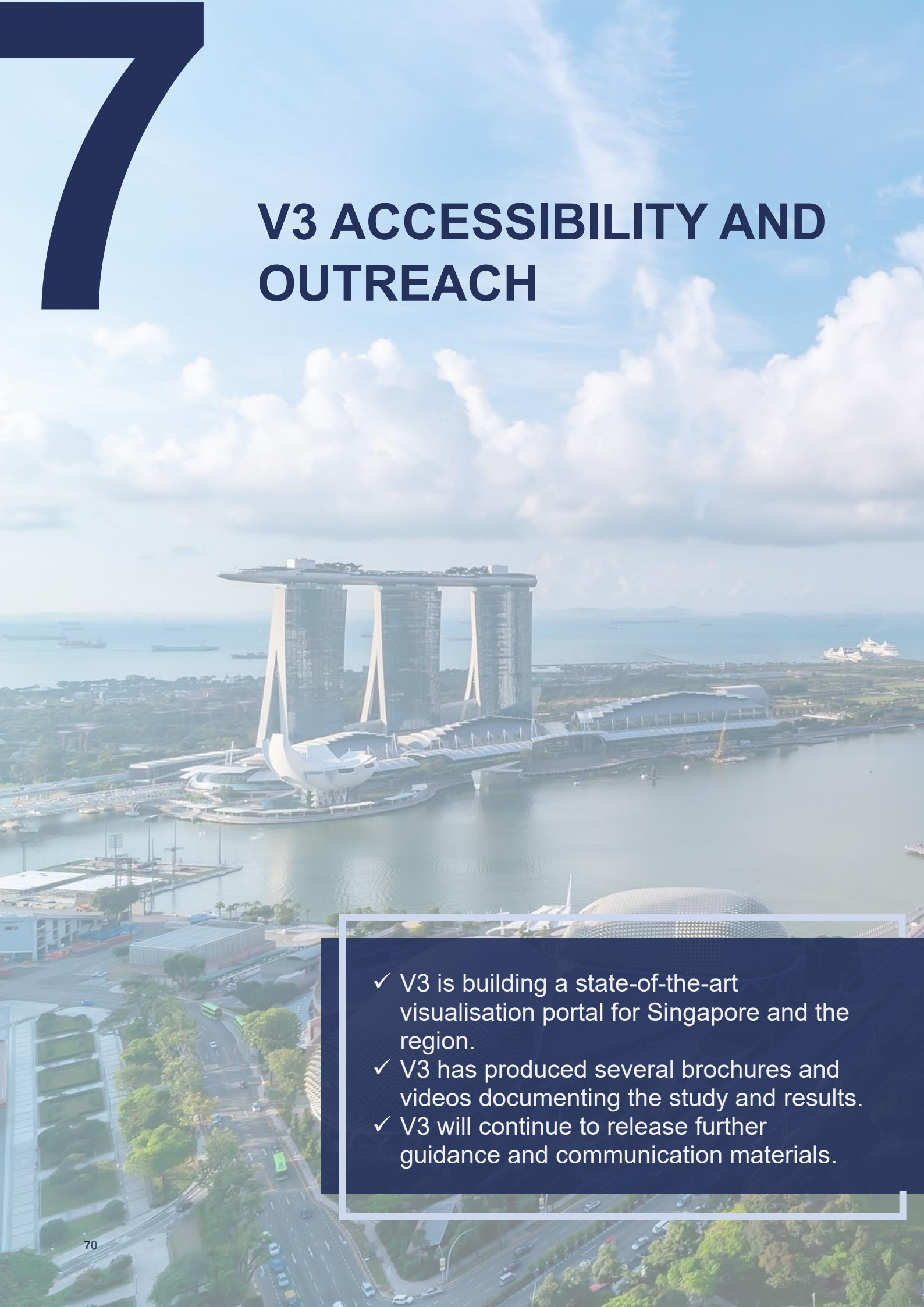
7

V3 ACCESSIBILITY AND OUTREACH



- ✓ V3 is building a state-of-the-art visualisation portal for Singapore and the region.
- ✓ V3 has produced several brochures and videos documenting the study and results.
- ✓ V3 will continue to release further guidance and communication materials.

There are multiple target audiences for V3 that include government agencies, scientific community, businesses, and the public. A differentiated communications and engagement plan will be used to make V3 more accessible. For example, V3 findings and its use for subsequent adaptation planning will be shared with national and regional stakeholders by conducting relevant workshops.

