# Using Climate Data

## A primer to inform the use of climate data in financial institutions, businesses and governments.

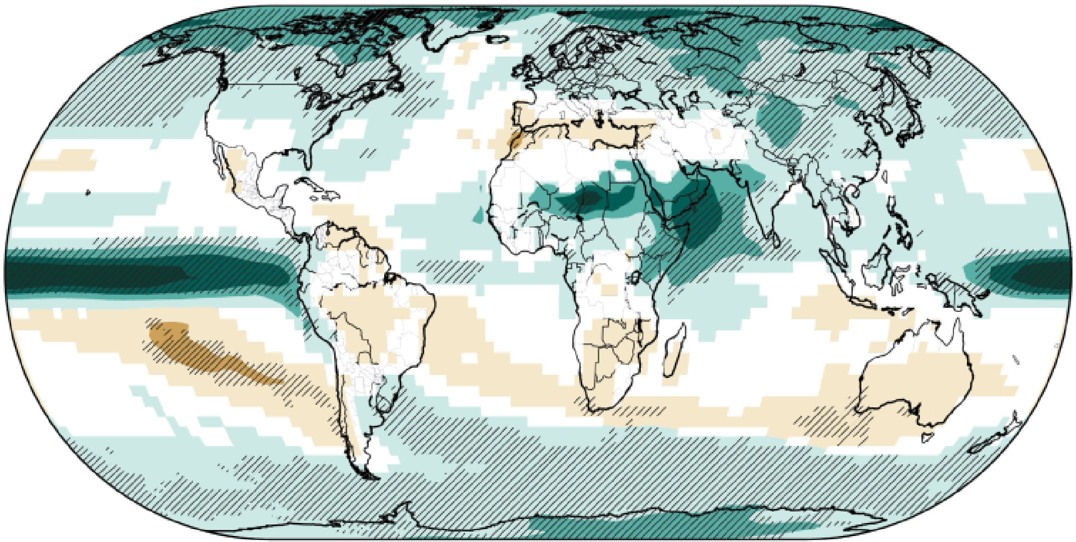


Image Source: NOAA NCDC / CICS-NC, from nca2014globalchange.gov

Four Twenty Seven, April 2018

## KEY TAKEAWAYS

- Climate models are simulations of the Earth's future conditions. Climate projections are based on a compilation of many models and are publicly available.
- Regional climate models and statistical downscaling improve the resolution of data produced by global climate models and are thus valuable options when projections are only needed for one location or several in the same region.
- Climate models can be used to project future trends in temperature and precipitation, but cannot project discrete storms or local flooding from sea level rise, which require additional data.
- Different time horizons of climate projections have different strengths and limitations so it is important to select the data product best suited to a specific project's goal.
- There are several drivers of uncertainty in climate models and strategies to hedge this uncertainty can help users correctly interpret and use climate projections.

## INTRODUCTION

Financial institutions, corporations, and governments are increasingly striving to identify and respond to risks driven by physical climate impacts. Understanding the risks posed by climate change for facilities or infrastructure assets starts with conducting a risk assessment, which requires an understanding of the physical impacts of climate change. However, climate data in its raw form is difficult to integrate into enterprise risk management, financial risk modelling processes, and capital planning. This primer provides a brief introduction to climate models and data from a business or government perspective.

## CLIMATE MODELS

Climate models are simulations of the future state of the Earth, which use physical equations to represent complex and interconnected Earth processes. These models are developed and run by governments and research institutions around the world. They incorporate cutting edge climate science and are treated as a plausible future climate from which to assess risk and impacts.

To evaluate future climate change, researchers often use the output from several distinct climate models and these projects are coordinated between organizations to allow for intercomparison. Their outputs are made publicly available for users interested in understanding future climate change scenarios or impacts.

For its Fifth Assessment report, the Intergovernmental Panel on Climate Change (IPCC) relied on an ensemble of over 40 such climate models from the Coupled Model Intercomparison Project Phase 5 (CMIP5), released in 2012.[1]

## CLIMATE DATA

Climate models produce gridded data globally (Figure 1). They contain historical observations and future projections for dozens of variables (e.g. air temperature, precipitation, ocean temperature). Each grid represents the approximate value for every variable on a daily basis (or sub-daily, e.g. 3-hour increments), over 95 years or more (2005-2100), for at least three greenhouse gas concentration trajectories: (RCP 2.6, 4.5 and 8.5), known as emission pathways.

