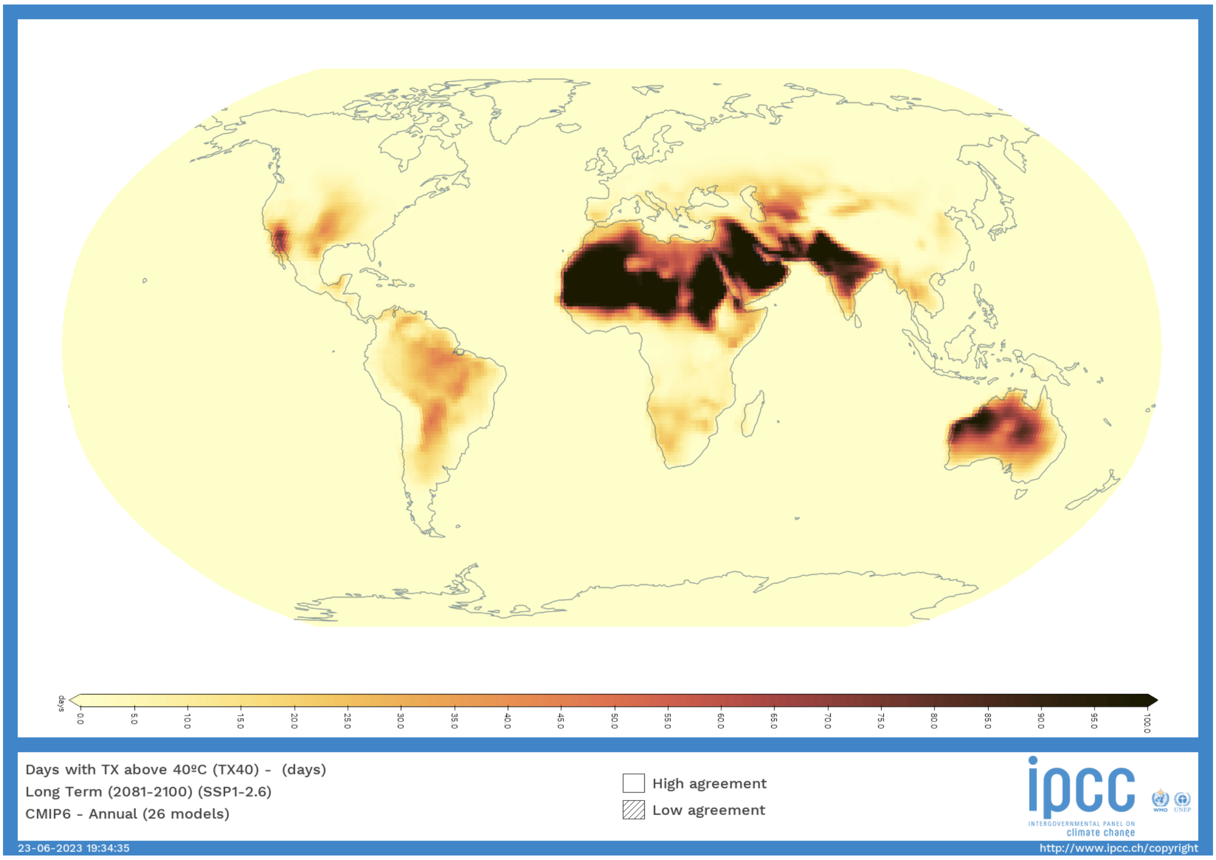
days
Days with TX above 40ºC (TX40) - (days)
Long Term (2081-2100) (SSP1-2.6)
CMIP6 - Annual (26 models)
High agreement
Low agreement
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23-06-2023 19:34:35
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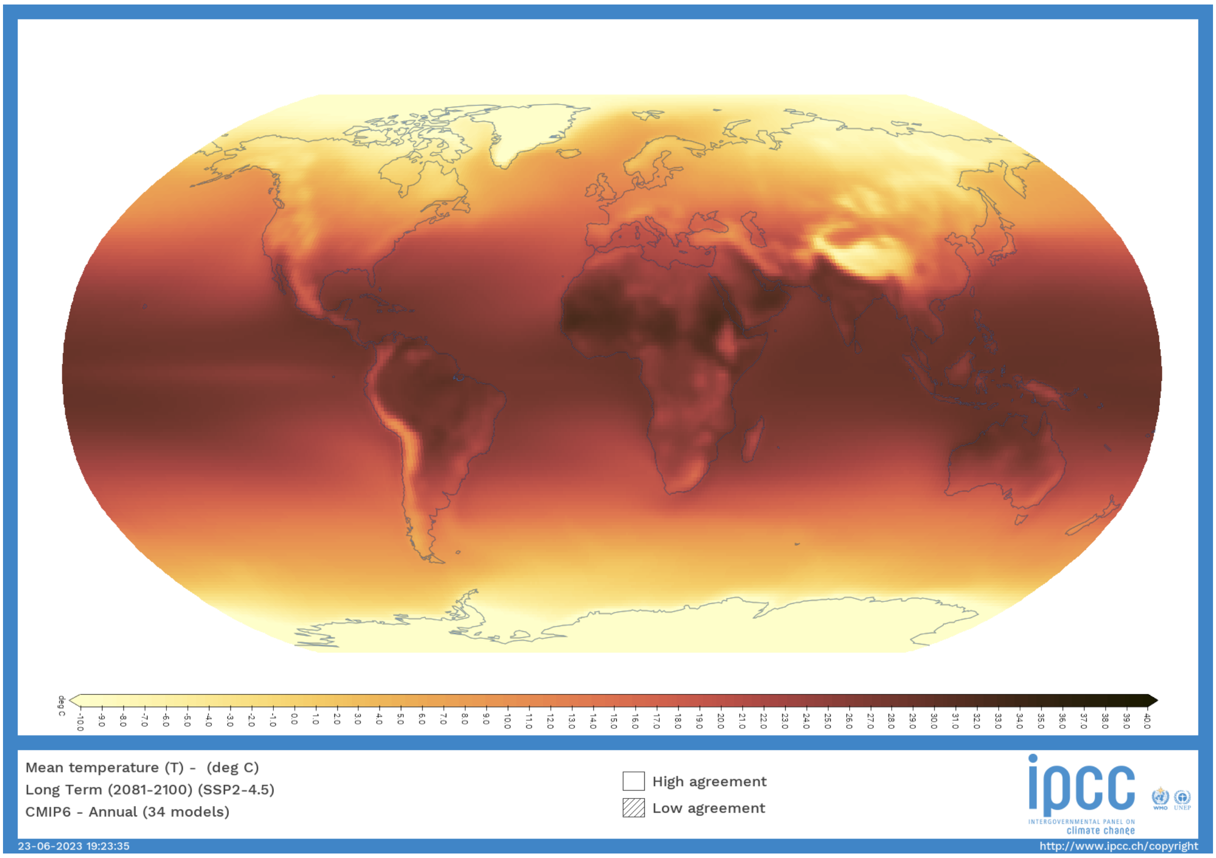
