POCKET GUIDE TO CLIMATE SCIENCE AND THE UNFCCC

ecbi

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SCIENCE CLIMATE GUIDE POCKET

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FOREWORD

For over a decade, the European Capacity Building Initiative (ecbi) has adopted a two-pronged strategy to create a more level playing field for developing countries in the UN Framework Convention on Climate Change (UNFCCC): training negotiators from developing countries; and providing opportunities for senior negotiators from developing countries and Europe to interact, and build mutual trust.

The first part of the strategy focuses on providing training and support to new developing country negotiators, particularly from Least Developed Countries. The climate change negotiations are often technical and complex, and difficult for new negotiators (who are most often not climate specialists) to fully grasp even over a period of two or three years. We hold regional training workshops to bring them up to speed on the negotiations. We also organise training workshops before each Conference of the Parties (COP) to the UNFCCC, covering topics specific to that COP. To ensure continuity in our capacity building efforts, we offer bursaries to a few women negotiators to attend the negotiations and represent their country and region/grouping. Finally, we help negotiators build their analytical capacity through our publications, by teaming them up with global experts to author policy briefs and background papers.

This strategy has proven effective over time. "New" negotiators that trained in our early regional and pre-COP workshops have risen not only to become senior negotiators in the process, but also leaders of regional groups and of UNFCCC bodies and committees, and ministers and envoys of their countries. These individuals remain part of our growing alumni, and are now capacity builders themselves, aiding our efforts to train and mentor the next generation. Their insights from once being new to the process themselves have helped us improve our training efforts.

The second ecbi strategy relies on bringing senior negotiators from developing countries and from Europe together, at the annual Oxford Seminars and the Bonn Seminars. These meetings provide an informal space for negotiators to try to understand the concerns that drive their specific national positions, and come up with solutions to drive the process forward. They have played a vital role in resolving some difficult issues in the negotiations.

Following the adoption of the Paris Agreement in 2015, ecbi produced Guides to the Agreement in English and in French. Since they proved popular with both new and senior negotiators, we developed this series of thematic Pocket Guides, to provide negotiators with a brief history of the negotiations on the topic; a ready reference to the key decisions that have already been adopted; and a brief analysis of the outstanding issues from a developing country perspective. These Guides are mainly web-based and updated frequently. Although we have printed copies of the English version of the Guides due to popular demand (please write to us if you would like copies), the online versions have the added advantage of hyperlinks to access referred material quickly.

As the threat of climate change grows rather than diminishes, developing countries will need capable negotiators to defend their threatened populations. The Pocket Guides are a small contribution to the armoury of information that they will need to be successful. We hope they will prove useful, and that we will continue to receive your feedback.

Anju Sharma

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GLOSSARY

CH_4	Methane
CO_2	Carbon dioxide
COP	Conference of the Parties
FGD	Final Government Draft
FOD	First Order Draft
GCOS	Global Climate Observing System
GWP	Global Warming Potential
ICSU	International Council for Science
IGBP	International Geosphere-Biosphere Programme
IPCC	Intergovernmental Panel on Climate Change
ISC	International Science Council
ISSC	International Social Science Council
LCIPP	Local Communities and Indigenous Peoples Platform
NWP	Nairobi Work Programme on Adaptation
RINGO	Research and Independent Non-Governmental Organisations
RSO	Research and Systematic Observations
SBI	Subsidiary Body for Implementation
SBSTA	Subsidiary Body for Scientific and Technological Advice
SEDs	Structured Expert Dialogues
SOD	Second Order Draft
SPM	Summary for Policymakers
TFI	Task Force on National Greenhouse Gas Inventories
UNEP	UN Environment Programme
WMO	World Meteorological Organization
ZOD	Zero Order Draft

CONTENTS

WHAT IS CLIMATE SCIENCE?

The international negotiations aimed at limiting the negative consequences of human-caused climate change are strongly influenced, on all sides, by appeals to 'be guided by the science'.

'Climate science' is the study of the climate system, specifically on planet Earth, though there are things we have learned from the climate of other planets too – such as that Venus is way too hot to support life partly because of its thick layer of carbon dioxide; and Mars is too cold because its atmosphere is so thin.

Because the climate system includes so many diverse parts, a 'climate scientist' *could* be a physical climatologist, but could equally be an oceanographer, a geologist, an ecologist, a social scientist, an economist, an engineer… or an expert in any one of the many, many other fields that have a bearing on how the climate system behaves and how we respond to it. (The terms 'science' and 'scientist' are used repeatedly in this Guide. They are intended in a broad sense, meaning a rational, evidence-based approach to knowledge creation, and the experts who do it, respectively. The terms may include many disciplines and practitioners who do not automatically think of themselves as 'scientists' in the narrow sense of the mathematical, physical, biological and Earth sciences, including for instance the social and economic sciences and cultural and development studies.)

The simple definition of 'climate' is 'the average weather'.[1] 'Weather' refers to short-term fluctuations in the various observable components that we associate with the 'climate system', such as the air temperature, precipitation, wind, humidity and many others. In more formal terms, climate is the statistical description of these variables. The statistics may refer to the average weather conditions (also called the 'mean'); or the distribution of weather events around the average (the 'variance'), resulting for instance in having more or fewer extreme weather events; or the change over time in either the mean or the variance ('trends'). These statistics are calculated over periods of time ranging from months to thousands or millions of years. The time-averaging smooths out the short-term 'weather' variations. The World Meteorological Organization (WMO) usually specifies a period of 30 years to calculate 'climate' from 'weather'.

The 'climate system' consists of all the features of the planet that contribute to how climate behaves, over time and in different places. It includes the atmosphere and all its components, such as gases, particles, clouds, air circulation patterns and the vertical structure of the atmosphere in terms of pressure, temperature and humidity. Less obviously, but very importantly, the climate system also includes the variations in the amount of solar energy reaching the Earth, the oceans and their circulation and structure, the 'cryosphere' (masses of frozen water, including polar ice caps, glaciers, sea ice and permafrost), the landmasses themselves, and all the living organisms on the planet. The climate of Earth is very different from that of any other planet in the solar system precisely *because* it contains life; and life currently on Earth is only possible because of the particular climate we have. People are *also* part of the climate system since you cannot understand changes in Earth's climate over the past two centuries without including the effects that human activities have had on it.

'Climate change', in its broadest sense, is any significant and lasting change in the statistical distribution of weather variables. The past six billion years of Earth's history has been characterised by repeated changes in the climate, which can be attributed to many factors, including processes in the oceans such as changes in oceanic circulation or stratification; biological processes, such as the uptake and release of carbon dioxide or other greenhouse gases by plants, microbes, and animals; variations in solar radiation received by Earth due to small fluctuations in the orbits of the planets or brightening or dimming of the Sun; slow movements of the Earth's crust ('plate tectonics'); and the volcanic eruptions associated with it.

Since about 10,000 years ago, this list includes human-caused alterations to the natural world. The warming of the oceans and lower atmosphere and the melting of the cryosphere that have been observed nearly everywhere over the past two centuries is, without any reasonable scientific doubt, mainly caused by human actions. Strictly speaking, this subset of the broad field of 'climate change and climate variability' should be referred to as 'modern anthropogenic climate change', but in the context of contemporary climate negotiations, we usually just abbreviate this to 'climate change'.

CLIMATE SCIENCE BASICS FOR POLICY-MAKERS

The climate system is a 'machine' that runs on radiant energy from the sun. The remarkably stable, and liveable, average temperature near the Earth's surface (approximately 15°C, averaged over the land and oceans Earth and the entire year) represents an equilibrium (a balance-point) between energy coming in from the Sun, and energy reflected, or re-radiated, back out into space by the Earth. That balance is controlled by the presence in the atmosphere of small quantities ('traces') of gases and particles that alter the amount of incoming or outgoing energy. These radiatively-active atmospheric constituents are generally called 'greenhouse gases'.

RADIANT FORCING

The concentration of greenhouse gases has increased over the past two centuries as a result of human activities, especially the burning of fossil fuels, but also the conversion of large land areas from native vegetation other land covers, particularly agriculture. As a result, at present more incoming solar energy is trapped by the Earth's climate system than leaves the system, causing a warming, called 'radiant forcing'. If the concentration of greenhouse gases is kept constant, the rate of warming will slow down and stop at a new, warmer balance point within a few decades. If the concentration of greenhouse gases continues to rise, so will the temperature near the Earth's surface, almost proportionately to the cumulative concentrations. If the greenhouse gas concentration declines, the Earth's surface will cool, rather slowly, because of the large amount of extra energy already stored in the oceans and cryosphere. Some changes in the climate system, such as sea level rise, will continue for hundreds or thousands of years *after* the global air temperature has stabilised.

ROLE OF OCEANS AND THE CRYOSPHERE

We think of the atmosphere as being where climate belongs, but actually some of the most important mechanisms in our climate engine are located in the oceans and cryosphere. This is because dry air has a relatively small capacity to store energy, whereas water in either its liquid or frozen form, has a large capacity. Similarly, the carbon stores and uptake potential in the oceans are larger than either on the land or in the atmosphere.

Weather 'events', such as winds, rainstorms, and snowstorms are the result of atmospheric circulation. The ultimate reason that circulation occurs is because the Earth gains much of its energy from solar insolation in the lower latitudes. This creates inequalities in pressure and heat between the equator and the poles, which drive the redistribution of energy through of winds and currents. Most of the energy is transported in the form of deep ocean currents, some of which take decades or centuries to reach their destination – which is why change is relatively slow. However, like all movement in fluids, eddies and circulation loops can form, dissipate, or switch direction relatively abruptly. This is why in the climate, change is not smooth, but irregular and one reason why certain changes, sometimes called 'tipping points', have unpredictable and hard-to-reverse consequences. Climate science and observations of past climates on Earth tells us that such tipping points exist, but it is hard to say exactly where they lie until they occur. This is one reason for exercising great caution in allowing the global climate to warm beyond the range it has occupied over the past 10,000 years of human experience.