The resolution of raw output from a CMIP5-era global climate model (GCM) is typically greater than 1 degree of longitude by 1 degree of latitude, (roughly 100km$^2$), and consequently does not

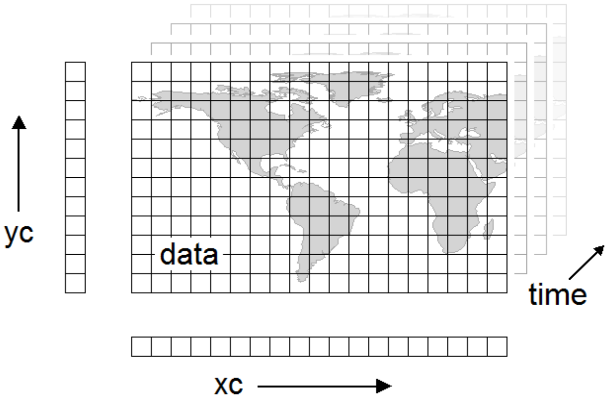


*Figure 1. Illustration of climate data grid over time. Source: UCAR NARCCAP*

---

[1] Flato, G., J. Marotzke, B. Abiodun, P. Braconnot, S.C. Chou, W. Collins, P. Cox, F. Driouech, S. Emori, V. Eyring, C. Forest, P. Gleckler, E. Guilyardi, C. Jakob, V. Kattsov, C. Reason and M. Rummukainen, 2013: Evaluation of Climate Models. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

sufficiently represent topography.[2] Figure 2 illustrates how global climate models in their raw form have very low resolution which limits their efficacy for impact analyses.

There are different responses to these issues. First, running Regional Climate Models (RCMs) can "dynamically downscale" the original GCMs, improving granularity and incorporating much better local topography. However, regional climate models do not cover the entire globe and do not allow for interregional comparison (e.g. to compare relative exposure between Europe and Asia).

Second, climate scientists have developed a set of methodologies to "statistically downscale" climate outputs and improve resolution. For example, NASA used statistical downscaling to produce global climate data at a scale of 1/4th of a degree, roughly 25km[2,3].

A more recent statistical downscaling project brought precision of 1/16th of a degree for the United States, but that precision is not yet available globally.[4]

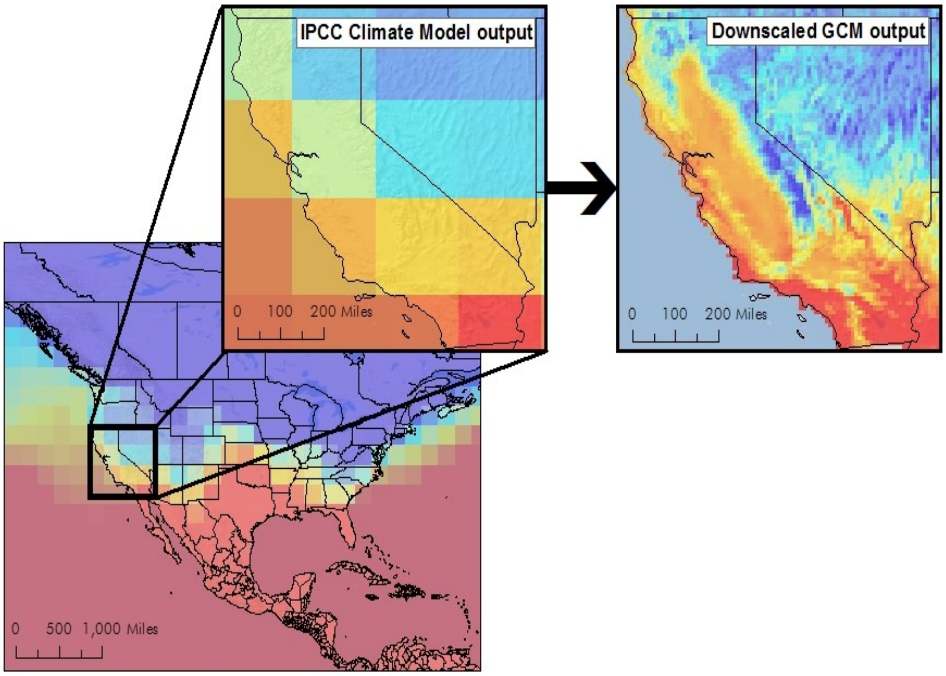


*Figure 2. Global climate models have low resolution output, which can be improved by downscaling. Source: Cal-Adapt*

## DATA FORMAT

Between all variables, time steps, scenarios, models, and institutions, the output from an intercomparison project routinely yields terabytes of raw data.