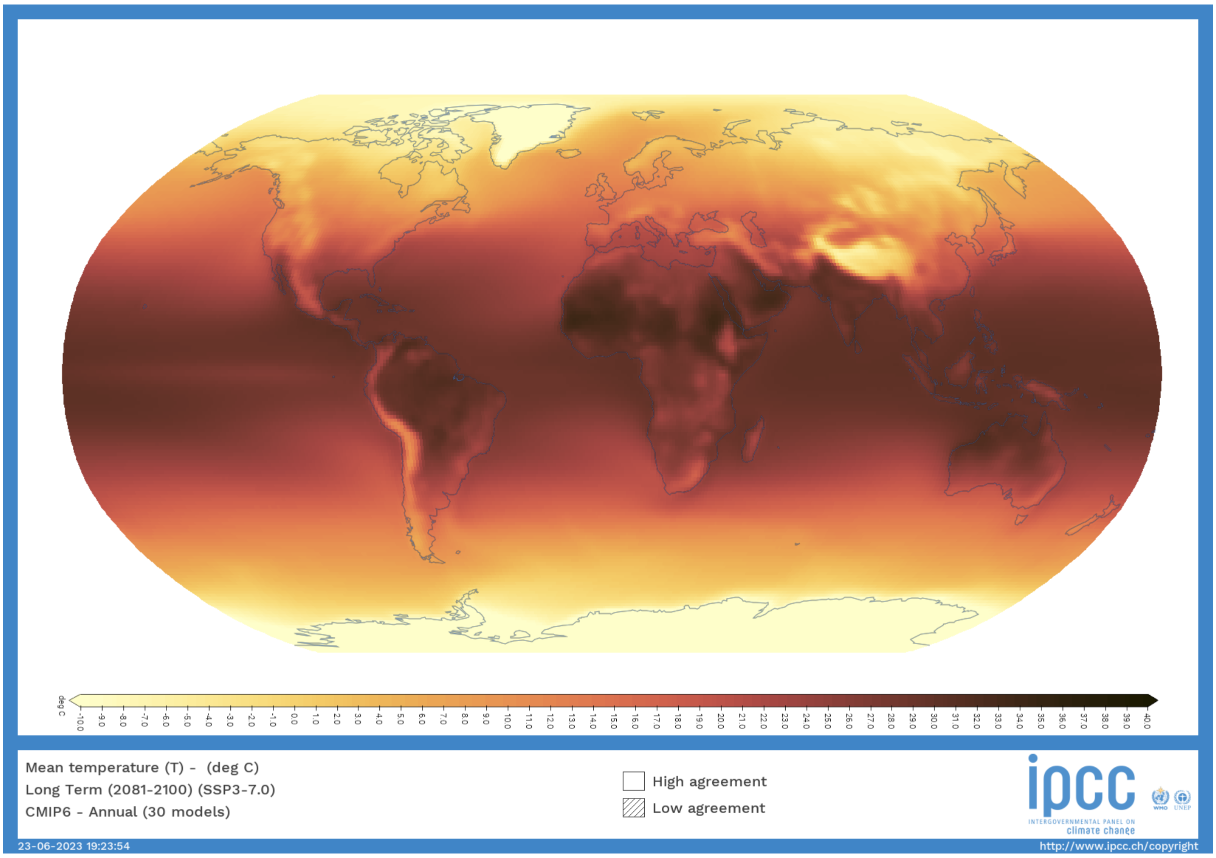

Mean temperature (T) - (deg C)
Long Term (2081-2100) (SSP2-4.5)
CMIP6 - Annual (34 models)
High agreement
Low agreement
ipcc
INTERGOVERNMENTAL PANEL ON climate change
23-06-2023 19:23:35
http://www.ipcc.ch/copyright


Mean temperature (T) - (deg C)
Long Term (2081-2100) (SSP3-7.0)
