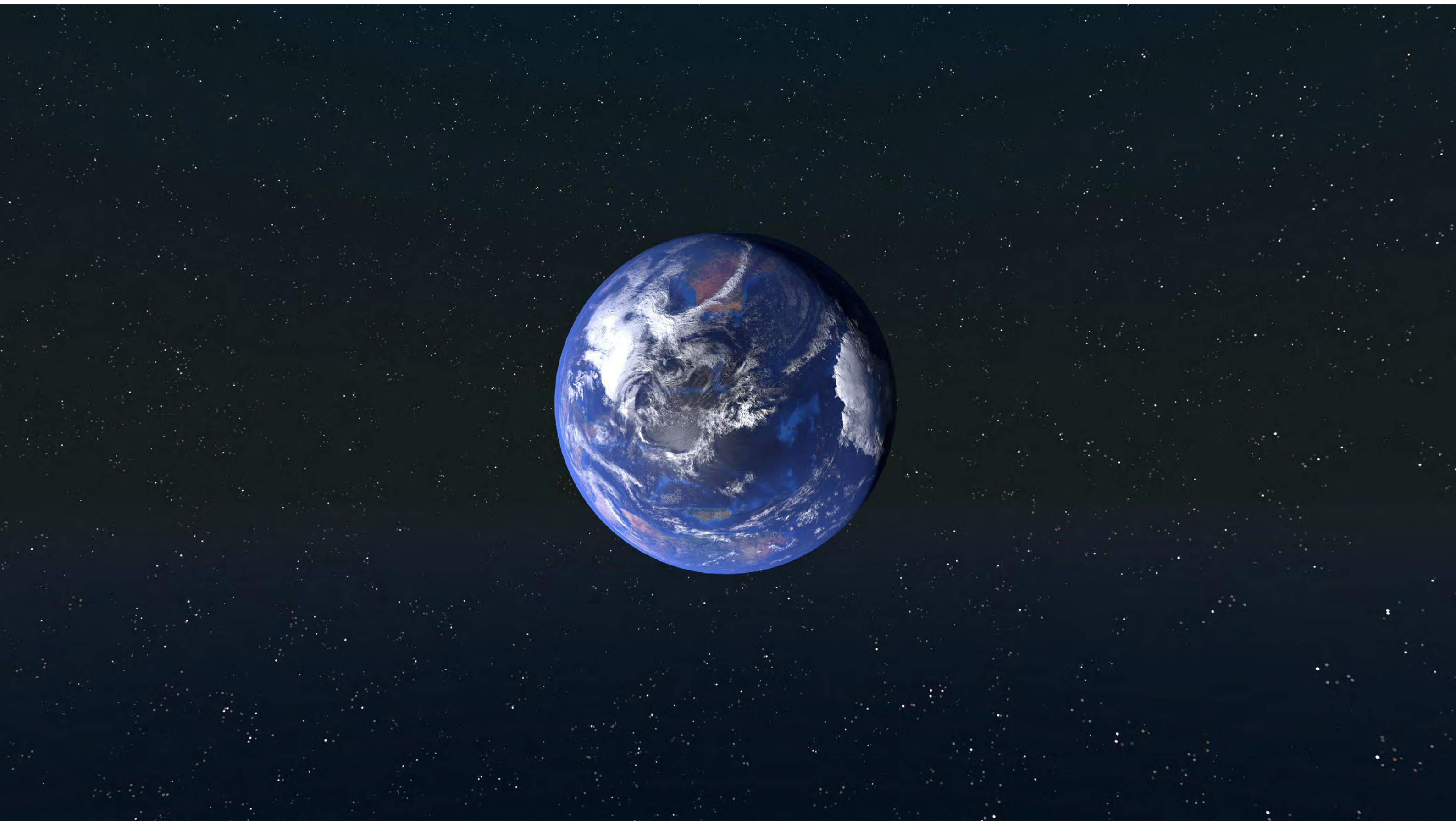
Clim INVEST

October 2020

Climate modeling 101

This factsheet is part of a suite of scientific factsheets intended to build financial decision makers' understanding about climate risk assessment, data needs, climate modeling and extreme events. For more detailed information about floods, heat waves, and drought, and associated indicators, see the ClimINVEST hazard factsheets. We also have a factsheet about physical climate risk assessment. This factsheet provides an overview of the basics of climate modeling and the uncertainties that come with them.



