

How can we estimate a future climate without knowing each day's weather?

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A climate projection does not have to identify the weather on every date to estimate how the distribution of weather changes. It asks a conditional question: under specified changes in greenhouse gases and other influences, what happens to averages, variability and the frequency of particular conditions? The unanswered date-by-date question and the answerable statistical question refer to the same physical system, but they demand different information.

That distinction creates a possibility, not a guarantee. Climate statistics must still be supported by physical understanding, observations and evaluated models. Calling a calculation “climate” does not make it accurate, and averaging cannot remove every source of error.

1. Change the question before comparing the answers

Suppose we ask whether a location will exceed a temperature threshold on one particular afternoon many decades from now. That requires a detailed future weather state. Asking how frequently that threshold is exceeded over a future multidecade interval requires a distribution of states instead.

The statistical question does not secretly contain a calendar. Two simulated sequences can have different hot days while producing similar frequencies over a long interval. Conversely, two sequences that happen to match on a particular day can have very different long-term behaviour. Agreement at one level cannot substitute for evaluation at the other.

IPCC's assessment of future global climate explicitly treats projections as scenario-based and combines models with observational constraints. It also considers initialized predictions for nearer-term questions, for which the current state can retain useful influence. [1] The boundary between weather and climate applications is therefore not an absolute rule that initial conditions never matter to climate.

2. What changing the boundary conditions can do

A deliberately small model makes the distinction concrete. Let T be a global temperature anomaly, C an effective heat capacity per unit area, F an imposed energy imbalance, and λ a positive restoring coefficient. Write $C \, dT/dt = F - \lambda T$. This is a one-box energy-balance illustration, not a full climate model.

The units must agree. If C is measured in joules per square metre per kelvin, dT/dt in kelvins per second, F in watts per square metre and λ in watts per square metre per kelvin, both sides describe energy transfer per area and time.

Under a constant F and this linear response assumption, the equilibrium anomaly is $T_{eq} = F/\lambda$. Starting from an anomaly T_0 , the solution is $T(t) = F/\lambda + (T_0 - F/\lambda) \exp(-t/\tau)$, where $\tau = C/\lambda$. The initial condition affects the approach, while the imposed imbalance and restoring coefficient determine the equilibrium in this model.

We can therefore calculate a conditional change in the model's long-term state without assigning a cloud pattern to a future Tuesday. The calculation does not prove the values of

F, C or λ , and it leaves out spatial structure, multiple ocean timescales and nonlinear responses. Its purpose is to expose the logic of the question, including the assumptions that make this particular answer possible.

3. A changed average can change a threshold frequency

Consider a second illustration, with no claim to describe a particular city. Let daily temperatures in a selected season follow a normal distribution with mean 15°C and standard deviation 3°C. A threshold of 21°C lies two standard deviations above the mean. Under that distribution, about 2.3% of days exceed it.

Now shift the mean to 17°C while holding the standard deviation and distributional shape fixed. The same threshold lies 4/3 standard deviations above the new mean, and the exceedance fraction is about 9.1%. No individual future day's temperature was needed to calculate either fraction.

The assumptions are doing substantial work. Actual temperature distributions need not be exactly normal, and their variance or shape may change. The example demonstrates how a frequency can respond to a changed distribution; it does not estimate a real regional heatwave trend. It also concerns individual threshold exceedances, not the duration of sequences of hot days, which additionally depends on temporal relationships.

4. Where the evidence enters

Neither illustration establishes how Earth's climate will change. Observations of temperature, energy exchange and other components constrain the physical response, while models connect those constraints to specified scenarios. IPCC's 2021 assessment compares observed and simulated changes and evaluates future changes across emissions pathways. [2]

A model's historical performance is relevant, but a good match to one variable is insufficient. The same temperature curve can sometimes be obtained by compensating errors elsewhere. Evaluation must ask whether the processes needed for the future question are represented adequately, and whether the comparison used independent information rather than only quantities already used in tuning.

This reasoning is especially important when moving from a broad average to a local quantity. A model that reproduces a global mean has not thereby validated every local rainfall change. Resolution, circulation, topography and the particular variable all matter to the next inference.

5. Why many runs are useful, but not a vote

Repeated runs with different starting states can explore internal variability within a model. Comparisons among models explore some differences in representation and response; different scenarios explore different imposed futures. IPCC discusses these distinct contributions in its assessment of projections. [1]

An ensemble is not automatically a random sample of all physically possible futures. If twelve of twenty models show a specified outcome, "60% probability" does not follow merely by counting. Models can share components, assumptions and limitations, and their selection is not equivalent to drawing independent outcomes from a known probability distribution.

The useful question is what the ensemble actually varies and what it holds fixed. A wide ensemble can still omit a shared mechanism; a narrow ensemble can reflect deliberately

restricted assumptions. Producing more runs reduces neither problem by itself. This is a limit on how to interpret the experiment, not a reason to discard it.

6. What is robust, and what remains conditional?

IPCC assesses internal variability as especially important for regional changes and near-term outcomes; it can strengthen or weaken an externally forced trend over those scales. Its assessment also distinguishes uncertainties in precipitation associated with models and aerosol forcing. [2] Calling all uncertainty “chaos” would erase physically different limitations.

A useful projection therefore identifies its scenario, time interval, spatial scale and target variable. Those labels are part of the result. Removing them can turn a supported conditional statement into a misleading unconditional promise.

We can estimate a future climate without knowing each day's weather because changes in the conditions governing a system can constrain its statistics without fixing its exact sequence. The evidence must establish how well that works for the quantity asked about. The misconception is to assume that ignorance of every future state means ignorance of every future distribution, or that knowing a distribution means knowing its individual events.

Related reading

Article 021, “Can a forest keep absorbing carbon forever?”, examines a changing component of the carbon balance. The connection is optional and does not make a forest's future uptake a fixed input known in advance.

References

[1] IPCC. Climate Change 2021: The Physical Science Basis. Chapter 4: Future Global Climate: Scenario-Based Projections and Near-Term Information.
<https://www.ipcc.ch/report/ar6/wg1/chapter/chapter-4/>

[2] IPCC. Climate Change 2021: The Physical Science Basis. Summary for Policymakers, especially Figure SPM.5 and section C.1. <https://www.ipcc.ch/report/ar6/wg1/chapter/summary-for-policymakers/>