CMIP6 - Annual (30 models)
High agreement
Low agreement
ipcc
INTERGOVERNMENTAL PANEL ON climate change
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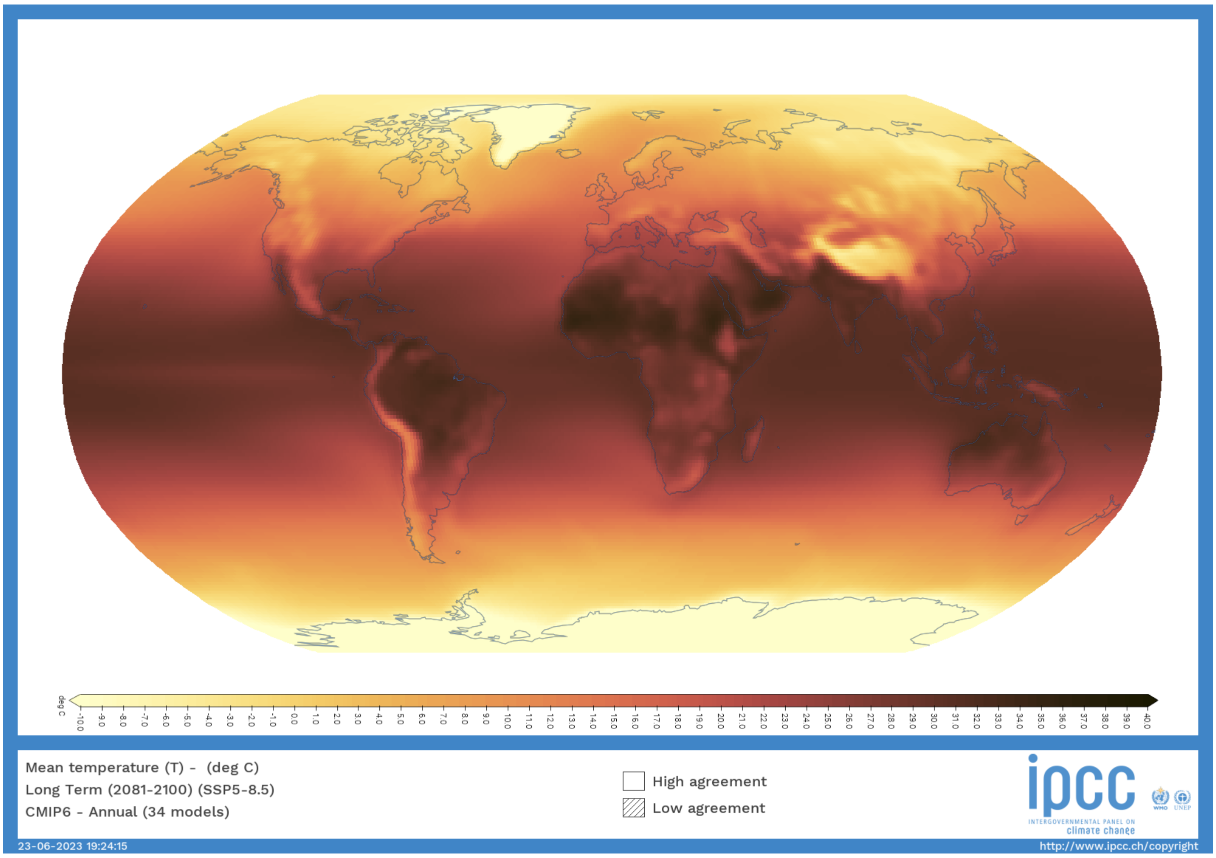
deg C
Mean temperature (T) - (deg C)
Long Term (2081-2100) (SSP5-8.5)
CMIP6 - Annual (34 models)
High agreement
Low agreement
ipcc