To accommodate its massive volume, climate data is usually produced and stored in netCDF files. This is a highly compressed file format that helps reduce the storage requirements for climate scientists, but also creates major technical barriers for inexperienced users.

Due to the file format and the raw size of the data, analysing the risks of climate change over many facilities with multiple metrics requires significant computing power and a specialized workflow.

---

[2] ENES (2016): https://portal.enes.org/data/enes-model-data/cmip5/resolution
[3] NASA Earth Exchange (NEX) (2015): https://nex.nasa.gov/nex/static/media/other/NEX-GDDP_Tech_Note_v1_08June2015.pdf
[4] Bureau of Reclamation (2016): https://gdo-dcp.ucllnl.org/downscaled_cmip_projections/techmemo/Downscaled_Climate_Projections_Addendum_Sept2016.pdf

## FROM RAW DATA TO CLIMATE INDICES

Since climate models aim to be complete simulations of the Earth's systems, their output spans a wide breadth of variables related to natural and anthropogenic processes.

Variables range from general (e.g. air surface temperature) to highly specialized (e.g. rate of emission of dry aerosol secondary organic matter).[5] Variable uses vary widely across disciplines, but the most useful metrics for impact assessments tend to be temperature and precipitation.

As with all climate data, temperature and precipitation projections come in daily or sub-daily time steps, and therefore need substantial processing before meaningful insights can be extracted. Full time series can be processed into indicators of extreme weather events, giving insight into changing extremes.

Dozens of indices, such as those developed by the Expert Team on Climate Change Detection and Indices (ETCCDI),[6] exist in scientific literature to help define and identify future occurrences of extreme weather events based on the output from climate models.

ETCCDI indicators include temperature percentile-based indices (TX90p and TN10p), which represent the warmest and coldest deciles, and precipitation percentile-based indices (R95p), which represent the most extreme precipitation events in a given year.

Climate models are not able to forecast the strength and timing of discrete events like storms and cyclones, as model resolution is too coarse to capture the intricacies of storm dynamics. However, models can provide insight into the broader environmental conditions related to cyclone activity.[7]

GCMs also do not project the impact of sea level rise directly. Sea level rise projections must be derived from a series of datasets and specific earth system models, including vertical land elevation, historical storm surge measured by local buoys, and rate of ice-sheet loss.[8]

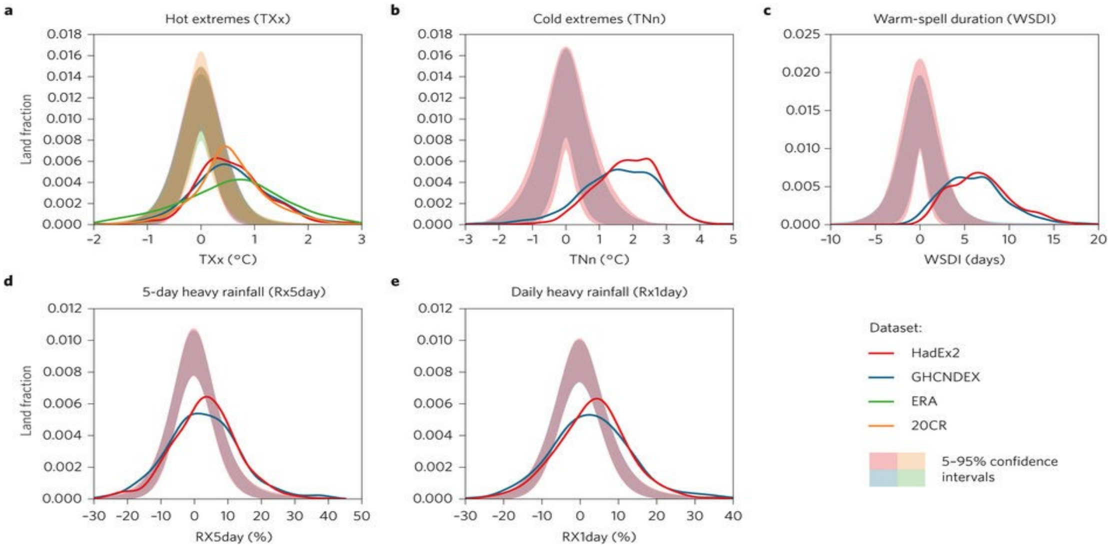


*Figure 3. Time series for climate projections must be processed into "climate indices" to extract insights on extreme weather events. Source: Nature Climate Change*