Climate modeling basics

Climate science uses an array of Global Climate Models (GCMs) and Regional Climate Models (RCMs) to represent our current knowledge of the climate system. These models can provide simulations of the past, present, and future climate. The models are made of thousands of lines of computer code solving the equations that represent the physical processes and interactions driving the Earth's climate, whose components are the atmosphere, the oceans, the land surface, the biosphere and the cryosphere (mostly ice sheets and sea ice). These models have been developed over the last decades and are constantly being improved by climate scientists. By solving these equations, the models generate large amounts of climate data, for example humidity, temperature, precipitation, wind, cloud characteristics, soil moisture, streamflow, snowfall or sea ice coverage. Observational data harvested from weather stations, satellites, buoys, ships and aircrafts are used to constrain and validate these models. Scientists use climate models and observational datasets to analyze changes in the mean state of the climate as well as long-term changes in extreme events.

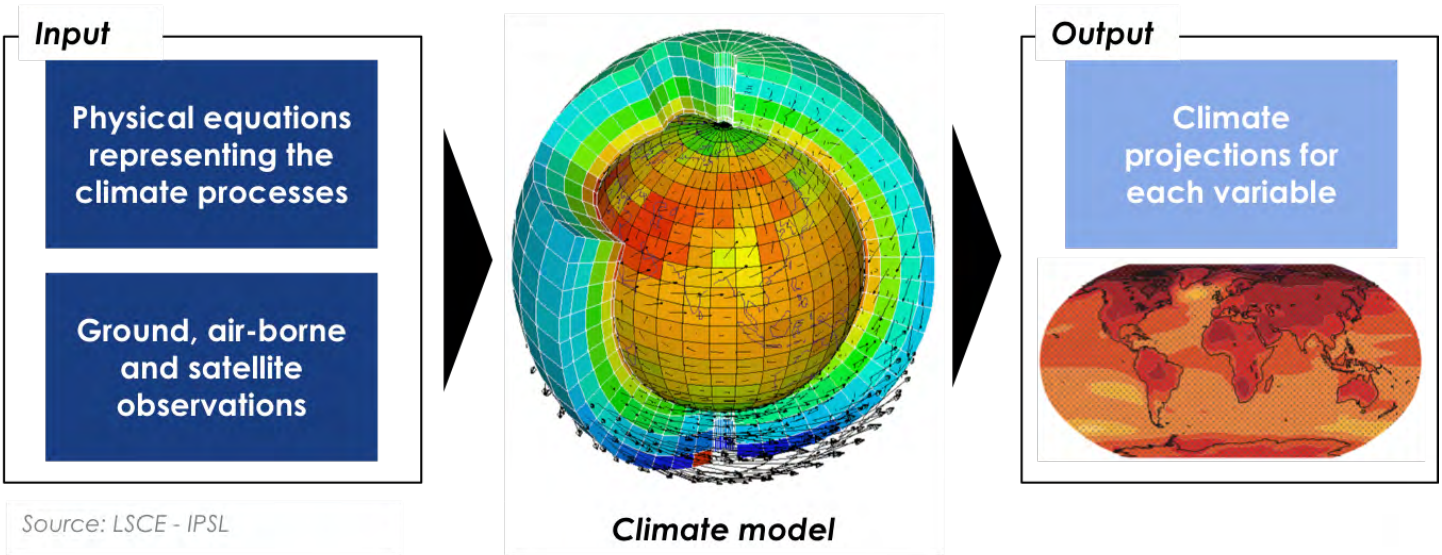


Fig. 1
Climate modeling

At present, there are around 20 to 30 different models from numerous modeling groups around the world. While the basic structure of these models is comparable, each model is built with slightly different parametrizations and resolutions that give partly different results in climate mean states and trends.