The rising water temperature throughout the ocean depths causes the water to expand by a small amount. Because the oceans are very deep, this translates into a measurable, and unavoidable, rise in the mean sea surface level. Warming also causes ice bodies to melt. Where the ice was on land, in the form ice-sheets, glaciers, and permafrost, the meltwater adds to the sea level rise. The land and ocean surfaces once covered by highly reflective ice or snow become darker, and absorb more solar energy, accelerating the warming. This is an important climate change amplifying effect currently operating in the Arctic.

GLOBAL WARMING POTENTIAL OF GASES

The element 'carbon' plays an oversize role in climate science. This is because the single largest directly human-caused radiant forcing is attributed to the gas carbon dioxide (CO_2), and the second-largest forcing is due to carbon-containing methane (CH_4). For convenience, we can convert the radiant forcing by most of the dozens of greenhouse gases, into approximately how many tonnes of carbon dioxide would have caused the same radiative forcing effect in the atmosphere as a tonne of the gas under consideration. This is known as the Global Warming Potential (GWP) of that gas, and the units are 'carbon dioxide equivalents', written CO_2e (**Table 1**). The conversion is only approximate, and requires certain assumptions, such as the time period over which you are calculating the warming effect. Nevertheless, it provides a useful agreed 'exchange rate' between the gases (see **Table 2** for the units used).

As a result of the dominance of carbon dioxide as a greenhouse gas, and its use as a 'common currency', we often talk about 'carbon accounting' and 'low-carbon futures'. However, it is not just carbon or carbon dioxide that matter – for some processes or sectors, non-CO_2 greenhouse gases matter even more.

CLIMATE ATTRIBUTION

The science of 'climate attribution' is a field that seeks to demonstrate not only that the climate has changed in a statistical sense, but to what degree that change can be associated with human causes. While there is no reasonable doubt that most of the warming observed since 1850 has been caused by anthropogenic (human-driven) changes in the composition of the atmosphere and to the surface of the land, associating *individual weather events* to anthropogenic climate change remains difficult. Nevertheless, in more and more cases it is possible to assign a likelihood that the event has human causes. This includes slow-onset events such as the gradual

Table 1. Atmospheric concentration of greenhouse gases changed substantially by humans

GAS	PRE-1750	2011	RADIATIVE FORCING IN 2011 (Wm^{-2})†; CONTRIBUTION TO TOTAL RADIANT FORCING (%)	GLOBAL WARMING POTENTIAL (100 YEAR)
Carbon dioxide (CO_2)	279 ppm	391 ppm*	1.68 (59.3%)	1
Methane (CH_4)	722 ppb	1803 ppb**	0.97 (34.3%)	21
Nitrous oxide (N_2O)	270 ppb	324 ppb	0.17 (6.0%)	290
'Montreal Protocol gases' ††	0 ppt	1319 ppt***	0.33	(Variable, but high)

Note: Water (H_2O) is also a strongly radiatively-active gas whose concentration in the atmosphere has increased as a result of human actions, but mostly indirectly, as a result of warming. †Radiative forcing at the top of the atmosphere in watts per square meter. †† Chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs) and others. *Parts per million. **Parts per billion. ***Parts per trillion.
Source: IPCC (2013). Anthropogenic and Natural Radiative Forcing. In: *Climate Change 2013: The Physical Science Basis*.

melting of the Greenland icecap, and the build-up of heat in the oceans, contributing to phenomena such as coral reef bleaching.

IMPACTS OF CLIMATE CHANGE

Often policymakers are not directly concerned about changes in the climate variables themselves, but with the things that the climate affects. For example, what the actual temperature is, in degrees Celsius or Fahrenheit or Kelvin, is less relevant to people than whether it is too hot or too cold for comfort. Changes in the 'climate system' have impacts on many other

Table 2. Commonly used climate science units and numbers

SCIENTIFIC NAME	DEFINITION	POLICYMAKER EQUIVALENTS	EXAMPLES OF USES
Petagram (Pg)	10^{15}g	A billion tonnes, a gigatonne	Global carbon cycle
Teragram (Tg)	10^{12}g	A million tonnes	Global methane or nitrous oxide cycle
Gigagram (Gg)	10^{9}g	A billion grams	National emissions
Megagram (Mg) (tonne)	10^{6}g	Tonne (1.2 Imperial tons)	Industry or project targets
Kilogram (kg)	10^{3}g	Kilogram, litre of water	Material use by one person

Note: 1 mass unit of CO_2 is 12/44 (=0.273) mass units of carbon. 1 mass unit of carbon is 44/12 (=3.67) mass units CO_2. 1 ppm CO_2 in the atmosphere amounts to about 7.8 PgCO_2, or 2.13 PgC.

linked systems on which we depend or consider important, and which in many cases have a strong feedback on the climate system. Examples include, among many others, the impacts of climate on the food system, the water supply system, the built environment, human health, and the ecosystems that support all the other species on Earth. Understanding these impacts is part of 'climate science', in the broad sense.

Due to the inertia in the climate system, plus the inertia in the human response to climate change, the emissions of greenhouse gases to the atmosphere since the start of the Industrial Revolution commit the world to a certain amount of current and future climate change , no matter how strenuously we try to limit the changes now. Whatever the outcome, people and ecosystems have no alternative but to adapt to the climate changes to which they are exposed.

An important scientific development has been the consistent comparison of projected impacts across a range of scenarios of future emissions – for instance, scenarios where the global mean temperature increase stays below 1.5°C, with those that reach (or temporarily exceed) 2°C, or scenarios with 3°C or more of warming. The key findings are that serious impacts are found even at 1.5°C of warming, and impacts grow disproportionately severe for further levels of warming.

ADAPTATION

The science of adaptation leads naturally on from the science of climate impact identification and quantification, since many of the same processes are involved. Once the steps and processes that lead to an outcome (the 'impact pathway') have been identified, the sensitivity to climate change of each of its elements can be evaluated, along with their capacity to absorb the changes autonomously, in other words, without human intervention. A high climate sensitivity plus a low autonomous adaptive capacity would result in a high vulnerability. Then various deliberate policy or management interventions can be evaluated in terms of how much they would reduce either sensitivity, or vulnerability, or both. It is often the case that there may be 'effects of the effects' (i.e. second or even higher order effects). For example, the warming of the oceans causes a melting of sea ice, which then causes an increase in the solar radiation absorbed by the ocean surface, which in turn accelerates the warming… etc. The longer this chain of causes is, and the more mechanisms and feedbacks involved, the more difficult it becomes to make precise predictions of the size of the response, because of the accumulation of uncertainties at each step. Most ecological or human outcomes have multiple causes *in addition* to climate change, so clear attribution to anthropogenic climate change becomes progressively harder to achieve the more steps you are away from the primary climate system variables themselves.

HUMAN AGENCY IN CLIMATE SCIENCE

Since humans are the main drivers of modern-day changes in the climate system, the only way to avoid or reduce the unacceptable impacts of those changes is to alter human actions. The things that humans can do to reduce climate change, or adapt to its consequences, include collective actions taken by governments, such as international, national or local laws, policies or regulations. It also includes actions partly taken by the private sector, such as pricing regimes for greenhouse gas emissions, or targets for renewable energy. It further includes individual actions taken by ordinary people, perhaps motivated by civil society. The area of research on 'mitigation' (reducing) the amount of climate change draws on, especially, the behavioural sciences, ranging from psychology, to economics and management. It also includes technological solutions, such as those provided by engineers. It may involve changes in the rules that govern social behaviour (i.e. the law), and achieving these often calls on political science. Since the causes and effects of climate change are not equally distributed across all people, especially when the unborn people of the future are included, combating climate change is an ethical question, and the hard choices can be guided by ethicists. Studies of environmental history may be needed to show what has changed, and how people responded to those changes in the past. People seldom change their behaviour on the basis of scientific evidence alone. They are convinced by their perceptions and emotions, particularly if the required change requires stopping doing something that is pleasurable or habitual. Understanding perceptions and emotions are the core domain of the social sciences, including psychology, the humanities and the arts. Thus the knowledge base required to both understand and address climate change encompasses nearly all disciplines and knowledge bases, including indigenous, traditional, and local knowledge.

OTHER WAYS OF KNOWING

'Science' in the climate change context may be narrowly interpreted as 'physical climate science', or more broadly, as in this guide, as all modern academic disciplines affected by, and affecting the climate system. But why stop there? Surely *any* body of knowledge that can be accessed and has something meaningful to say on the topic can potentially be useful in shifting to a more sustainable future? This 'non-scientific' knowledge has thus far only been used on the fringes of climate policy, but is gaining traction for several reasons.

Firstly, only a tiny fraction of people in the world have a deep understanding of 'climate science' in the narrow, disciplinary senses described above. Nevertheless, people everywhere make daily decisions based on some knowledge-basis – which may be their own experience, the prevailing social norms, what they have learned from their ancestors, or what they spiritually believe. If you need to convince people coming from vastly different backgrounds to take concerted and collective action on climate change, you need to involve them through processes of participation, which requires that you engage them through *their* worldview, not yours; and that worldview may not be primarily 'scientific', or scientific at all.

Secondly, knowledge derived through approaches different to the formal 'scientific method' may nevertheless be rigorous, reproducible and valid, though just like scientific knowledge, if it is to be used for public policy purposes, it should be subject to inquiry and debate. In given specific situations, the rich detail in 'local knowledge' may be more applicable than the generalities of science. Local knowledge has many more practitioners, and sometimes more information at its disposal, than formal science. 'Traditional' or 'indigenous knowledge' is a special category of knowledge, with the virtue that it has withstood the test of time; and is thus both locally-attuned *and* long-standing. Traditional and indigenous knowledge may not, however, have any insight into phenomena that they have never been exposed to in the past, or phenomena taking place at global scales.

Thirdly, for decisions based on human values, and especially those not amenable to quantification, the 'scientific method' does not have a special or unique claim to power.

Engaging these 'non-scientific' sources of knowledge is not without problems in the crafting of policy, which is one reason why their role in the climate question has thus far been quite limited. Sometimes the knowledge is 'privileged' – in other words, it belongs to a limited set of people, who are reluctant to share it openly. Often it is hard to access, because it is not written down, or is expressed in languages other than one of the dominant scientific languages. The knowledge may be disputed – different groups have different interpretations – and it may not agree with 'scientific knowledge'.