---

[5] Coupled Model Intercomparison Project: https://cmip.llnl.gov/cmip5/docs/standard_output.pdf
[6] CCI/CLIVAR/JCOMM Expert Team: http://etccdi.pacificclimate.org/
[7] Camarago (2013): http://journals.ametsoc.org/doi/full/10.1175/JCLI-D-12-00549.1
[8] Tebaldi (2012): http://iopscience.iop.org/article/10.1088/1748-9326/7/1/014032

Likewise, wildfires result not only from a combination of heat and lack of precipitation, but also from a combination of terrain, soil moisture, wind, and human processes such as land use and forest management. Climate models are thus also limited in their ability to project wildfires.[9] Similarly, to understand drought and water risk, local water supply and demand must be accounted for.

## TIME HORIZONS IN CLIMATE AND WEATHER PROJECTIONS

Climate models are intended to represent changes in the Earth's systems over time, and are most often used to project both direction and degree of change, which both emerge most significantly on a mid- to late-century time-scale. This is a particularly major challenge for financial institutions and businesses, where long-term is anything beyond the current quarter, and rarely extends beyond a 3-5 year outlook. At the other end of the spectrum, weather forecasts attempt to predict weather a few days out, but their performance drops substantially more than 15 days out.

There are inherent limitations in projecting weather and climate change over time. For each future time horizon, including daily, sub-seasonal, seasonal, inter-annual, and decadal, a specific data product is needed to accurately represent weather or climate, each with its own limitations and appropriate use cases.

The most near-term time horizons – daily, sub-seasonal, seasonal – depend heavily on accurately capturing "initial conditions," or the state of the Earth's systems when the models begin running, and performance decreases the further into the future the model is run. Products related to these time horizons, such as weather forecasts and seasonal outlooks, are helpful for informing short-term decisions, as they represent the expected weather in the coming days or months with a relatively fine degree of precision.

Intermediate time horizons – inter-annual and decadal – depend upon a robust implementation and representation of initial conditions and natural variability in the Earth's system (e.g. natural drivers of climate like El Niño). This time horizon is notoriously difficult to evaluate,[10] as it is far enough into the model runs that the initial conditions (e.g. distribution of global sea surface temperatures) have evolved dramatically from the beginning of the model run, and even small discrepancies and errors can lead to drastically different results. Capturing natural variability and oscillations across the globe, their interplay, and how they are manifest at specific locations, is extremely difficult to understand and model, and is the focus of heavy scientific research.[11] As a result, some inferences may be made about weather and climate during this time horizon, but the relevant use cases are limited due to the higher degree of uncertainty.

Longer time horizons – a few decades and beyond – have their own uncertainties, mostly resulting from scenario uncertainty (e.g. how $CO_2$ emissions will change over time), as well as structural uncertainty in the models (e.g. how accurately they are representing dynamics and feedbacks in the Earth's systems). Generally, these time horizons afford better insight into long term direction and degree of change, around which natural variability plays out. Conclusions drawn from climate model projections in this time window do not represent the actual conditions at a specific future date, but rather show the trends and how they may evolve over time.

---

[9] C2ES: https://www.c2es.org/content/wildfires-and-climate-change/

[10] Meehl et al. (2014): http://journals.ametsoc.org/doi/full/10.1175/BAMS-D-12-00241.1

[11] Ibid.

# UNCERTAINTY IN CLIMATE MODELS

Understanding the inherent limitations and embedded uncertainties underlying every model run and its subsequent outputs is critical to using climate data properly.