Topical brochures and videos have been produced on the following topics to engage the stakeholder agencies and the public:

1. V3 Explained
2. Climate Change - From Global to Local
3. Past and Future Sea-level Change
4. Understanding Climate Extremes

Additional brochures and videos will be produced after the public launch of V3 as part of continued outreach efforts.

V3 gives us an opportunity to bolster Singapore's international contributions and efforts towards understanding and addressing climate change. V3 data will be shared with regional countries/partners to understand the effects of climate change on the region.

V3 findings and outreach material (Stakeholder and science reports, images/charts, brochures, videos and more), along with information on upcoming events will be made available through the V3 portal (https://www.mss-int.sg/V3-climate-projections).

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Annex A: Guidance on using projections

Which SSP do I use?

The three Shared Socioeconomic Pathways (SSPs) used in V3 aim to capture a range of uncertainties in future concentrations of greenhouse gases, which drive climate change. SSP5-8.5 is a scenario representing a future with very high greenhouse gas concentrations that continue to increase throughout the 21st century, similar to the characteristics of RCP8.5. SSP2-4.5 is a scenario where concentrations peak mid-century and then decline, resembling aspects of RCP4.5. SSP1-2.6 represents a low-emission scenario with strong mitigation efforts, aiming to limit global temperature increases to well below 2°C above pre-industrial levels.

Note that the projected changes under SSP5-8.5 are generally greater than those under SSP2-4.5 and SSP1-2.6, and this should be taken into consideration when making adaptation decisions.

SSP1-2.6, with its focus on sustainable development and significant mitigation efforts, aligns with a pathway that meets the international target of keeping temperature rise below 2°C. SSP2-4.5 represents a moderate scenario with some efforts towards mitigation, while SSP5-8.5 aligns with a high-emission scenario and can be regarded as a business-as-usual pathway. SSP5-8.5 provides a reasonable estimate of the high-end impacts of climate change and should be considered for use in adaptation planning where high investment is required and decisions cannot easily be updated.

V3 results emphasise the need for mitigation action by quantifying the substantial climatic changes that may occur if no action is taken under SSP5-8.5 scenario, underscoring the importance of considering SSP1-2.6 to SSP2-4.5 as pathways involving significant and moderate mitigation efforts, respectively.

Why are mid-century projected changes sometimes larger than those at the end of the century?

Total 'change' in climate is a combination of long-term trends and natural variations within the climate system. The natural climate variation, as simulated in any specific model, has the potential to either amplify or reduce the impact of the long-term trend in that model.

This becomes particularly significant when the modelled amplitude of decadal variations is similar in size to the climate change signal, as is observed in changes in mean and extreme rainfall in the Singapore region. Although the models can capture, to some extent, the natural decadal variations in the climate system, predicting the evolution of these variations into the future remains challenging.

In reality, the anthropogenic climate change signal is not linear, and its interaction with natural variability is complex. Despite this complexity, the fundamental point remains valid: both anthropogenic and natural climate variations will play crucial roles in shaping the net change in climate at any given point in the future.

Why are projected changes under the SSP2-4.5 scenario sometimes larger than those under SSP5-8.5?

This can occur for the same reasons illustrated in the preceding question. As mentioned earlier, this issue typically arises when the natural decadal fluctuations of climate are of a comparable or greater magnitude than the overall change signal. This is particularly relevant for rainfall variables, where the modelled natural decadal variations can be similar to or even exceed the anticipated changes. However, it's important to note that this issue is often less pronounced when considering projected future temperature changes. In this context, the anticipated temperature changes are generally considerably larger than the natural variability.

How can I use the group of model results?

This study presents outcomes from six distinct GCMs that have been downscaled over Singapore and SEA. While the report provides an overview of the range of results from all six models and presents average (or median) changes where applicable, it intentionally does not delve into individual model results. The reason is that no particular model is afforded greater confidence, and all offer plausible

climate futures. Consequently, it is recommended to utilise the entire ensemble for comprehensive insights.

However, in cases where specific model results are required for further modelling work related to decision-making, careful selection of one or more models becomes necessary. For robust decision-making, it is beneficial to consider models that indicate both the largest and smallest increases in variables of interest. Relying solely on the median model is discouraged, as it does not necessarily represent the most likely change. In instances where significant impacts and adaptation costs are anticipated, particularly associated with high-end scenarios, it is advisable to explore potential changes beyond the conventional scenarios.