HOW CAN YOU TELL CREDIBLE SCIENCE FROM FAKE SCIENCE?

Within the broad definition of 'scientists' used here, there is a spectrum of views regarding the degree to which science is universal and objective, versus subjective and open to multiple interpretations, or even deliberate manipulation. There is similarly a range of viewpoints between scientists and policymakers. Despite these differences, the climate science process needs to be unbiased, balanced and fair. Two key principles are applied to ensure this.

The first is **openness** (also called transparency). The majority of climate science is published in the open, peer-reviewed literature. Here, 'open' means that there is no restricted, secret or confidential information involved. It does not mean, unfortunately, that in practice everyone can access it easily. Many scientific journals require payment, either at the time of access or at the time of publication. The sums of money involved are unaffordable in many developing countries. There are also barriers of language – the overwhelming majority of scientific articles are currently published in English -- and in a very hard to understand form of academic English. The requirement for peer-reviewed publication is a barrier to local, traditional and indigenous knowledge. In assessment bodies it is not an absolute rule that all findings must be based on peer-reviewed, formally published information. Any material that is in the public domain can be used, provided it is made accessible for evaluation, in perpetuity.

The second principle is **participation**. This means that the science, and its assessment, must be done by as many of the stakeholders and experts as possible. On complex topics such as climate change, there is seldom just a single valid viewpoint. The purpose of assessment is not to force a consensus where one does not exist, but to reflect the valid range of observations, projections and informed opinions. This is why the author teams are large, multidisciplinary and multinational, and why review editors are required to certify that reviewer comments are fairly and comprehensively addressed, and interpretations that are supported by evidence are correctly represented.

Formal scientific assessment processes, such as the Intergovernmental Panel on Climate Change (IPCC), embody these two principles (and the more detailed guidelines in **Box 1**), which is what makes them the gold standard of carefully-evaluated, relatable climate science.

For people without deep experience in a topic, it is extremely difficult to distinguish between legitimate and fake science. **Box 1** provides some guidance.

WHEN SCIENTISTS SAY THEY ARE UNCERTAIN, DOES IT MEAN THEY ARE WRONG?

The best argument in favour of the scientific method is that it is self-correcting. It is said that 'science is not always right, but it is never wrong for long'. Contrary to popular perception, science does not set out to 'prove' things, but to try to disprove ideas, even its own. So scientific 'facts' and 'theories' are always to some degree provisional, pending a better explanation of the observed phenomenon. Uncertainty and scepticism are therefore central to science, not an unfortunate feature that should be ignored.

Scientific uncertainty has several causes. The first we could call 'ignorance', which is an absent or inadequate theory. This cause can be reduced by targeted research. There will always remain areas of climate science where knowledge is to some degree incomplete, but by-and-large we already have much more knowledge than is needed to make decisions affecting

Box 1: How to identify credible science

Many contributions on the topic of climate change present themselves as 'science'. Which should you trust? Here are some guidelines, none of which are infallible, but together they can alert you to advocacy-based pieces.

- **Are the authors qualified to comment on the topic at hand?** Even if an author has a high qualification in another area, this does not necessarily equip them to comment on an issue beyond their training and experience. Look at the credentials and experience of the authors.
- **Is there evidence of a thorough and independent review process?** The process may be stated, or it may be implicit by reference to the procedures of the publisher. There are lists of 'predatory journals' that do not follow these processes. The journal website should provide details of the review process.
- **Is the place where the contribution is published reputable?** Formal, peer-reviewed professional journals, particularly those with a long history, high standing and high citation index, are more likely to be reliable sources than the Internet, social media, the traditional media or in-house publications of entities that have vested interests in the finding. Check the citation index of the journal.
- **Are assertions in the contribution supported by evidence?** This can take the form of data, or traceable, reproducible evidence, or by citation of sources which have such evidence. Check each important statement for evidence.
- **Are the methods sufficiently described that the findings can be checked?** The methods should be given in sufficient detail that another scientists could repeat the study.

the climate system that will perform much better than pure guesswork. This category also includes what have been called 'unknown unknowns' – in other words the surprising things that we did not even imagine when designing research strategies and programmes. By definition, there is not much we can do or say about those, except that the history of human knowledge tells us that they exist, and we should be open to recognising them when they become known.

The second uncertainty results from 'measurement error'. Even our most precise scientific instruments contain some inaccuracy, which can be reduced by greater sampling effort and improved technology. The most dangerous type of measurement error is bias, in which the mistakes are systematic. Bias can be reduced by carefully designed sample methods, the use of multiple independent sources of information, and careful calibration of instruments. It is also reduced by more intensive observations, especially in parts of the world which are presently under-represented in the databases. This requires an increase in the amount of resources being dedicated to climate system observations (in the broad sense), and a more even distribution of that effort.

The third source of uncertainty is unpredictability. Some processes simply cannot be accurately predicted beyond a limited time in the future, or further than some distance from an observation point. The reason is rooted in measurement error. For complex systems, even tiny variations in their starting points eventually propagate to giant differences in outcome. The issue is also impacted by the finite space and time scales that can currently be modelled, due to computational limits. The solution to this kind of uncertainty is often to step back, and solve the question probabilistically (rather than deterministically), at a larger scale in space or time. This is why models of the climate can be accurate many decades into the future, even while the predictive capacity of weather models breaks down after about ten days.

Human behaviour is one such poorly predictable system. Therefore, when climate scientists talk about aspects of the future that depend on human responses (i.e., narratives or scenarios), they use the word 'projections' rather than 'predictions'. This source of uncertainty – not knowing how people will react – is usually the largest unknown in climate science. It is a professional requirement among scientists that when findings are communicated, the confidence that can be placed in the finding must be given as well. This leads to quite complicated messaging from scientists, especially to non-scientists who don't share that training. It can sound like an unwillingness on the part of the scientists to be clear and unequivocal. For numerical values resulting from multiple, independent, unbiased observations the communication of uncertainty is done statistically, by reporting the mean, the standard deviation and the sample size (for instance, $x = 5.1$, $sd = 1.3$, $n=5$). An alternative but equivalent approach is to report the mean with a confidence interval corresponding to a stated likelihood that the true value falls within it (for instance, 5.1 + 2.5, where the latter I the 95% CI). Other approaches are to report the absolute range (such as 2.7-7.4); or a probability of being wrong (for instance, $p<0.001$, which means that there is a less than 1 chance in 1000 of the result being obtained by chance).

For various reasons, much climate science as broadly defined above does not lend itself to this kind of statistical presentation, which is also hard for non-experts to understand. Therefore assessment bodies like the IPCC have adopted a system of calibrated 'reserved language' for expressing certainty (see next section). The uncertainty category is based on two factors: how much evidence there is in support of the finding, and how much agreement is there between the observations and among experts. Confidence language may be used anywhere in scientific assessment reports, but is obligatory for 'high level' summary statements that may drive important decisions.

TIMELINE

1879
International Meteorological Organization (now WMO) begins to compile and standardise global weather data, including temperature

1896
Svante Arrhenius publishes first calculation of global warming from human emissions of carbon dioxide

1976
Studies show that chlorofluorocarbons (1975) and methane and ozone (1976) can make a serious contribution to the greenhouse effect

1979
First World Climate Conference convened by WMO warns that effects of global warming may be detectable before the end of the century and become significant by the middle of the next century

1985
Villach Conference declares consensus among experts that some global warming seems inevitable, calls on governments to consider international agreements to restrict emissions

1988
Toronto Conference on the Changing Atmosphere calls for a 20% reduction in global carbon dioxide emissions from 1988 levels by 2005. Intergovernmental Panel on Climate Change (IPCC) established

1990
First IPCC report says world has been warming and future warming seems likely 2020

1992 — **UNFCCC** adopted

1995 — **Second IPCC report** declares that serious warming is likely in the coming century

1997 — **Kyoto Protocol** establishes emissions reduction targets for developed countries

2001 — **Third IPCC report** states global warming is "*very likely*" with highly damaging future impacts and possible severe surprises

2007 — **Fourth IPCC report** warns that serious effects of warming have become evident; cost of reducing emissions would be far less than the damage they will cause

2014 — **IPCC Fifth Report** introduces the idea of a global carbon budget if the world is to stay below 2°C warming

2015 — **Paris Agreement** sets target of holding the increase in the global average temperature to well below 2°C above pre-industrial levels, and pursuing efforts to limit the increase to 1.5°C above pre-industrial levels

2018 — **IPCC Special Report on 1.5°C warming** concludes that urgent and substantial effort is needed to keep temperature rise to 1.5°C

WHAT IS THE ROLE OF SCIENCE IN THE CLIMATE NEGOTIATIONS?

The origins of climate science date back more than two centuries, with the recognition that human actions, such as deforestation, could impact the local climate. The link between greenhouse gases and the global temperature was first demonstrated in 1824 by French scientist Joseph Fourier, who explained that the Earth's temperature would be much lower if the planet lacked an atmosphere. This was followed by the findings of Swedish scientist Svante Arrhenius, in 1896, that burning fossil fuels and releasing carbon dioxide into the atmosphere could raise the Earth's average temperature. By 1968, studies were suggesting the possibility of collapse of Antarctic ice sheets due to global warming, resulting in catastrophic sea level rise and the displacement of more than a billion people.[2] By 1976, the serious contribution that chlorofluorocarbons, methane, and ozone could make to global warming also became known.

Alarmed by these findings, the WMO organised the first World Climate Conference in 1979, which resulted in the creation of a World Climate Programme under the auspices of UN Environment Programme (UNEP), the WMO, and the International Council for Science (ICSU, after its former name, International Council of Scientific Unions). A series of expert workshops followed in Villach, Austria, in 1980, 1983, and 1985. In the 1985 workshop, the participating scientists concurred that "*in the first half of the next century a rise of global mean temperature would occur which is greater than any in man's history*". They recommended that "*scientists and* *policymakers should begin active collaboration to explore the effectiveness of alternative policies and adjustments*".