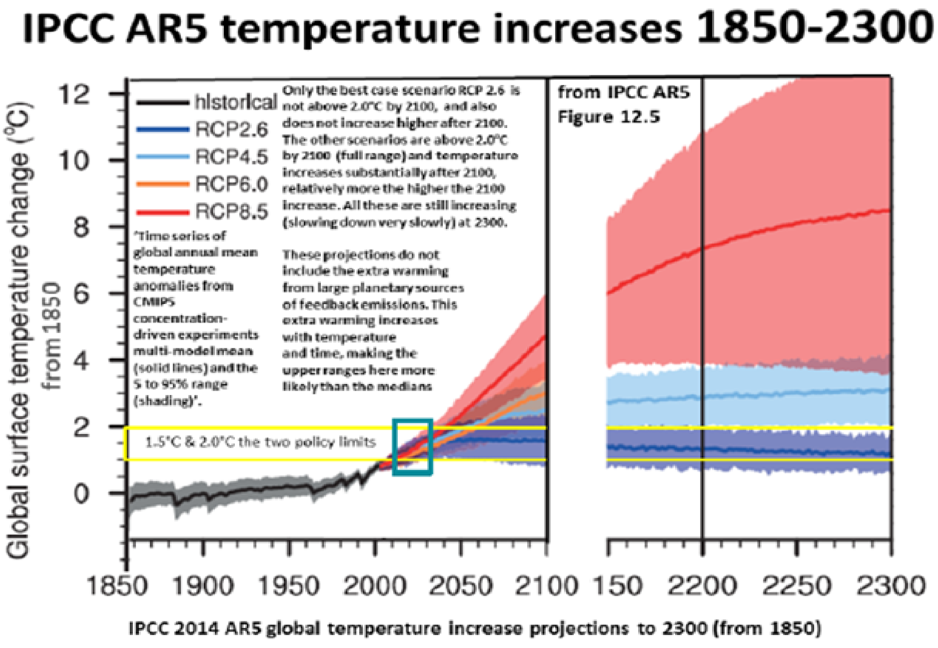
There are four main drivers of uncertainty in climate models:

- Boundary (external forcing, e.g. from $CO_2$ emissions pathways or volcanic eruptions)
- Initial conditions (capturing the state of the Earth's system when the model run begins)
- Model structure (resolution of the climate models and their ability to resolve small scale process like storms)
- Parameterization (how natural Earth processes are represented in the models)

Each factor contributes to uncertainty in the accuracy of the climate represented by the models.[12] Therefore, to interpret the climate model outputs and begin to understand risks and impacts, it is important to understand the range of uncertainty and to find ways to represent future scenarios appropriately.

There are analyses that leverage the output from climate models to provide insight into the range and likelihood of certain outcomes, while considering uncertainties. Most simply, models from different institutions can be averaged together to create a multi-model ensemble mean, which effectively hedges some uncertainty arising from initial conditions and model structure and indicates the average outcome based on available data.

Additionally, an envelope-based evaluation of all models groups outcomes into "high," "medium," and "low" tiers so that the full range of outcomes is represented,[13] and provides a more robust picture of future change.[14]



Only the best case scenario RCP 2.6 is not above 2.0°C by 2100, and also does not increase higher after 2100. The other scenarios are above 2.0°C by 2100 (full range) and temperature increases substantially after 2100, relatively more the higher the 2100 increase. All these are still increasing (slowing down very slowly) at 2300.

'Time series of global annual mean temperature anomalies from CMIP5 concentration-driven experiments multi-model mean (solid lines) and the 5 to 95% range (shading)'.

These projections do not include the extra warming from large planetary sources of feedback emissions. This extra warming increases with temperature and time, making the upper ranges here more likely than the medians

*Figure 4. Emission scenarios are one form of boundary condition. Different emission pathways do not cause much variation in temperature projections in the next 30 years. Source: IPCC*

---

[12] Tebaldi and Knutti (2007): http://climate-action.engin.umich.edu/CLIMATE_530_Uncertainty_Stationarity_Readings/Tebaldi_Knutti_Model_Uncertainty_Ensemble_PhilTranRoySoc_2007.pdf

[13] Lutz et al. (2016): http://onlinelibrary.wiley.com/doi/10.1002/joc.4608/full

[14] Ibid.

## ACCESSING CLIMATE DATA

Climate models provide the foundation for climate risk assessments, but raw climate data require substantial analysis and enrichment to be turned into measures relevant for planning and decision-making by businesses and governments.