INTERGOVERNMENTAL PANEL ON climate change
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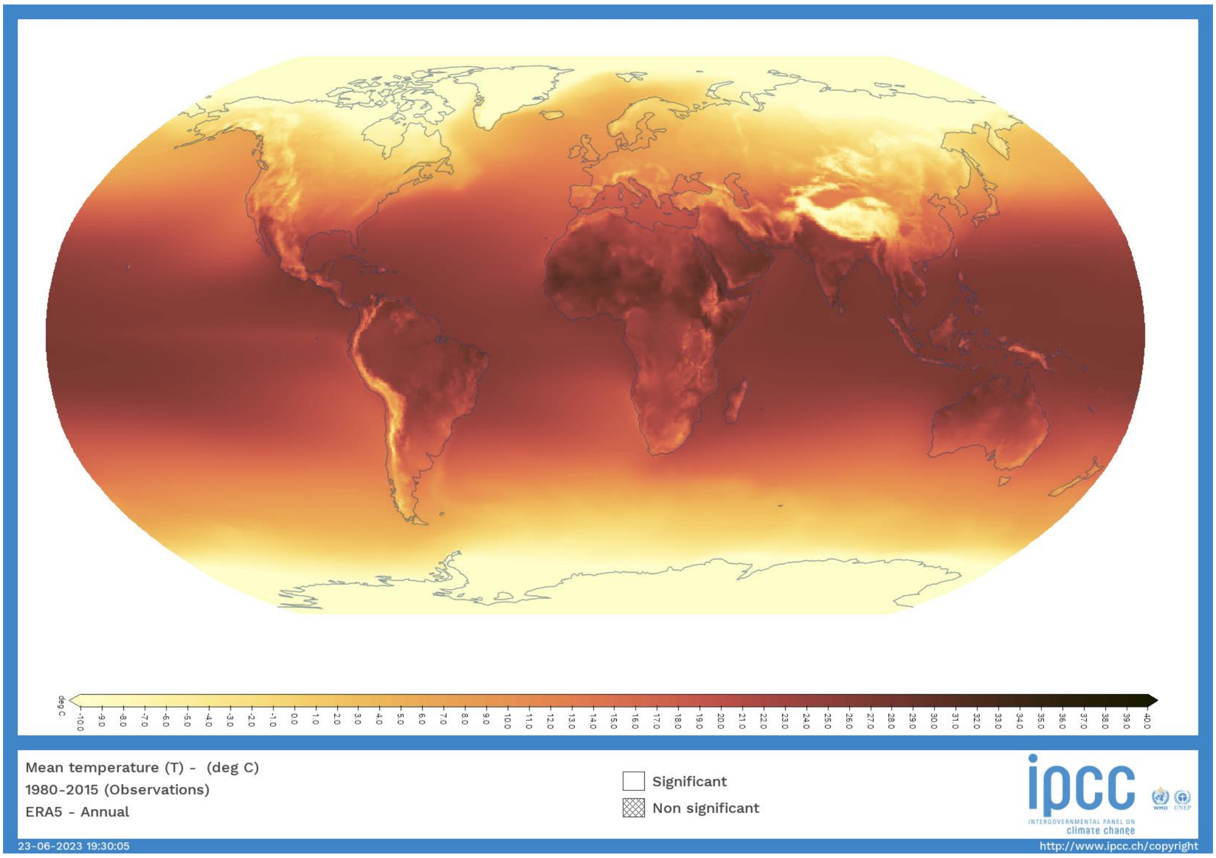
deg C
Mean temperature (T) - (deg C)
1980-2015 (Observations)
ERA5 - Annual
Significant
Non significant
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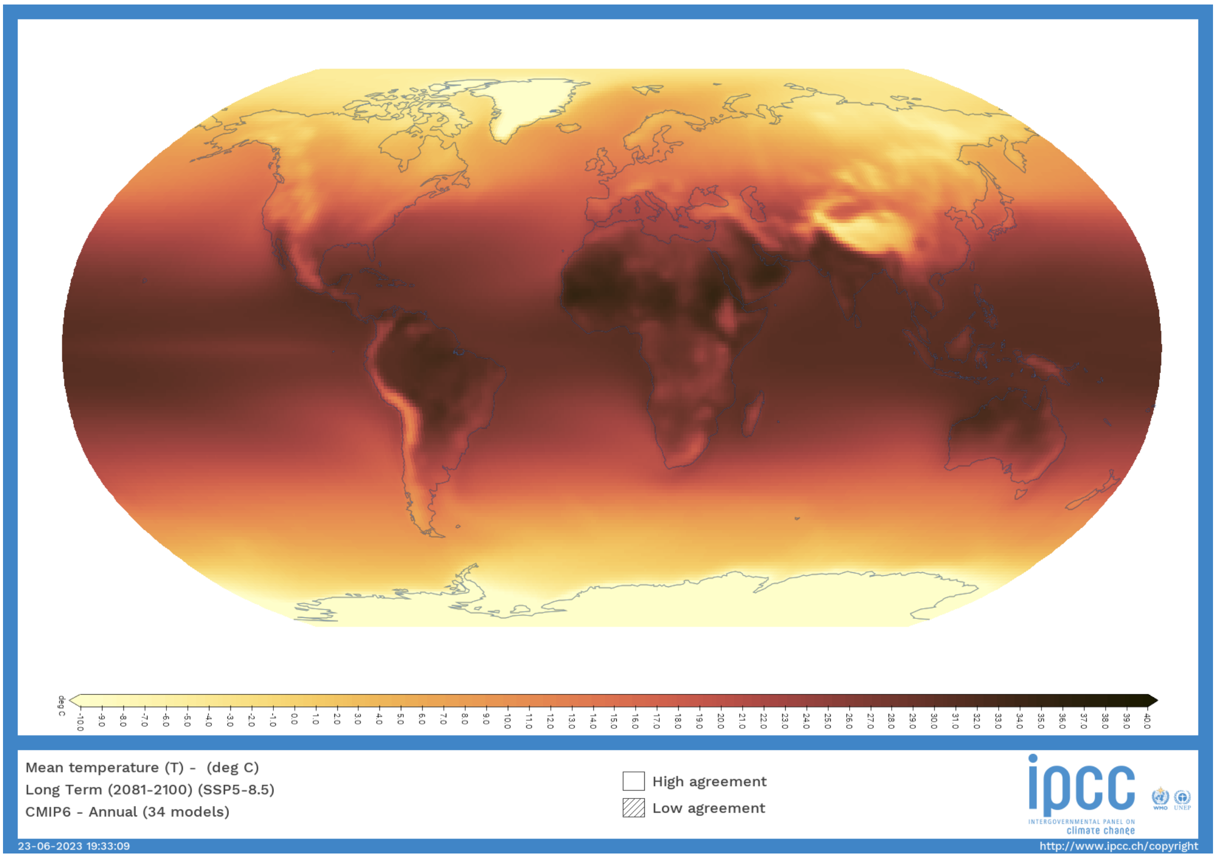