It was also suggested that "*UNEP, WMO, and ICSU should establish a small task force on greenhouse gases ... to initiate if necessary, consideration of a global convention*". Initially, an Advisory Group on Greenhouse Gases was established in 1986 in response to this suggestion, with seven members from the three organisations. For a number of reasons, and as a result of "*an intensely political process within the US and the UN system*", this was soon replaced by a joint UNEP/WMO *intergovernmental* mechanism.[3]

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE

The proposed intergovernmental mechanism emerged as the Intergovernmental Panel on Climate Change (IPCC) in 1988, established to carry out comprehensive assessments of the science, impacts, and responses under three Working Groups:

- **Working Group I:** Scientific Assessment of Climate change (changed to Physical Science Basis from the 2007 Fourth Assessment Report onwards).
- **Working Group II:** Potential Impacts of Climate Change (changed to Impacts, Adaptation and Vulnerability 2001 Third Assessment Report onwards).
- **Working Group III:** Formulation of Response Strategies (changed to Mitigation of Climate Change from the 2001 Third Assessment Report onwards).

A **Task Force on National Greenhouse Gas Inventories** (TFI) was established in 1998 to develop and refine a methodology and software to calculate and report national greenhouse gas emissions and removals.

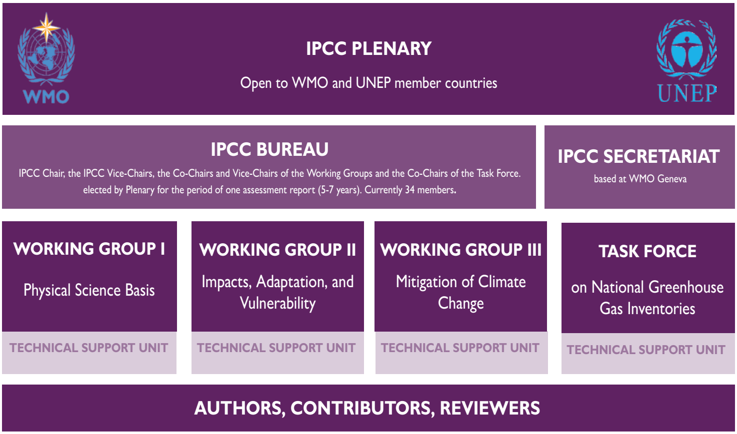
The IPCC, which aims to be 'policy relevant' but not 'policy prescriptive', was designed to allow for the participation of high caliber scientists (under the leadership of an independent scientist as IPCC Chair), with the engagement of governments. 195 governments are currently members of the IPCC. Their representatives set out the agenda for the Panel during Plenary meetings, which take place approximately once a year. The IPCC Bureau, made up of about 34 scientists elected by the Plenary for the duration of one assessment cycle, provides guidance to the Plenary on the scientific and technical aspects of the Panel's work and on related management and strategic issues. The government representatives elect the IPCC Chair and Working Group Co-Chairs. Each participating government also has a National Focal Point to serve as a point of contact; provide lists of national experts to engage with the IPCC; and integrate government comments on report drafts.

The work of the Panel is supported by a small secretariat located in the WMO offices in Geneva, Switzerland, and by four Technical Support Units distributed worldwide (see **Figure 1**).

ASSESSMENT REPORTS, SPECIAL REPORTS, AND SYNTHESIS REPORTS

The Assessment Reports of the IPCC, produced every five to seven years since 1991, have been at the heart of the evolution of global, regional, and national policy responses to climate change. In between full Assessment Reports, the IPCC undertakes 'Special Reports' on particular topics on the request of the IPCC Plenary. Methodology Reports are also produced to provide practical guidelines for the preparation of greenhouse gas inventories. The IPCC Synthesis Reports,

Figure 1: IPCC Structure



meanwhile, integrate the Assessment Report and any Special Reports prepared during an assessment cycle.

IPCC reports undergo multiple rounds of drafting and review to ensure they are comprehensive, objective and produced in an open and transparent way. In addition to the hundreds of authors, thousands of governmental and non-governmental experts contribute to the reports by acting as reviewers. This helps ensure that the reports reflect the full range of views in the scientific community. Teams of Review Editors provide a thorough monitoring mechanism for making sure that review comments are fairly and adequately addressed.[4]

Each Assessment Report involves hundreds of leading scientists who volunteer their time and expertise as Coordinating Lead Authors and Lead Authors. They enlist hundreds of other experts as Contributing Authors, to provide complementary expertise in specific areas. Countries – and other interested people or organisations who may not be members of the IPCC Plenary or Parties to the UNFCCC – have several opportunities to engage with the contents of the IPCC reports. The authors first produce a 'Zero Order Draft' (ZOD), simply listing the topics to be covered in the report. It is evaluated by the IPCC Bureau in relation to the scoping document approved by the Plenary, and adjusted if necessary.

Then a 'First Order Draft' (FOD) is produced, containing rough text and draft figures and tables. It may contain many gaps and placeholder text. The FOD goes out to teams of expert reviewers, many of whom are nominated by countries. The expert reviewers' comments must be individually addressed, and the action taken documented by the authors, as they write the Second Order Draft (SOD).

The SOD goes back to the expert reviewers, but also to the national member countries of the IPCC, who can send it to anyone to review. Thus effectively anyone in the world can comment on the SOD, and again the authors must respond to each comment. The Bureau appoints two or three review editors to each chapter, based on domain expertise, experience, and geographical balance, to certify that they have done so fairly.

A 'Final Government Draft' (FGD) is produced, along with a Summary for Policymakers (SPM). Every statement in the SPM has to be traceable to a passage in the FGD.

NEGOTIATING THE CONTENT AND OUTCOMES OF IPCC REPORTS

The SPM is then approved line-by-line by a Plenary Session of the IPCC, with Party delegates (who are generally not scientists, but may be advised by scientists) in dialogue with

Box 2: Participation of developing country scientists in the IPCC

The first Chair of the IPCC, Bert Bolin, observed that many countries, especially developing countries, simply do not trust assessments in which their scientists and policymakers have not participated. Global credibility demands global representation, he noted.[i]

The IPCC Bureau established an Ad-hoc Sub-group on Ways to Increase Participation of the Developing Countries in IPCC Activities at its first session in February 1989, and the second IPCC Plenary in 1989 established a Special Committee on the Participation of Developing Countries. The latter listed five factors which limit full participation by developing countries: insufficient information about the problem; ineffective channels to disseminate this information; limited number of trained scientists; institutional difficulties such as lack of coordination between various ministries which might have a stake in the climate issue; and limited financial resources.

Over the years, the IPCC has undertaken several specific measures to encourage participation by developing country scientists both as authors and reviewers, including expanding financial support for developing country experts to attend IPCC sessions; developing 'master resource lists' of experts at the national level; and providing inputs to shape the research priorities of regional organisations. The engagement of developing country experts has been increasing over the years, particularly in reports and assessments with chapters on regions, but balanced representation still remains a challenge, especially in the context of experts from LDCs and Small Island Developing States.[ii] Of the 721 experts selected for Sixth Assessment Report, 44% come from developing countries and countries with economies in transition, compared to 37% for the Fifth Assessment Report.[iii] For the special report on *Global Warming of 1.5°C*, 6% of the authors and review editors were from LDCs, and 7% were from Small Island Developing States.[iv]

The IPCC passed an important milestone with the Special Report on Climate Change and Land, released in 2019, where over half of the author team (53%) came from developing countries.

i. Agrawala, S. (1998). Structural and process history of the Intergovernmental Panel on Climate Change. *Climatic Change*. 39: 621-642.
ii. Singh, A. & Patwardhan, A. (2014). Assessing the effects of participation in IPCC: Implications in capacity building of scientists from developing nations in research for adaptation and mitigation. *Global Nest Journal*. 17(1):22-28.

iii. IPCC (2018). *Selection of Authors for IPCC Sixth Assessment Report*. Press Release.

iv. Thomas, A. (2018). *Authors from vulnerable nations in IPCC reports*. Climate Analytics Blog.

the authors. Only the SPM is reworked in this way, not the underlying report (see below on how it is accepted). The authors are present in the discussion to explain the science that underlies the statements.

There are three levels of endorsement:

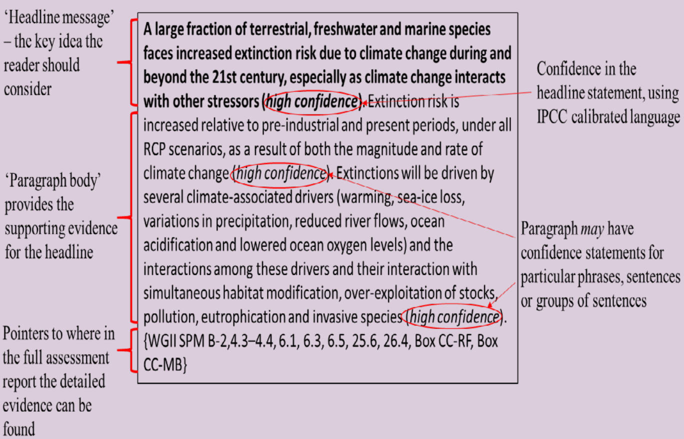
- 'Approval' means that the material has been subjected to detailed line-by-line discussion and agreement. This is the procedure used for the SPMs.
- 'Adoption' describes a section-by-section endorsement. This is used for the Synthesis Report and overview chapters of Methodology Reports.
- 'Acceptance' signifies that the material has not been subject to line-by-line or section-by-section agreement but nevertheless presents a comprehensive, objective, and balanced view of the subject matter.

It is tacitly accepted that the underlying main report may not say anything that is contradictory to what is in the SPM. There is no mechanism for voting on the wording of the SPM or underlying report, so for text to be accepted it must represent a consensus of Parties, often following intense discussions and compromises reached outside the chamber. This slow and exhausting process has the advantage of leading to a high degree of national buy-in (countries cannot then say they did not know of, or disagree with, the findings), but how can it then be claimed that the science is independent of 'political' influence?

In practice, the plenary sessions where the SPM text is agreed seldom make substantive changes to the science, though they may change virtually every word in the text. First, the base text that is used for the SPM is written by the scientific authors, taking care to reflect the science accurately. Second,

Box 3: How to read an IPCC Summary for Policymakers

The structure, language and style of a SPM paragraph is standardised and formal. Here is an example, with notes pointing out the main elements.