There are a number of publicly available tools and portals that allow users to drill down to a specific place and/or time to visualize the evolving climate trends, ranges of variability, or potential risks for a location.[15] These tools are often useful for local governments and community users, with emphasis on social rather than economic impacts. However, many of these tools do not allow users to compare or examine multiple site-specific locations, limiting their application for business users.

Perhaps the most well-known global source for aggregated climate data is the Intergovernmental Panel on Climate Change (IPCC). The IPCC releases regular assessment reports and issue-specific analyses based on climate projections. Several other open source databases for climate data are described below. They vary in the specificity of their data, as some are valuable resources for climate projections and visualizations, while others offer more specific assessments tailored to particular audiences.

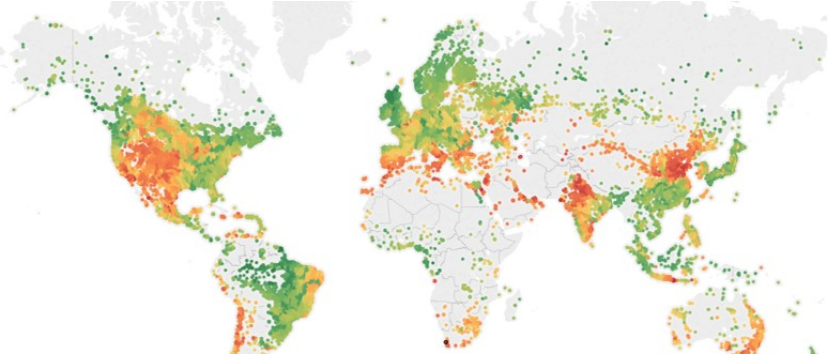


*Figure 5. Exposure to water stress for facilities owned by MSCI ACWI companies, with red being the most exposed sites and green being the least exposed. Source: Four Twenty Seven.*

The World Bank's Climate Change Knowledge Portal (CCKP) provides a compilation of climate data and reports, sorted by region. The Partnership for Resilience and Preparedness (PREP) maintains an interactive map displaying several climate and socioeconomic indicators and a variety of dashboards with location-specific stories. Similarly, The US Climate Resilience Toolkit includes a Climate Explorer dashboard with maps and region-specific data projections, as well as case studies. The Climate Impact Map displays United States and Global maps showing projected temperatures and number of extreme hot and cold days under two different emissions scenarios.

The Notre Dame Global Adaptation Initiative (ND-GAIN) compiles a Country Index, overlaying climate projections with socioeconomic data to rank countries' vulnerability to climate change impacts and their readiness to adapt. Of particular interest to government stakeholders is ND-GAIN's forthcoming Urban Adaptation Assessment which assesses climate vulnerability and readiness to adapt at the U.S. city level, through the lens of social equity.

For investors and corporate stakeholders striving to identify their assets' risk to climate change, Four Twenty Seven maintains a proprietary database using climate projections at the locations of thousands of corporate facilities to assess their exposure to heat stress, water stress, extreme precipitation, sea level rise, hurricanes, and wildfires. Likewise, Four Twenty Seven conducts risk assessments of infrastructure and other real assets, screening for exposure to climate hazards.

---

[15] See for example: IRI Data Library (http://iridl.ldeo.columbia.edu/index.html?Set-Language=en), Climate Explorer (https://toolkit.climate.gov/climate-explorer2/)

## GLOSSARY OF TERMS

- Climate: Average weather over time. The statistical mean and variability of weather over a set timeframe.
- El-Niño: Often referred to as the El Niño-Southern Oscillation (ENSO). An event in the Tropical Pacific, characterized by a weakening of the easterly winds near the equator (known as the trade winds), a shift in ocean currents and a warming of the ocean surface temperatures. These events have far-reaching atmospheric impacts, affecting conditions across the globe.
- Greenhouse Gas Concentration Trajectories: Scenarios of the future rate of global greenhouse gas concetrations, used as inputs into climate models to account for the uncertainty of policy and mitigation actions.

    Representative Concentration Pathway (RCP) 2.6: strict mitigation action taken and warming stays below 2˚C.

    RCP 4.5: and RCP 6.0: intermediate mitigation action

    RCP 8.5: business as usual scenario.