Mean temperature (T) - (deg C)
Long Term (2081-2100) (SSP5-8.5)
CMIP6 - Annual (34 models)
High agreement
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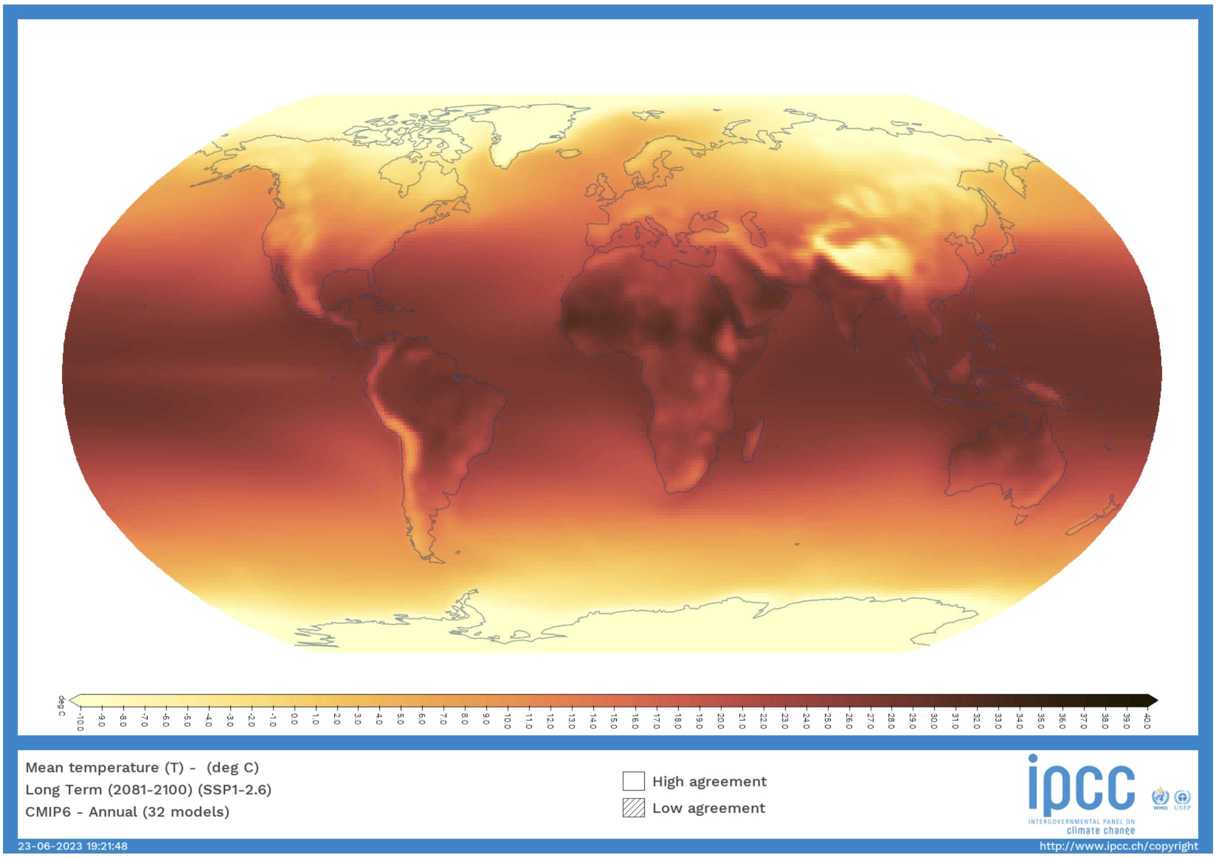
Mean temperature (T) - (deg C)
Long Term (2081-2100) (SSP1-2.6)
CMIP6 - Annual (32 models)
High agreement
Low agreement
ipcc