A large fraction of terrestrial, freshwater and marine species faces increased extinction risk due to climate change during and beyond the 21st century, especially as climate change interacts with other stressors (*high confidence*). Extinction risk is increased relative to pre-industrial and present periods, under all RCP scenarios, as a result of both the magnitude and rate of climate change (*high confidence*). Extinctions will be driven by several climate-associated drivers (warming, sea-ice loss, variations in precipitation, reduced river flows, ocean acidification and lowered ocean oxygen levels) and the interactions among these drivers and their interaction with simultaneous habitat modification, over-exploitation of stocks, pollution, eutrophication and invasive species (*high confidence*). {WGII SPM B-2,4.3–4.4, 6.1, 6.3, 6.5, 25.6, 26.4, Box CC-RF, Box CC-MB}

The IPCC uses calibrated language to communicate the degree of confidence in the findings of the assessment process, using five qualifiers: very low, low, medium, high, and very high, always typeset in italics. The following terms have been used to indicate the assessed likelihood of an outcome or a result: virtually certain (99-100% probability); very likely (90-100%); likely (66-100%); about as likely as not (33-66%); unlikely (0-33%); very unlikely (0-10%); and exceptionally unlikely (0-1%). Additional terms may also be used when appropriate, such as extremely likely (95-100%); more likely than not (>50-100%); more unlikely than likely (0-<50%); and extremely unlikely (0-5%).

the authors are on the podium when changes are proposed, and can offer their opinion and suggest text which is both true to the science and acceptable to the Parties. The scientific authors do not have a veto right, but their interventions are usually taken very seriously. Third, if a country or group of countries propose text that is incompatible with the science, other countries (often advised by scientists associated with their delegation) quickly point this out.

The result of this negotiation process is usually quite complicated text, as it struggles to incorporate the various viewpoints, but it is not knowingly wrong. Since the plenary proceedings are in the public domain, and are followed with interest by the media, there is a strong disincentive for individual countries to take an isolated position on an issue. Instead, they use their influence outside of the IPCC to convince other countries to support their position. Even so, it is hard to introduce something that has no evidentiary support. The most that can be achieved is to water down the confidence in a finding or introduce contradictory evidence – but that has to be in the underlying Assessment Report in the first place. In rare cases, where no consensus text can be reached, a sentence or section needs to be dropped from the SPM altogether, which may lead to text being dropped from the underlying Assessment Report as well.

SCIENCE UNDER THE UNFCCC AND ITS PARIS AGREEMENT

The UNFCCC calls on Parties to promote and cooperate in research, systematic observation and the development of data archives, including through exchange of information; supporting and developing programmes, networks and organisations; and taking into account the needs and concerns, and building the capacity, of developing countries (Article 4.1.g. and 5). Parties report on research and systematic observations in their National Communications.

The Paris Agreement recognises the need for an effective and progressive response to the urgent threat of climate change on the basis of the best available scientific knowledge. Perhaps the best-known parts of the Paris Agreement are the limits to global mean temperature rise which they establish, for the first time as a collective goal. The agreed target of keeping warming below 2°C, and an aspirational target of staying below 1.5°C, have been strongly informed by climate science along with many other considerations, such as national circumstances and technology readiness.[5]

Article 4.1 of the Agreement calls on Parties to limit global greenhouse gas emissions as soon as possible, and at the lowest possible resultant concentrations, and "*to undertake rapid reductions thereafter in accordance with best available science*". The intent is to achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century, on the basis of equity, and in the context of sustainable development and efforts to eradicate poverty.

In Article 7.5 of the Paris Agreement, Parties acknowledge that adaptation action "*should be based on and guided by the best available science and, as appropriate, traditional knowledge, knowledge of indigenous peoples and local knowledge systems…*".

Article 14 calls for the five-yearly global stocktakes to take stock of the implementation of the Agreement "*in the light of equity and the best available science*".

The Agreement identifies the need to enhance and strengthen systematic observation, climate services and knowledge sharing (Article 7), and recognises that systematic observation and early warning systems are areas of cooperation and facilitation to enhance understanding, action, and support (Article 8).

In addition to the reference to indigenous peoples and local knowledge systems in Article 7.5, the preamble of the Paris Agreement calls on Parties to respect, promote, and consider the rights of indigenous peoples and local communities, among others. Paris Decision 1/CP.21 recognises the need to strengthen knowledge, technologies, practices, and efforts of local communities and indigenous peoples related to addressing and responding to climate change, and establishes a platform for the exchange of experiences and sharing of best practices on mitigation and adaptation in a holistic and integrated manner (§135). The Local Communities and Indigenous Peoples Platform (LCIPP) was launched in 2017 (Decision 2/CP.23), to:

- Strengthen the knowledge, technologies, practices, and efforts of local communities and indigenous peoples related to addressing and responding to climate change.
- Facilitate the exchange of experience and the sharing of best practices and lessons learned on mitigation and adaptation in a holistic and integrated manner.
- Enhance the engagement of local communities and indigenous peoples in the UNFCCC process.

The LCIPP provides recommendations to the Subsidiary Body for Scientific and Technological Advice (SBSTA) on issues affecting their constituencies and also provides advice based on indigenous knowledge.

(For more details on the provisions of the Convention and the Paris Agreement, see the *Pocket Guide to the UNFCCC*, the *Pocket Guide to the Architecture and Processes of the UNFCCC*, and the *Guide to the Paris Agreement*).

SBSTA AND SBI

Article 9 of the UNFCCC establishes a SBSTA to provide the Conference of the Parties (COP) to the Convention with "*timely information and advice*" on scientific and technological matters. While the body is open for participation by all Parties, Article 9 calls for multidisciplinary participation, comprising of government representatives competent in the relevant field of expertise.

The UNFCCC calls on SBSTA to, among other things:

- Provide assessments of the state of scientific knowledge relating to climate change and its effects.
- Prepare scientific assessments on the effects of measures taken in the implementation of the Convention.
- Identify innovative, efficient and state-of-the-art technologies and know-how and advise on the ways and means of promoting development and/or transferring such technologies.
- Provide advice on scientific programmes, international cooperation in research and development related to climate change, as well as on ways and means of supporting endogenous capacity-building in developing countries.
- Respond to scientific, technological and methodological questions that the COP and its subsidiary bodies may put to the body.

Article 10 establishes a Subsidiary Body for Implementation (SBI) to assist COP in the assessment and review of the effective implementation of the Convention. SBI is tasked, among other things, to consider the overall aggregated effect of the steps taken by Parties in the light of the latest scientific assessments concerning climate change. This includes, for instance, the measurement, reporting, and verification (MRV) of climate action by Parties. SBI also works with SBSTA on crosscutting issues, such as vulnerability and adaptation, response measures, the Technology Mechanism, the Adaptation Committee and the Warsaw International Mechanism for Loss and Damage.

SBSTA and SBI also serve as Subsidiary Bodies to the Kyoto Protocol and the Paris Agreement. Article 18 of the Paris Agreement states that SBSTA and SBI sessions of the Agreement will be held in conjunction with the meetings of, respectively, the SBSTA and SBI of the Convention.

RESEARCH AND SYSTEMATIC OBSERVATIONS

The negotiations on Research and Systematic Observations (RSO) are considered by SBSTA, with research usually considered at the first sessional period of the year and systematic observation at the second sessional period. Systematic observations focus on worldwide, long-term observations of the climate system to understand climate change and its associated impacts, and helps scientists determine future trends. Climate change research considers on a wide range of topics, such as Earth sciences, climate processes and variability, climate modelling and prediction; climate change impacts, vulnerabilities, risks and extreme events, as well as research on adaptation and mitigation. It covers a broad spectrum of sectors, society, economies, and ecosystems and includes crosscutting and interdisciplinary research.

SBSTA has mandated the UNFCCC secretariat to organise annual Research Dialogues and Earth Information Days. The Research Dialogues take place at the mid-year session of the SBSTA, and focus on a topic identified by the Parties. They are a key way of sharing up-to-date scientific information and Parties' needs to support the science-policy interface under the

Convention. Experts are invited to deliver presentations on the topic and then engage in a dialogue with the negotiators. The SBSTA debates the issue and drafts a conclusion arising from the debate. The draft decision is submitted to the COP, in particular when it contains an invitation to the financial mechanism of the Convention to provide support to strengthen systematic observation. The Earth Information Days take place during the COP, during which scientific agencies are invited to make presentations on their work.

The Nairobi Work Programme on Adaptation (NWP) also convenes a dialogue at each COP. Organisations that are members of the NWP make presentations on specific topics and these are acknowledged in the SBSTA conclusion on RSO.

COOPERATION WITH OTHER BODIES

SBSTA serves as a link between the scientific information provided by expert sources such as the IPCC, and the policy-oriented needs of the COP. The Secretariats of the WMO, Global Climate Observing System (GCOS), and the Committee on Earth Observation Satellites (CEOS) are invited to deliver statements at the SBSTA plenaries. These statements inform the deliberations on various SBSTA agenda items. The SBSTA Chair also engages in discussions with relevant scientific agencies during sessions. At the mid-year session, these include discussions with agencies and countries which support GCOS and with scientists who will participate in the Research Dialogue. At the COP session, the SBSTA Chair holds a meeting with the IPCC Chair, along with officers representing the IPCC's three Working Groups and Task Force on inventories. The Chairs of relevant constituted UNFCCC bodies are also invited to these meetings, for instance the Chair of the Adaptation Committee and the Executive Committee of the Warsaw International Mechanism.

SBSTA regularly cooperates with the IPCC and seeks its advice. For instance, SBSTA convened dialogues on the IPCC's Special Reports on *Global Warming of 1.5°C*, *Climate Change and Land*, and *Oceans and the Cryosphere in a Changing Climate*.

The UNFCCC Secretariat has Memorandums of Understanding with various scientific organisations such as the WMO, and some of these bodies have tailored arrangements to engage with the UNFCCC. For instance, the WMO's Climate Coordination Panel has a subsidiary body of Climate Policy Advisors to provide recommendations on WMO's involvement in policy processes such as the UNFCCC.