- Envelope-based evaluation: A method of accounting for uncertainty in climate models by grouping models into tiers (e.g. low, medium, high) to allow for consideration of the full spectrum of outcomes.
- Intergovernmental Panel on Climate Change (IPCC): The international organization responsible for reviewing and assessing the corpus of peer-reviewed climate science with the objective of communicating the current state of research and understanding of climate change and its societal impacts.
- Precipitation percentile-based indices: Standardization of precipitation measurements into location-specific percentiles to allow for comparability across regions.
- Statistical downscaling: An approach used to improve the resolution of coarse global circulation models (GCMs) based on their statistical relationship with local observed climate variables.
- Temperature percentile-based indices: Standardization of temperature records into location-specific percentiles to allow for comparability across regions.
- Time horizons

    Daily: Weather conditions spanning approximately one or two days up two weeks.

    Sub-seasonal: Weather conditions spanning approximately two weeks up to one or two months.

    Seasonal: Weather conditions spanning approximately two to three months up to six months.

    Interannual: Prevailing climate conditions spanning year-to-year timeframes.

    Decadal: Prevailing climate conditions spanning one to several decades.

- Weather: Atmospheric conditions at a certain time, manifested through temperature, precipitation, wind, and clouds.

Four Twenty Seven

## AUTHORS

**Lead author:** Colin Gannon, Senior Data Analyst • cgannon@427mt.com • +1.415.930.9090, Ext: 1003

**Contributor:** Nik Steinberg, Director of Analytics • nsteinberg@427mt.com • +1.415.930.9090, Ext: 1003

**Editor:** Natalie Ambrosio • nambrosio@427mt.com • +1.415.930.9090, Ext: 1005

## ABOUT FOUR TWENTY SEVEN

Four Twenty Seven (427mt.com) is the leading provider of market intelligence on the impacts of climate change for financial markets. We tackle physical risk head on by identifying the locations of corporate production and retail sites around the world and their vulnerability to climate change hazards such as sea level rise, droughts, floods and tropical storms, which pose an immediate threat to investment portfolios.

Four Twenty Seven's ever-growing database now includes close to one million corporate sites and covers over 2000 publicly-traded companies. We offer subscription products and advisory services to access this unique dataset. Options include data licenses, an interactive analytics platform, and company scorecards, as well as reporting services, scenario analysis, and real asset portfolio risk assessments.

Four Twenty Seven has won multiple awards for its innovative work on climate risk and resilience and our work has been featured by Bloomberg, the Financial Times and the UNFCCC. Four Twenty Seven was founded in 2012 and is headquartered in Berkeley, California with offices in Washington, DC and Paris, France.

## DISCLAIMER

The information provided in this report was collated by Four Twenty Seven. Publications of Four Twenty Seven are for information purposes only. Other than disclosures relating to Four Twenty Seven, the information contained in this publication has been obtained from sources that Four Twenty Seven believes to be reliable, but no representation or warranty, express or implied, is made as to the accuracy, completeness, reliability or timeliness of any of the content or information contained herein. As such, the information is provided 'as-is,' 'with all faults' and 'as available.' The opinions and views expressed in this publication are those of Four Twenty Seven and are subject to change without notice, and Four Twenty Seven has no obligation to update the information contained in this publication. Further, neither Four Twenty Seven nor its directors, officers, employees or agents shall be held liable for any improper or incorrect use of the information described and/or contained herein, nor does Four Twenty Seven assume responsibility for anyone's use of the information. Under no circumstances shall Four Twenty Seven or any of its directors, officers, employees or agents be liable for any direct, indirect, incidental special, exemplary or consequential damages (including, but not limited to: procurement of substitute goods or services; loss of use, data or profits; or business interruption) related to the content and/or to the user's subsequent use of the information contained herein, however caused and on any theory of liability. User agrees to defend, indemnify, and hold harmless Four Twenty Seven and its directors, officers, employees and agents from and against all claims and expenses, including attorneys' fees, arising out of the use of information herein provided.

## CONTACT INFORMATION

**San Francisco Bay Area, CA**
2000 Hearst Ave, Ste 304
Berkeley, CA 94709
Tel: +1.415.930.9090

**Washington, D.C.**
718 7th St. NW
Washington, D.C. 20001
Tel: +1. 202.897.4020

**Paris, France**
2, rue du Helder
75009 Paris, France
Tel: +33. 01.53.34.11.87