Regional climate models (RCMs) can be run at higher resolution than global climate models (GCMs) but for a limited region, by using GCM's data to 'zoom in' on that region. The Coupled Model Intercomparison Project (CMIP) and the Coordinated Regional Downscaling Experiment (CORDEX) are model comparison initiatives for global and regional climate models, respectively, coordinated by the World Climate Research Program (WCRP). The WCRP ensures that global and regional climate models across the world are coordinated by an international comparison program and can be systematically compared and evaluated. Each of these models can be used to simulate the future climate, according to different radiative forcing (or 'greenhouse intensity') scenarios corresponding to different possible future trajectories of greenhouse gas (GHG) emissions and atmospheric concentrations. These scenarios are called RCPs (Representative Concentration Pathways) in the United Nations' Intergovernmental Panel on Climate Change (IPCC)'s fifth assessment report (AR5) and represent different possible futures depending on levels of GHG emissions.

Climate model limitations and uncertainties

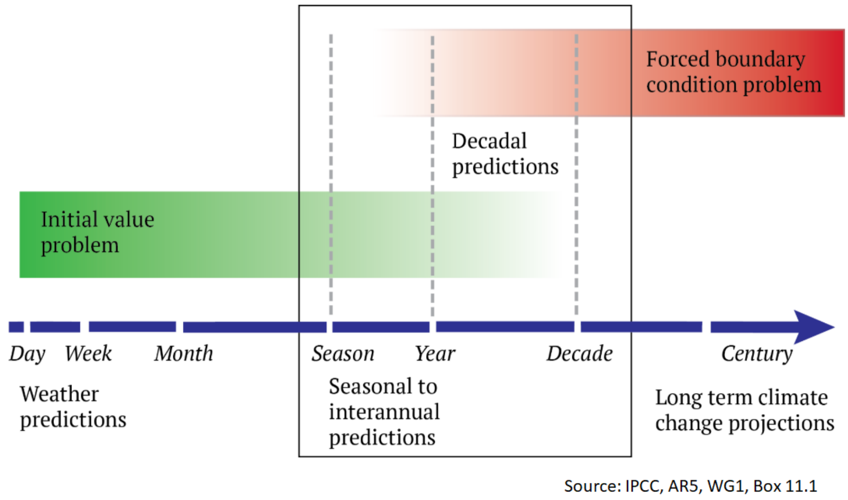


Fig. 2 Climate predictions and projections

Climate models, like all models, are subject to certain limitations and uncertainties that should be considered when used to inform decision-making. These are discussed briefly below.

Time horizons

The global climate system experiences year-to-year and multi-year fluctuations referred to as natural variability; these constitute variations from the averages observed over long periods. Long-term average values in modelled data are calculated to adequately project future climate. The IPCC considers 20 years as the minimum amount of time needed to establish relevant statistics and collect a big enough sample of extreme events. Climate science provides continuous simulations from pre-industrial times to beyond 2100, from which 'time slices' of up to a minimum of 20 years can be selected.

By attempting to represent all the underlying physical processes in the climate system, climate models allow us to quantify the long-term changes in the probability of extreme climate events like storms, droughts or heatwaves. However, decision makers such as investors, seeking information about short term changes in extreme events and their impacts, may need to use other types of data, such as sub seasonal and seasonal forecasts, as well as decadal predictions.

Climate prediction or projection: what is the difference?

Predictions describe probable future climate, from the next several weeks to decades, based on the past on current state of the climate.

Projections describe possible future climate conditions, based on assumptions for greenhouse gas emissions associated with different socioeconomic pathways.