PERIODIC REVIEW OF THE LONG-TERM GLOBAL GOAL

At COP16 in Cancun, in 2010, UNFCCC Parties agreed to a long-term global goal to hold the increase in global average temperature below 2°C above pre-industrial levels. They also agreed to periodically review the adequacy of this long term goal, and overall progress towards achieving it.

The first periodic review was conducted in 2013-2015, through Structured Expert Dialogues (SEDs) convened by SBSTA and SBI. The SED sessions were organised as fact-finding, face-to-face exchanges of views between Parties and experts. In response to the outcome of the review, Parties agreed to strengthen the global goal in Paris in 2015. They agreed that the goal is to "*hold the increase in the global average temperature to well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5°C above pre-industrial levels*" (Decision 10/CP.21). The second periodic review of the long term goal started in 2020.

OTHER SCIENTIFIC INSTITUTIONS INVOLVED IN THE NEGOTIATIONS

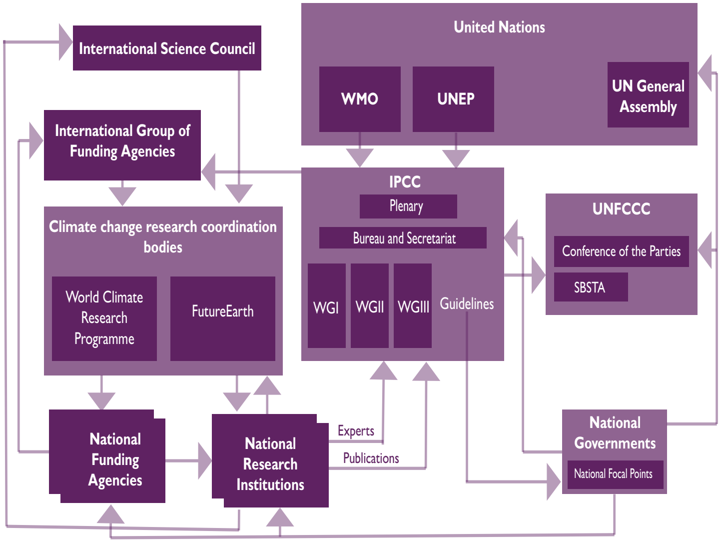
Around 100,000 researchers worldwide are engaged in climate-related work to some degree, but only a small fraction is engaged as IPCC authors or reviewers or as advisors to national delegations. Most climate scientists are therefore not engaged in the structures described above. How then is the global effort research effort coordinated? The answer is: only loosely and partially, and that may be a good thing.

The main coordination body resides under the International Science Council (ISC), which brings together 40 international scientific Unions and Associations and over 140 national and regional scientific organisations including Academies and Research Councils. The ISC was created in 2018 as the result of a merger between the International Council for Science (ICSU) and the International Social Science Council (ISSC). ICSU had launched the International Geosphere-Biosphere Programme (IGBP) in 1987 to coordinate interdisciplinary work on global change in the natural sciences. The ISSC established the International Human Dimensions Program (IHDP) in 1990 to coordinate the social science effort. The two streams converged in 2015 in an integrated programme called FutureEarth.

Climate modellers, meanwhile, are organised by the World Climate Research Programme which resides under WMO, and is not part of FutureEarth.

In general, these programmes do not fund research, but support and guide the development of third-party funded but coordinated global research programmes and projects that are remarkably effective in advancing global change research. A degree of international funding coordination has been achieved by a consortium called the International Group of Funding Agencies, and another known as the Belmont Forum.

Figure 2: Main institutions involved in the science-policy interaction that supports climate negotiations



Almost all climate science is funded nationally, or within blocs such as the EU. Some research is funded by private foundations, or by corporations. Many countries have national coordinating bodies for global change research, often reporting to their research funding agencies, or to national academies, or to National Focal Points for climate change, which report to the UNFCCC.

Non-government and not-for-profit research institutions are represented through the Research and Independent Non-Governmental Organisations (RINGO) constituency to the UNFCCC. RINGOs are one of nine NGO constituencies recognised by the UNFCCC.

HOW DOES CLIMATE SCIENCE INTERACT WITH CLIMATE POLICY?

The 'classical' view of science, still held by some scientists and many non-scientists, is that researchers work in academic environments, inspired only by the desire to advance human knowledge. They report their discoveries in language comprehensible only to fellow scientists. If any scientific advances leak out into the real world, they do so serendipitously, or because the scientists have deliberately explained ('transferred') them to technologists, who then transfer them to society in an applied form.

In reality, for at least the past 70 years, the majority of scientists don't work this way, most of the time. Typically they work on problems posed by society, guided by research funding grants designed to answer specific questions. Scientists are expected to report back to society and funders with solutions. This cycle requires two-way, iterative communication: users must state their needs, and scientists test the options to addressing them. When the loop is working most tightly, the new knowledge that results is said to be 'co-generated' or 'co-produced' by the scientists and users-of-science. This is one meaning of the word 'transdisciplinary'. Climate science, in the context of international climate negotiations, mostly works in this interactive way, between science and society.

The climate negotiations are strongly influenced by science, but the scientists are seldom in the room. Each UNFCCC Party has representatives, usually supported by advisors. For wealthier countries or for countries with a lot at stake, the advisory teams can number tens of people, whereas for poor or small countries the team may consist only of the representative, and that may not even be their full-time job. Some of the advisors, and a few of the representatives, have a scientific background. Most are career diplomats, often with a background in law and international affairs, whose knowledge of climate science, while sometimes deep, has been acquired 'on the job'. It is the task of the advisors to provide them with briefings on the technical issues. On the other hand, the 'back-office' of scientists and technical experts is often politically and diplomatically naïve. Therefore, the generation of a national position is best thought of as 'co-produced' between the two groups of experts, one on the political side, and one on the technical side. The closer you get to more 'political' bodies such as the COP, the greater the dominance of non-scientists among the people involved.

There are other mechanisms to facilitate the interaction between climate science and policy, including the formal bodies set up for this purpose (such as the IPCC and SBSTA); structures convened to advise governments at national, state, or local levels, and sometimes within industrial sectors or individual non-governmental entities; and interaction between scientists and the public through science outreach and the media.

For example, in the three decades leading up to the 2015 Paris Agreement, tens of thousands of scientists, in hundreds of institutions, separately funded by their governments (and to a lesser degree by private foundations or corporations), worked in a loosely coordinated way to understand the global climate system, and how and why it was changing. This enormous body of work has been periodically 'assessed' (collated, evaluated, summarised and communicated), particularly but not exclusively by the IPCC.

As gaps and uncertainties were revealed, science funders supported programmes to help fill them, and scientists, out of a combination of interest, ambition and desire to address an important problem, aligned their research with the key questions. The evidence presented in the Second Assessment Report of the IPCC in 1995 was insufficient to drive a global climate deal in Copenhagen in 2001, and the Third Assessment Report delivered in 2001 was a little too late to do so, but the Fourth Assessment Report in 2007, and especially the Fifth Assessment Report in 2014, helped to build a level of agreement and body of evidence that contributed substantively to the agreement reached in Paris. A science summit, Our Common Future Under Climate Change, held in Paris in July 2015, five months before the political summit, helped to develop the momentum towards the outcome, which was a commitment to keep global warming below 2°C (with an aspirational goal to limit it at 1.5°C).

In the run-up to the Paris Agreement, the Parties most vulnerable to climate change had been pushing for the 1.5°C target. Paris Decision 1/CP.21 invited the IPCC to develop a Special Report exploring the additional benefit (or reduction in climate risk) of a 1.5°C limit rather than a 2°C limit, and whether the lower target is attainable (§21). *Global Warming of 1.5°C*, published by the IPCC in 2018, found that climate-related risks for natural and human systems are higher for global warming of 1.5°C than at present, but lower than at 2°C. It also found that to achieve the 1.5°C goal, a 45% reduction of emissions from 2010 levels is needed by 2030. This message is being used by stakeholders to convince policymakers to push for urgent action over the next decade to meet the 1.5°C aspiration of the Paris Agreement. At the same time, work on the Report offered new insights, for instance into the technological implications of zero emissions, the identification of new climate hotspots and impacts on specific regions, and impacts on specific sectors such as marine fisheries.[6] Some Parties sought to play down the importance of the Report by resisting references to it in COP decisions. This was viewed by many as an attempt to deny and discredit the science.[7]

EXISTING AND FUTURE CHALLENGES RELATED TO CLIMATE SCIENCE

As the global focus shifts from negotiations to implementation of the Paris Agreement, the scientific community, along with other stakeholders, will have to shift gears to deliver new requirements, while addressing existing challenges, for instance the disparity in data and analytical capacity between developed and developing parts of the world. The scientific community will continue to play a key role in, among other things, defining future emission pathways to meet the long-term goals of the Paris Agreement; identifying barriers and solutions to the transformational change; informing the preparation of Nationally Determined Contributions and of Low Emission Development Strategies; ensuring that the global stocktakes are carried out "*in the light of equity and the best available science*"; and contributing to adaptation efforts and to minimising loss and damage due to climate change.[8]

This could mean that existing processes have to be adapted. For instance, there have been discussions on whether the five to seven year cycle of the IPCC Assessment Reports should be shortened, to align with the five-yearly cycles of the global stocktakes. The IPCC discussions on this issue have been heated, with some Parties opposing such a change. Other Parties, including Small Island Developing States, support the alignment to prompt accelerated action and increased ambition by the global community. They view efforts to block the alignment as efforts to block the provision of scientific information by the IPCC to the global stocktake. A Task

Group on the Organization of the Future Work of the IPCC in Light of the Global Stocktake presented alternatives to the 52nd session of IPCC in February 2020, and discussions will continue.[9]

INTEGRATION IN THE WORK OF THE IPCC

Initially, the authorship of the IPCC reports was overwhelmingly dominated by physical climatologists, physicists and mathematical modellers. For instance, the first Assessment Report (1990) had no chapter on climate adaptation at all. As the work began to extend into the environmental and social impacts of a changing climate, many more non-climatologists became involved. The scope began to consider many more human-related rather than purely biophysical effects, drawing in social scientists. The 'centre of gravity' of the assessments began to move away from proving that climate change existed, to understanding its consequences, and then to seeking solutions to the problem. More and more economists, engineers, and political scientists became involved. Since these groups of experts all have different traditions, training, and worldviews, the 'science culture' of the IPCC is a mixture that continues to evolve.