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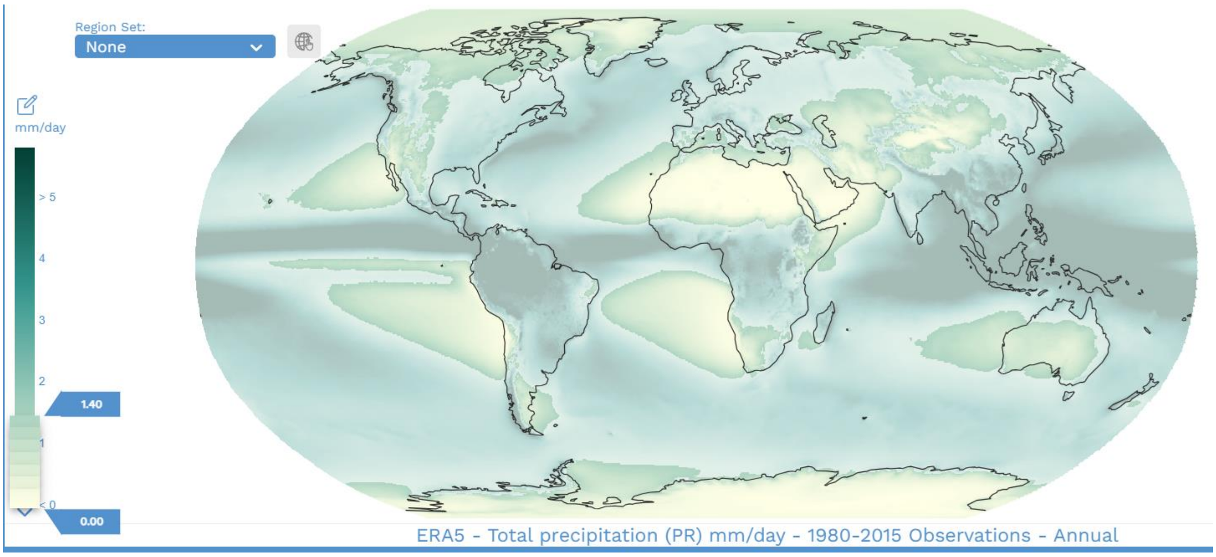
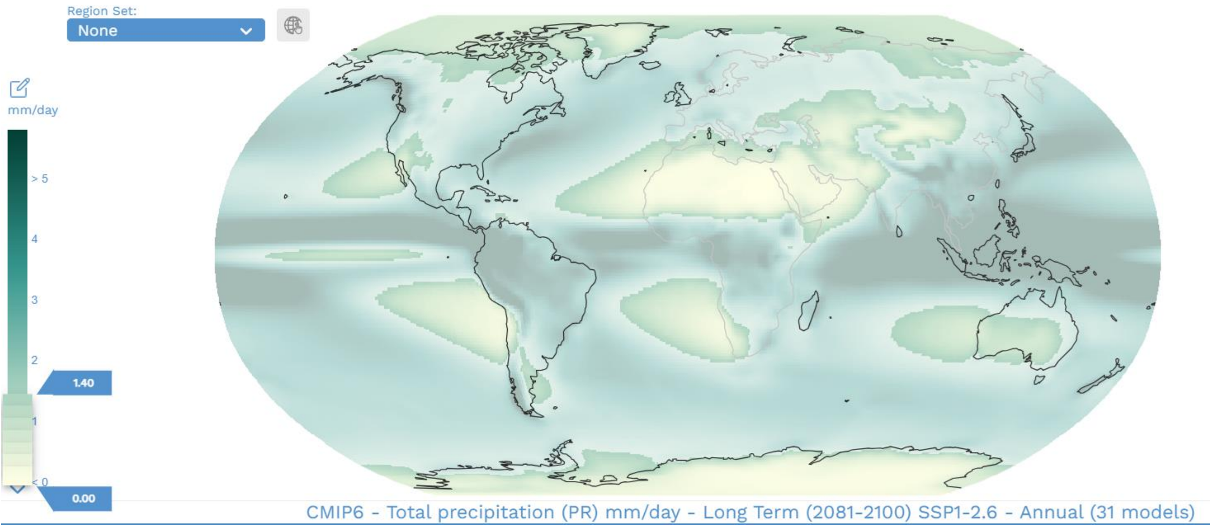
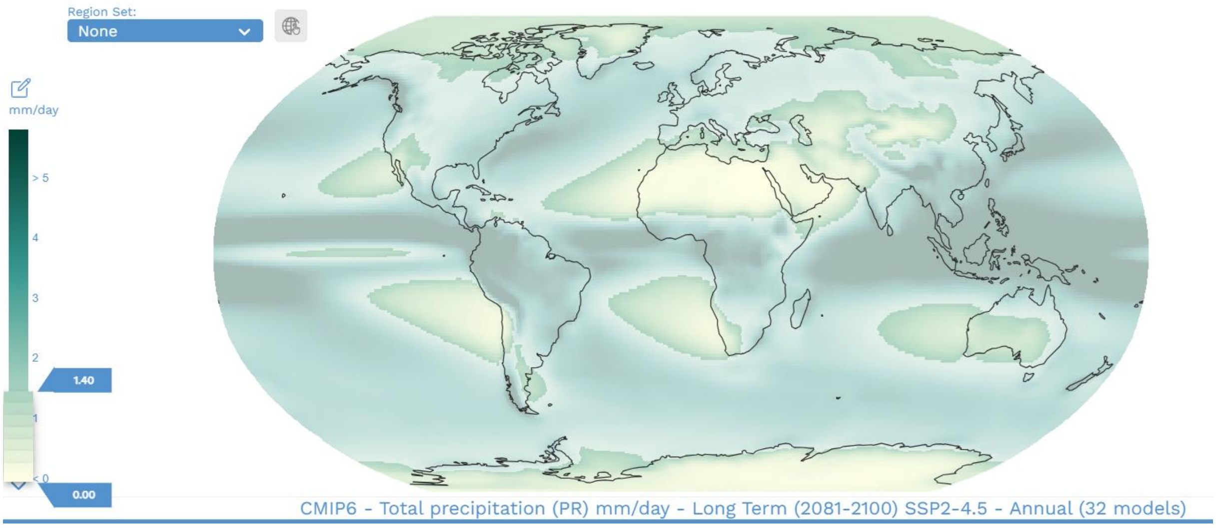
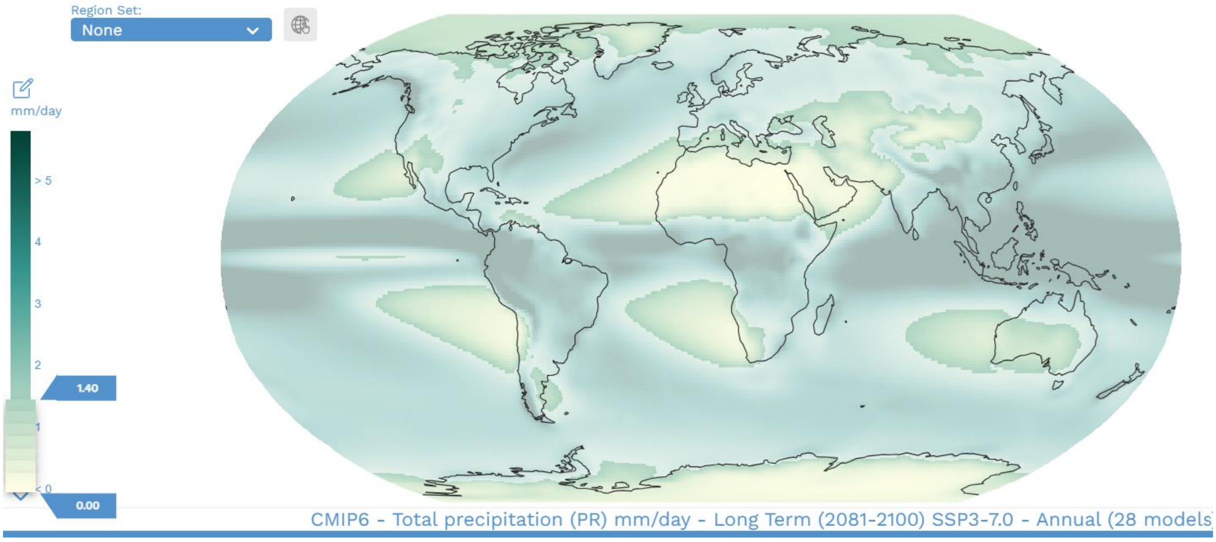


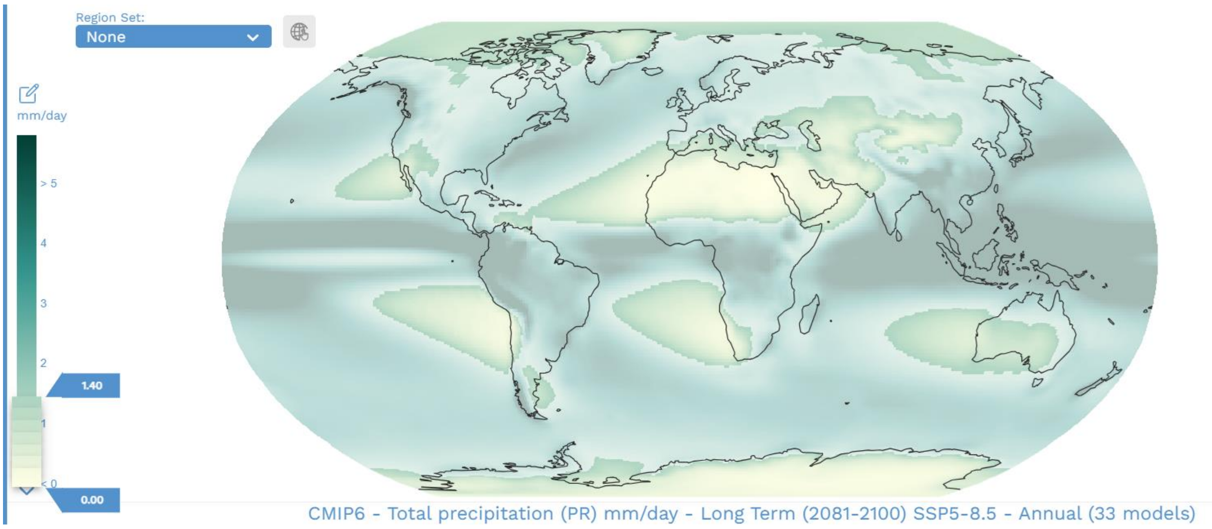
Oben: Era5 Daten für Totale Niederschlagsmengen von weniger als 1.4 mm pro Tag =ca 500mm/Jahr. Gemäss meiner Erinnerung ist das das Limit für Landwirtschaft ohne Bewässerung (oder waren es 300? (Natürlich spielt auch noch die Verteilung über das Jahr eine Rolle, auf die ich hier nicht eingehen kann.)

Unten: Szenarien




Region Set:
None
mm/day
> 5
4
3
2
1.40
1
< 0
0.00
CMIP6 - Total precipitation (PR) mm/day - Long Term (2081-2100) SSP2-4.5 - Annual (32 models)


Region Set:
None
mm/day
> 5
4
3
2
1.40
1
< 0
0.00
CMIP6 - Total precipitation (PR) mm/day - Long Term (2081-2100) SSP3-7.0 - Annual (28 models


Region Set:
None
mm/day
> 5
4
3
2
1.40
1
< 0
0.00
CMIP6 - Total precipitation (PR) mm/day - Long Term (2081-2100) SSP5-8.5 - Annual (33 models)