Table 1. Climate predictions and projections by time-horizon

Model	Time horizon	Type of data / source	Strengths and Limitations
Sub-seasonal	Every week; up to 5 weeks	Adapted version of weather forecast models	Provide a general idea of the coming weeks, but generally little skill at higher latitudes.
Seasonal	Every month; up to 4-7 months.	Adapted versions of GCMs	Provide an outlook of future monthly to quarterly averages. Skillful in the Tropics and coastal areas, where the atmosphere is strongly coupled to the ocean. Sometimes skillful in the higher latitudes (winter).
Decadal	Annual, multi-Annual to decadal.	GCMs. (e.g. CMIP)	Useful to understand process in the climate system; still being developed.
Scenarios	Hundreds of years	GCMs and RCMs run within intercomparison projects e.g., CMIP and CORDEX	Our best estimates of future climate, good estimates of the different source of uncertainties as several ensemble members are run in parallel. They can be used to look at the next 10, 20, 30, years and beyond. GCMs: global simulations but relatively coarse spatial resolution. RCMs: Higher spatial resolution but only regional /localized simulations.

Predicting extreme events

Extreme events are by definition events that rarely happen. Since these events rarely occur, we do not have reliable statistics for them in the relatively short period of time in which we have observational record (past 50 to 100 years). It is therefore not always possible to assess whether some of these extreme events become more or less frequent due to climate change based only on observations. Climate change shifts the statistics of extremes affecting their frequency and intensity.

We can use climate models to simulate the recent past many times over, and so obtain a much larger sample of plausible 'pasts' and hence, better statistics. This is also routinely done with future projections with the same goal: obtaining more robust statistics. However, climate models are also known to not always represent these extreme events very well. In general, scientists are confident in the model's representation of heatwaves, but less so in very localized events, such as heavy precipitation from thunderstorms in the summer.

Spatial resolutions

GCMs simulate the climate on a global grid ranging between 50x50 km to 300x300 km. RCMs provide the same type of information as a GCM for a specific region (e.g. Europe or southeast Asia) with higher spatial resolution. Some regional climate models can provide grid box sizes down to a couple of kilometers. Overall, increasing resolution can provide more spatial detail, which is important especially in mountainous and coastal areas. Data from regional models covering a specific continent (e.g. Europe, Africa or North America) with a spatial resolution of 10-50km derived from RCMs can therefore be more informative than global data from GSMs (resolution of 100-200km) for local and regional decision making.

Bias correction

The statistics of historically modeled climate data and historical observations can deviate from each other, since climate models are – although currently the best possible option – only an approximation of the real-world. To correct for such deviations, bias correction procedures are often used. Bias correction involves a statistical correction of model data based on observations with the aim to improve the reliability of future projections.

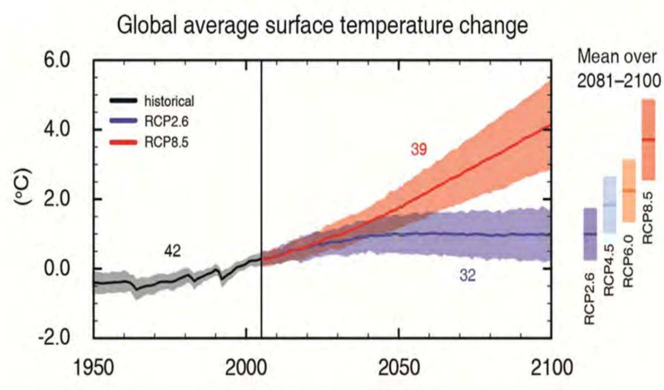


Fig. 3: Climate projections across different scenarios

Climate variables and indicators

The output data from climate models are called climate variables, for example temperature, precipitation or humidity. Some variables are better represented by climate models than others. Changes in average temperature are easier to predict than changes in extreme precipitation. There are some parts of the world where models agree well on future change (more, less or no change in precipitation for example) and other regions where they disagree.