How can I downscale the data further to conduct analyses at higher resolution?

V3 data will be provided on 8km and 2km grids. Notably, temperature, rainfall, winds, and relative humidity data over Singapore have undergone bias adjustments using observations.

For studies focusing on even finer resolutions, particularly those requiring insights into urban microclimates, utilising an urban-scale model with detailed urban morphology may be more suitable. Such models can offer a more nuanced and accurate representation of local conditions in urban areas, providing valuable information for impact modelling and detailed analyses.

Moreover, it is crucial to exercise caution when employing interpolation techniques, as they assume spatial smoothness in the microclimate. This assumption may not always be valid, and the results should be interpreted with this in mind.

Are urban effects taken account of in the projections?

The projections in the 8km and 2km simulations include a basic representation of the urbanisation of the Singapore landscape. However, it is crucial to highlight that detailed aspects of the urban environment cannot be comprehensively captured in models with such resolutions. More sophisticated sub-km scale urban modelling is essential to realistically incorporate the full spectrum of urban effects. Such models can provide more accurate insights into the complex interactions between urbanisation and climate, ensuring a more comprehensive assessment of future climatic conditions in urban areas.

It is also important to note that the future projections in the V3 study align with the latest SSP scenarios. Nevertheless, these projections do not explicitly consider changes in the Singapore urban landscape and their potential impact on the microclimate.

Annex B: Glossary

A

Adaptation Initiatives and measures to reduce the vulnerability of natural and human systems against actual or expected climate change impacts.

Adaptive capacity A system's ability to implement adaptation measures to climate change (including climate variability and extremes).

Anomaly Value that represents the difference between the value for a given year or season from the normal of the reference period.

Anthropogenic climate change Human-made climate change - climate change caused by human activity as opposed to natural processes.

AR4 Abbreviation for the Fourth Assessment Report produced by the Intergovernmental Panel on Climate Change (IPCC), which was published in 2007. The report assessed and summarised the science of climate change at the time of its release.

AR5 Abbreviation for the Fifth Assessment Report from the Intergovernmental Panel on Climate Change (IPCC), which was published over 2013 and 2014.

AR6 Abbreviation for the Sixth Assessment Report from the Intergovernmental Panel on Climate Change (IPCC), which was published over 2021 and 2022.

Atmosphere The atmosphere is a mixture of gases that surrounds the Earth. It helps make life possible by providing us with air to breathe, shielding us from harmful ultraviolet (UV) radiation coming from the Sun, trapping heat to warm the planet, and preventing extreme temperature differences between day and night.

Atmospheric aerosols Microscopic particles suspended in the lower atmosphere that reflect sunlight back to space. These generally have a cooling effect on the planet and can mask global warming. They play a key role in the formation of clouds, fog, precipitation, and ozone depletion in the atmosphere.

B

Barystatic sea-level change Global-mean sea-level change due to the addition of water that is formerly residing on land or atmosphere, or the removal of water from the oceans.

Bias Adjustment A sophisticated statistical method used to correct systematic errors (biases) in climate model outputs to make them more similar to climate observation data. The biases can occur when models do not accurately represent real-world conditions. Bias adjustment techniques are applied to improve the reliability of climate change impact assessments for various sectors like water resources, agriculture, and more. Bias adjustment in The Third National Climate Change Study (V3) makes use of the trend-preserving ISIMIP3BASD (V1.0) method described by: *Lange, S.: Trend-preserving bias adjustment and statistical downscaling with ISIMIP3BASD (v1.0), Geosci. Model Dev., 12, 3055–3070, https://doi.org/10.5194/gmd-12-3055-2019, 2019.*

Bioenergy Bioenergy is a form of renewable energy generated when we burn biomass fuel. Biomass fuels come from organic material such as harvest residues, purpose-grown crops and organic waste from our homes, businesses and farms.

Biofuels Gas or liquid fuel made from plant material. Includes wood, wood waste, wood liquors, peat, railroad ties, wood sludge, spent sulphite liquors, agricultural waste, straw, tires, fish oils, tall oil, sludge waste, waste alcohol, municipal solid waste, landfill gases, other waste, and ethanol blended into motor gasoline.

Business as usual (BAU) A scenario used for projections of future emissions assuming no action, or no new action, is taken to mitigate the problem. Within IPCC AR6, the BAU scenario is the SSP5-8.5 scenario.