From the second assessment onwards, the broad disciplines have been functionally separated into the three Working Groups. To some extent this has entrenched the science-culture differences between the groups, and hampered an integrated view, which only really happens in the Synthesis Report. Working Group 1 reports precede Working Group 2 in time, which in turn precede Working Group 3. This forces the later Working Groups to adopt positions already embedded in earlier Working Groups. There have been many suggestions for restructuring the IPCC, but this basic format has proven resistant to change. Crosscutting work is easier to achieve in Special Reports and workshops, but even then, they are often 'owned' by one of the Working Groups.

The separation of 'mitigation' actions (that is, those that lead to net reductions of greenhouse gas concentrations in the atmosphere) from 'adaptation' actions (steps to reduce the impacts of a changing climate) can be traced to the original language of the UNFCCC (see **Box 4**). Initially, these were seen as two quite distinct classes of responsibility: mitigation by the Annex 1 countries, and adaptation by the non-Annex 1 countries. Both the science and the politics have resulted in this distinction becoming blurred. Firstly, mitigation actions can have positive or negative consequences for adaptation, and vice versa. Second, even rich, industrialised countries need to adapt to the climate change that is now inevitable. Unlike mitigation, nobody can do it for you. Third, to gain from the technological opportunities offered by a switch to low-carbon energy sources, developing countries also need to implement mitigation actions. In addition, developing countries are now among the major emitting nations and their emissions are increasing.

LINKS WITH SUSTAINABLE DEVELOPMENT

The relationship of climate change policies to sustainable development is another area of change, both on the policymaker side and the research side. In 1995, the view was that climate policy was the responsibility of the major emitting countries, largely synonymous with the industrialised world, and listed in Annex 1 of the UNFCCC. In the next decade it became clear that meaningful progress on reducing emissions will require the participation of all Parties, that climate policy is inextricably linked to development policy, and both are

Box 4: Adaptation plays catch up with mitigation

In the early years of the UNFCCC (1992-2005) the major emphasis in climate science, negotiations, and implementation was on mitigation. This was mainly because some developed countries were under the impression that climate change was a gradual incremental process, and that there would be time to slowly reduce emissions. Adaptation was viewed as a cost of failed mitigation. Former US Vice-President Al Gore, for instance, opposed adaptation in 1992, saying it represented a "kind of laziness, an arrogant faith in our ability to react in time to save our skins".[i]

Therefore, the 1990 Working Group II report of the IPCC did not include a chapter on adaptation, and the 1995 report had separate chapters on mitigation, but not on adaptation. It was not until 2001 that a chapter was included on *Adaptation to Climate Change in the Context of Sustainable Development and Equity*.

Some developed countries were reluctant to place as much emphasis on adaptation as mitigation, or even discuss adaptation, for two main reasons. First, they felt that talk of the need for adaptation would suggest that the climate change problem could not be successfully managed by mitigation. It threatened or reduced the credibility of the mitigation effort. Second, and somewhat inconsistently, the developed countries did not want to open themselves up to financial demands to assist the developing countries with the costs of adaptation (although Article 4.4 of the UNFCCC calls on developed countries to assist developing countries in meeting costs of adaptation).

It was the poorer countries, especially the least developed countries (LDCs) that pressed for more attention to adaptation. They argued, with evidence from IPCC assessments, that they were most exposed and vulnerable, and would feel the impacts of climate change more quickly and more severely than the developed countries. Developing countries also pointed out how little they contributed to total global emissions. In effect, climate change impacts were going to be imposed upon them by the developed countries.

Since the early years of the 21st century, adaptation has steadily gained stronger recognition and importance as climate change has happened more rapidly than initially expected. The interconnections between adaptation and mitigation are increasingly recognised. This is leading to a more comprehensive and systemic approach to climate change in which all possible actions are under evaluation.

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i. Pielke, R. *et al* (2007). Lifting the taboo on adaptation. *Nature*. 445, 597-598.

connected to a series of other global challenges, eventually defined in 2015 as the Sustainable Development Goals (SDG). The IPCC Fifth Assessment Report (2014 and 2015) had a strong sustainable development focus in Working Group 2, and this framing was adopted across all Working Groups in the Sixth Assessment report.

The IPCC has grappled with issues of justice and fairness ('equity'). For example, the Third Assessment Report was revealed to have used different economic values when accounting for the lives of people in developing countries and developed countries.[10] There are technical issues relating to reporting both the 'average' climate impact and its 'distributional effects' – that is, the spread of those impacts across different groups of affected people. It is clear across all scales that the groups causing and benefiting from the activities leading to climate change are different from those bearing its negative consequences, and the burden fall disproportionately on the poor and politically marginalised. Awareness of this problem has resulted in the inclusion of more political economists and ethicists within the author teams, but the tensions between 'efficient' solutions and 'just' solutions continue. **Box 5** addresses the specific issue of gender bias in climate science.

ENGAGING WITH CLIMATE CHANGE SCIENCE

The majority of global scientists, across almost all fields, are citizens of developed countries. Most are resident in the northern hemisphere. By far the largest climate science research budgets are spent in developed countries, where most of the scientific infrastructure, including climate modelling capacity and climate observation equipment, is located. The peer-reviewed scientific literature on climate change

Box 5: Climate science and gender

Climate change has differential effects on different people, depending on where they live, their social circumstances, and their gender, among other factors. Similarly, the differentially-affected people have varying capacity to alter their futures. This is potentially problematic in the context of climate change science and policy, when such differences are not recognised by the science or not taken into consideration in the policy. The best way to guard against this outcome is to ensure empowered participation in both the scientific and policy-making processes by all relevant groups.

A radical feminist critique of science in general, which could be extend to climate science, is that it is inherently paternalistic and hierarchical, and therefore either at best partly blind to gendered issues, and at worst actively dismissive of them. It is worth noting that indigenous and traditional knowledge systems also display gendered differences. It is well-known that policymakers, worldwide, are disproportionately male. Therefore deliberate steps to consider gendered perspectives at all stages in the process, and to be vigilant for inequities of all sorts, is justified.

There are many women (and people with non-binary gender perspectives) at all levels in the climate science research community, the climate science assessment bodies, and in the international climate policy-making institutions. Nevertheless, research on the gender composition of IPCC authors, and women's experiences within the IPCC, both show that despite steady progress, a fully gender-representative state has not yet been reached.[i] The IPCC has a Gender Policy and Action Plan, adopted in 2020, and the UNFCCC has a Gender Action Plan (see *Pocket Guide to Gender Equality under the UNFCCC*). Feminist Participatory Action Research is an example of an alternative way of producing knowledge, aimed at promoting the voice of marginalised groups and gendered perspectives in research.[ii]

i. Gay-Antakia, M. & Liverman, D. (2018). Climate for women in climate science: Women scientists and the Intergovernmental Panel on Climate Change. *Proceedings of the National Academy of Sciences*. 115:2060-2065.
ii. Godden, N.J., Macnish, P., Chakma, T. & Naidu, K. (2020). Feminist Participatory Action Research as a tool for climate justice. *Gender & Development*. 28(3).

is dominated by developed world authors and a handful of developed country-based publishing houses. These inherent imbalances in the structures of science have the potential to lead to unintended biases, or in the opinion of some, deliberately partial conclusions.

Awareness of the potential for real or perceived bias has led the IPCC to implement policies aimed at promoting balance and completeness. Virtually all the countries of the world are Parties to the UNFCCC and members of the IPCC, and through their plenaries are able to participate in the discussions and decisions regarding what topics should be covered, who will lead the assessments, and who will serve as authors. All countries are encouraged to nominate both authors and reviewers. The leadership of every assessment comprises at least two co-chairs and often more, who are always split between developed and developing countries. All assessment chapters have at least two convening lead authors and several lead authors balanced in a similar way, as well as across genders (see **Box 5**), scientific disciplines, and other relevant factors. This balance is striven for chapter-by-chapter as far as possible, but is certainly achieved in aggregate. Contributing authors (who deliver relatively small amounts of text) do not need to be pre-approved by the IPCC Bureau, but their country of origin, gender, and discipline are in the public record. The review editors, also balanced and vetted by the Bureau, are tasked with evaluating whether the review comments received on IPCC drafts are drawn from all parts of the world and are handled fairly and appropriately in all cases.

The participation costs for scientists from the developing world, excluding their time, are paid by the IPCC Trust Fund. The IPCC conducts training for would-be participants, including fellowship programmes aimed specifically at early career developing country researchers.

Despite these precautions and interventions, it remains much harder for developing world countries to have a voice within the climate science-policy interface that is proportional to their population, climate risk level, or territorial area. Apart from political and economic marginalisation, they are disadvantaged by language and the 'Western' nature of the scientific culture. In countries with small populations and economies, the depth of scientific expertise is often insufficient to allow them to have specialists in all domains, and their negotiating teams are not supported by large numbers of science advisors.

Developing countries can help to address these shortcomings in several ways, since in the big picture it is in their interests to do so. First, they must adequately support their national science community to develop the necessary human and infrastructural research capacities. This has many spin-off benefits for their economies as a whole. Second, countries from the global South must nominate their scientists for roles in the IPCC and in climate research bodies, and support the nominations of suitable candidates from other developing countries. Third, scientifically smaller countries can combine efforts to elevate regional issues. Fourth, countries in the under-sampled parts of the world can partner with other countries to ensure more even coverage, for instance by hosting infrastructure paid for by wealthier countries.

GLOSSARY

Adaptation

The process of adjustment to the climate and its effects, in order to moderate harm or exploit beneficial opportunities. In natural systems, it involves behavioral, physiological or evolutionary change, including migration. In human systems it can occur ahead of the change in climate, based on expected change.

Anthropogenic

Resulting from, or caused by, human beings; specifically used to distinguish those elements of climate change and variability resulting from human actions after about 1750 (the nominal start of the Industrial Age), from natural fluctuations and trends in the climate system.