Climate variables can be used as such or can be converted into climate indicators, which can be used to classify and quantify potential impacts of climate events. Model led climate indicators can be validated similarly as the raw climate variables, i.e. by comparing them to climate indicators computed from observations. Examples of climate indicators include heat waves, cold spells, or precipitation. Several indicators can be used to describe the different aspects of climate events. Indicators can potentially be adapted to users' needs, visualized as maps and be used to demonstrate an asset's exposure to a climate hazard. See climate hazard factsheets on flooding, heat stress and drought for more information.

Table 2. Climate variables

Climate variable	Climate indicator
Temperature	Probability of exceeding 35 degrees C
Precipitation	Frequency of 'very wet' days exceeding 20 mm of rain
Humidity	Apparent temperature
Wind speed	Extreme wind

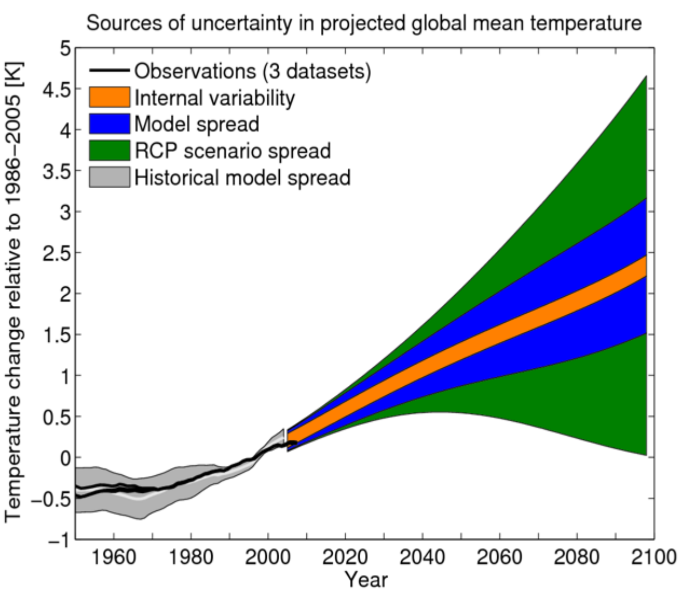


Fig. 4 Sources of uncertainty. IPCC, AR5.

Emissions and potential future scenarios

Climate scenarios provide us with a range of possible futures, which are similarly likely to happen. While climate scenarios are developed on a global scale, the regional implications of global warming can be very different.

Climate researchers have developed around 1200 scenarios that chart different possible levels of future emissions among other aspects such as land use changes. These scenarios all represent different assumptions and are loosely grouped into four representative scenarios with an associated range of global warming. These four representative scenarios are called Representative Concentration Pathways (RCPs). The RCPs describe different potential warming from emissions, going from the most optimistic (RCP 2.6) to the most pessimistic (RCP 8.5). RCP 2.6 is associated with global warming below 2°C by 2100.

RCP8.5 describes a fossil-fuel intensive future with close to 5°C warming by 2100.

Figure 3 shows the global average surface temperature projections for RCP 2.6 and RCP 8.5 starting from 2006 and historical simulations from 1950 to 2005. The uncertainty around the RCPs are shown by the red (or purple) shading around the average coming from the simulations of 39 (RCP8.5) and 32 (RCP2.6) models, respectively. For example, with RCP8.5, global mean temperatures at the end of the century can range between approx. 2.8-5.4 °C due to different models and natural variability.

It is important to note that a scenario describes plausible climate conditions but is **not associated with a specific probability.**

The IPCC's 6th Assessment Report (2021-2022) and Shared Socioeconomic Pathways

The RCPs, developed as part of the IPCC's Fifth Assessment Report (AR5) in 2014, are intended to reflect different potential climate outcomes but they lack any consistent set of socio-economic assumptions driving future emissions. The IPCC's Sixth Assessment Report (AR6) will compare five Shared Socioeconomic Pathways (SSPs), representing socioeconomic and demographic trajectories that the world could follow this century. Each of these SSPs has a baseline in which no climate policies are enacted after 2010. The SSPs, unlike the RCPs, are assigned probabilities to help decision makers select the most likely scenarios.

Scenario uncertainties

Future greenhouse gas emissions will be determined by socio-economic and political decisions made today, such as the rate and level of deployment of carbon pricing, energy efficiency, renewable energy, electric vehicles, sustainable land use and carbon capture and storage. It is not possible to accurately predict how all these factors will evolve in the long-term. To get a glimpse of the possible futures, climate scientists develop projections in the form of RCPs and SSPs, which are highly uncertain. Figure 4 shows that there are three main sources of uncertainty in climate projections: scenario uncertainty (green), inter-model differences (blue) and internal climate variability (orange). The spread between scenarios is the dominant source of uncertainty. Scenario uncertainty refers to the imperfect knowledge regarding future emissions and socio-economic and demographic developments in the future. Inter-model differences or model uncertainty refers to the differences in projections derived from different models and our imperfect knowledge about the climate system. Internal or natural variability refers to changes in weather and climate that are not a result of anthropogenic activities. This variation of the climate system around the mean state is due to the natural, internal processes that occur in the climate system. Figure 4 also shows that decisions made now can have a significant impact on the climate in the future while the scenario uncertainty (i.e. what pathway we follow) increases the longer the time frame considered ahead.

Business-as-usual uncertainty

The Paris Agreement sets global targets to keep warming well below 2 °C above pre-industrial levels. Current National Determined Contributions (NDCs) and existing policies point to 3 °C or 4 °C warming through the end of the century, associated most closely with RCPs 4.5 and 6.0. The business-as-usual trajectory – one where progress on climate policy and clean technology stays the same – is contested among scientists because the effects of feedback effects, such as emissions from thawing permafrost, deforestation rates, are uncertain.

Recent research suggests that a 3°C increase above pre-industrial levels is more likely than a 5°C increase given the falling cost of clean energy sources and clean transportation technologies, as well as the general consensus that coal use peaked in 2013. "Emissions pathways to get to RCP 8.5 generally require an unprecedented fivefold increase in coal use by the end of the century, an amount larger than some estimates of recoverable coal reserves."

As outlined in the section above, the choice of scenario is more relevant for longer time horizons than for the near term (i.e. 10-20 years). Using the "worst case" RCP 8.5 scenario to stress test systems can be a useful exercise to stress test response systems or portfolios, but it should not be assumed the business-as-usual scenario.

Key takeaways

Emissions associated with every long-term investment or policy decision count. Scenario uncertainty depends on policy and investment decisions made today. Long-term uncertainty can be reduced by making clear decisions on energy infrastructure investments and policy that either reduce or lock-in long-term emissions.

For the next 0 to 5 years, natural variability presents the biggest unknown. Because past emissions have locked in the current climate effects, scenario selection is not relevant for this timeframe.

> **Data sources:** Statistics on climate events can be drawn from observations, and sub-seasonal and seasonal forecasts. The latter can provide information on the likelihood of extreme events or anomalous seasons for 3 to 6 months ahead.

For the next 5 to 20 years, natural variability still presents the biggest unknown. The effects of past emissions are still locked in, but some difference in scenario trajectory may be decipherable.

> **Data sources:** Decadal predictions (see CMIP decadal predictions) can help assess general climate trends but will not provide robust statistics for extreme events nor predictions of when extreme events will occur.

For over 20 years in the future, climate model uncertainties present the biggest unknown. The choice of RCP and SSP will be relevant and significant. In order to assess which RCP or SSP is appropriate, a careful analysis of given locations and sectors should be made.

> **Data sources:** Information about the probability of an extreme event happening within that timeframe is available via CMIP and CORDEX.

References

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Project ClimINVEST is part of ERA4CS, an ERA-NET initiated by JPI Climate, and funded by RCN (NO), ANR (FR), NWO (NL) with co-funding by the European Union (Grant 690462)