Annex I countries (and, by exclusion, non-Annex I countries)

Countries listed under Annex I of the UNFCCC, which are expected to take the lead in mitigation actions due to their history of greenhouse emissions. Includes developed countries that are members of the Organisation for Economic Co-operation and Development (OECD), plus countries with economies in transition (EIT). Non-Annex I countries are developing countries, expected to have less stringent emission reduction targets.

Assessment report (IPCC)

A scientific assessment, in this case on climate change, its implications and potential future risks, as well as to put forward adaptation and mitigation options. The main series of IPCC assessment reports is produced approximately every six years.

Atmosphere

The layer of gases surrounding the Earth or other planets.

Biophysical effect

An Earth system process that depends entirely on biology, physics, or chemistry, not requiring any human agency.

Carbon (C)

A nonmetallic chemical element with the symbol C, atomic number 6 and atomic mass of 12.011 g mol-1 that forms the backbone of life on Earth; carbon-containing compounds are therefore also called 'organic molecules', although many are now synthesised by humans found in all natural element combinations and some man-made element combinations.

Carbon dioxide (CO2)

A naturally occurring gas in Earth's atmosphere. It is the principal anthropogenic greenhouse gas that affects the Earth's radiative balance. CO2 is taken out of the atmosphere by plants through the process of photosynthesis, and returned to the atmosphere through respiration and decomposition of organic matter. It is a byproduct of fossil fuel combustion and biomass burning, and is also emitted by non-combustion industrial processes. It can be emitted or taken up by land use changes.

Carbon dioxide equivalent (CO_2e or CO_2eq)

An approximate metric used to compare the emissions of the different greenhouse gases based upon their global warming potential (GWP).

Celsius (also Fahrenheit & Kelvin)

A scale for the measurement of temperature, named after the Swedish scientist Anders Celsius, abbreviated °C, where 0°C is the freezing point of pure water and 100°C is its boiling point (both at sea level) . The same scale was formerly known as 'centigrade'. 'Absolute temperature is expressed in degrees Kelvin, with its zero (0 K)at the coldest temperature in the universe, -273.15° Fahrenheit (°F) is a scale still used in some countries. To convert °C=(°F-32)*5/9.

Climate

Climate refers to the average weather, or more rigorously, the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. The WMO specifies a minimum period of 30 years for calculating climate from weather.

Climate change

A change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings, or to persistent anthropogenic changes in the composition of the atmosphere or in land use.

Climate science

The study of the climate system, generally of planet Earth. Climate science seeks to understand how global, regional and local climates are maintained as well as the processes by which they change over time.

Climate scientist

A person who studies any aspect of the climate system, using scientific approaches.

Climate system

The system which controls the climate of the Earth. In its pre-human state it consisted of five major components: the atmosphere, the oceans, the cryosphere, the land surface, the biosphere. It behavior is strongly influenced by the interactions between them (which is what makes it a 'system', and leads to complex outcomes). In modern times it also includes human actions. There are minor contributions from variations in the input of solar radiation, and Deep Earth processes such as volcanism.

Confidence interval

How much certainty (or uncertainty) is associated with a given numerical value. In science it is conventionally expressed and the 95% confidence interval; in other words there is only a 1 in 20 chance that the true value lies outside this range. It can also be expressed as the range (that is, the maximum and minimum ever observed). It is sometimes expressed as the standard deviation or standard error, from which the confidence interval can be calculated.

Cryosphere

Cold places on the Earth where low temperatures cause the water to be in solid, frozen form. Includes ice caps, ice sheets, glaciers, permafrost (frozen ground) sea ice, lake ice, river ice and snow cover.

Deterministic

A calculation with an exact solution, without the involvement of randomness.

Eddies (and loops)

An eddy is a loop of a fluid that is cut off from the main current. It is temporary and small relative to the main current, but eddies in the ocean can be hundreds of kilometers across and persist for months. The atmosphere also contains eddies.

Global South

Refers broadly to the regions of Latin America, Asia, Africa, and Oceania that are predominated by countries with less developed or emerging economies. It is a political or socio-economic grouping, rather than a geographical one, although most of these countries lie 'south' of the main OECD countries. It is a more inclusive term than 'developing countries' and regarded as less pejorative.

Global Stocktake

The assessment of collective progress towards achieving the Paris Agreement, to take place in 2023 and every five years thereafter.

Global Warming Potential (GWP)

An index representing the climate-altering effect of a greenhouse gas, relative to carbon dioxide. The calculation includes consideration of the relative effectiveness of the gas in absorbing outgoing infrared radiation, but also its lifetime in the atmosphere. GWP, despite its approximate nature, has become the default metric for converting emissions of different gases to a common scale. The GWP, over a time horizon of 100 years, was adopted as a metric to implement the multi-gas approach in the UNFCCC. The GWP cannot be calculated with sufficient accuracy and universal applicability for very short-lived gases, such as tropospheric ozone.

Greenhouse gases (also called Radiatively-active gases)

Those gaseous constituents of the atmosphere, both natural and anthropogenic, which absorb and emit radiation at specific wavelengths within the spectrum of thermal infrared radiation emitted by the Earth's surface, by the atmosphere itself, and by clouds. This property causes the greenhouse effect. Water vapor (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), and ozone (O_3) are the primary greenhouse gases in the Earth's atmosphere.

Impact pathway

The mechanism, which may include several steps and several causal factors, by which a given effect leads to particular consequences.

Indigenous knowledge

The understandings, skills and philosophies developed by societies with long histories of interaction with their natural surroundings. For indigenous peoples, who are predominantly rural, indigenous knowledge informs decision-making about fundamental aspects of day-to-day life. See also 'Local knowledge'. UNESCO and other sources do not distinguish between indigenous and local knowledge.

Local knowledge

Knowledge derived from local experience or observation, often held by non-scientists. It can be either rural or urban, and in immigrant populations as well as the original inhabitants of an area. See also the related, but different, concept of 'Indigenous knowledge'.

Mean

A statistic calculated as the sum of all the valid values in the data set divided by the number of valid values in the data set. It is also called the 'average' or the 'expected value' and is the most widely-used measure of central tendency. For data where the distribution is high skewed, the median is preferred.

Measurement error

The difference between a measured quantity and its true value; also called 'observational error'. It includes random error (naturally occurring variations that are to be expected with any experiment); gross error (occurring due to human mistakes) and systematic error (caused by a misaligned instrument that affects all measurements).

Methane (CH4)

A powerful greenhouse gas found in small quantities in Earth's atmosphere, with many natural and human-altered sources, including wetlands, ruminants and fossil fuels.

Microbe

Any tiny living thing too small to be seen by the naked eye, including bacteria, yeasts, fungi and viruses, among others.

Mitigation (of climate change)

A human intervention to reduce the sources or enhance the sinks of greenhouse gases.

Paris Agreement

A legally-binding agreement under the UNFCCC, reached in Paris in 2015, with the objective to limit temperature increases to well below 2°C above pre-industrial levels, and pursue actions to further limit the global temperature increase to 1.5°C. The participating countries ('Parties': 195 countries had signed, of which 183 countries had ratified, the Paris Agreement by the end of 2020) commit to develop, implement and periodically update nationally determined contributions that reflect highest possible ambition and include targets they intend to achieve, recognising differing national circumstances.

Peer-reviewed

Articles reviewed by several other experts in the same field before publication, in order to ensure the article's quality.

Predatory journals

Exploitive publishing practices, not involving a credible peer-review process, containing false or misleading information, lacking in transparency, and deviating from best quality-assurance practices.

Probabilistic

An outcome or solution where the results are given in the form of a likelihood or a probability distribution, ranging between 0 and 1 where 0 indicates impossibility and 1 indicates certainty.

Tipping point

A level of change in system properties beyond which a system reorganises, often abruptly, and does not return to the initial state even if the drivers of the change are abated. For the climate system, it refers to a critical threshold when global or regional climate changes from one stable state to another stable state. The tipping point event may be irreversible.

Radiative forcing (RF)

The strength of drivers of anthropogenic climate change are quantified as Radiative Forcing, in units of watts per square meter (Wm^{-2}) . Radiative forcing is the change in energy flux at the top of the atmosphere (sometimes at the tropopause) caused by that driver, averaged over the entire Earth surface. Positive numbers result in global warming.

Sample size (n)

The number of individual observations used in an empirical study. Inferences are made about the population based on the sample; therefore a higher n is almost always better. Studies with a low n are less reliable.

Science

In the narrow sense, science is the systematic study of the structure and behaviour of the physical and natural world through observation and experiment. In the broader sense, as used in this guidebook, it is an approach to making sense of the world based on verifiable evidence and logical deduction, and can include studies that involve humans and their actions as their subject.

Solar radiation

The electromagnetic radiation originating from the sun, also called 'sunlight', although most of it lies outside the visible spectrum of light.

Standard deviation

A statistical measure of the spread of the data. It is how far, on average, the observed values are from the mean.

Sustainable Development Goals (SDGs)

A set of 17 goals adopted by the United Nations Member States in 2015 as a universal call to action to end poverty, protect the planet and ensure that all people enjoy peace and prosperity by 2030. SDG 13 relates to climate action.

Transdisciplinary (research)

Research efforts conducted by investigators from different disciplines working jointly to create new conceptual, theoretical, methodological, and translational innovations that integrate and move beyond discipline-specific approaches to address a common problem. The word 'trans' refers to that which is across, beyond, and outside all the disciplines. 'Deep transdisciplinarity' involves co-generation of outcomes by people with very different knowledge systems, for instance indigenous knowledge and scientific knowledge. Trandiscplinarity can also be used to define processes where the outcome is co-produced by both 'experts' and 'users' of the knowledge. It is not synonymous with either 'multidisciplinary' or 'interdisciplinary'.

Weather

The short-term (hourly to weekly) fluctuations in various manifestations that we associate with the 'climate system', such as the air temperature, precipitation, wind and many others.

Weather events

The occurrence of a value of a weather or climate variable above (or below) a threshold value between the mean and the upper (or lower) ends of the range of observed values of the variable; or the drift over time in either the mean or the variance ('trends'). Weather events (also called an 'anomaly') with an exceptionally large deviation from the norm are referred to as 'climate extremes'.

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