C

Carbon capture and storage The collection and transport of concentrated carbon dioxide gas from large emission sources, such as power plants. The gases are then injected into deep underground reservoirs. Carbon capture is sometimes referred to as geological sequestration.

Carbon Cycle All parts (reservoirs) and fluxes of carbon. The cycle is usually thought of as four main reservoirs of carbon interconnected by pathways of exchange. The reservoirs are the atmosphere, terrestrial biosphere (usually includes freshwater systems), oceans, and sediments (includes fossil fuels). The annual movements of carbon, the carbon exchanges between reservoirs, occur because of various chemical, physical, geological, and biological processes. The ocean contains the largest pool of carbon near the surface of the Earth, but most of that pool is not involved with rapid exchange with the atmosphere.

Carbon dioxide (CO_2) Carbon dioxide is a gas in the Earth's atmosphere. It occurs naturally and is also a by-product of human activities such as

burning fossil fuels. It is the principal greenhouse gas produced by human activity.

Carbon dioxide (CO_2) equivalent Six greenhouse gases are limited by the Kyoto Protocol and each has a different global warming potential. The overall warming effect of this cocktail of gases is often expressed in terms of carbon dioxide equivalent - the amount of CO_2 that would cause the same amount of warming.

Carbon footprint The amount of carbon emitted by an individual or organisation in a given period of time, or the amount of carbon emitted during the manufacture of a product.

Carbon sink Any process, activity or mechanism that removes carbon from the atmosphere. The biggest carbon sinks are the world's oceans and forests, which absorb large amounts of carbon dioxide from the Earth's atmosphere.

CCRS Centre for Climate Research Singapore. CCRS is the research division of the Meteorological Service Singapore (MSS) and was established on 23 March 2013.

Climate The long-term average (typically spanning decades to centuries) of weather patterns and conditions observed in a particular region or globally. It is characterised by temperature, precipitation, humidity, wind and other atmospheric conditions. Climate is influenced by various factors including latitude, altitude, topography, ocean currents and the distribution of land and water bodies.

Climate change A pattern of change affecting global or regional climate, as measured by yardsticks such as average temperature and rainfall, or an alteration in frequency of extreme weather conditions. This variation may be caused by both natural processes and human activity. Global warming is one aspect of climate change.

Climate change scenario A description of the evolution in the climate for a given time period in the future, using a specific modelling technique and under specific assumptions about the evolution of greenhouse gas emissions and other factors that may influence the climate in the future. Climate projections from climate models often serve as the raw material for constructing climate scenarios in the most widely-used method of climate scenario construction.

Climate feedback An interaction in which a perturbation in one climate quantity causes a change in a second, and that change ultimately leads to an additional (positive or negative) change in the first.

Climate information Refer to climatic data that describe either past conditions, obtained from meteorological observations (stations, satellites, radars), or the future, obtained from the outputs of climate models.

Climate model A numerical representation of the climate system based on the physical, chemical, and biological properties of its components, their interactions and feedback processes, and accounting for most of its known properties.

Climate projection A climate projection refers to the response of the climate system over the next several decades and beyond under a given scenario of future global greenhouse gas emissions and certain assumptions of human activity. Different scenarios of human activity and associated global emissions lead to different levels of global warming, thus giving a range of possible future outcomes. In this way, climate projections are distinguished from climate predictions as the latter are climate model forecasts of the most likely future climate conditions in the next few months and years based on the current observed conditions, its natural variability and expected changes from global emissions in the near future.

Climate scenario A plausible and often simplified representation of the future climate, based on an internally consistent set of climatological relationships that has been constructed for explicit use in investigating the potential consequences of anthropogenic climate change, often serving as input to impact models.

Climate sensitivity The effective climate sensitivity (units; °C) is an estimate of the global mean surface temperature response to doubled carbon dioxide concentration that is evaluated from model output or observations for evolving non-equilibrium conditions.

Climate services An organisation that supplies climate information to users. The roles of these organisations may include providing historical climate data, running climate simulations, and tailoring their outputs to suit the needs of individual users.

Climate variability The variations above or below a long-term mean state of the climate. This variability can be due to natural internal processes within the climate system (internal variability) or to variations in anthropogenic external forcing (external variability).

Cloud condensation nuclei Airborne particles that serve as an initial site for the condensation of liquid water, which can lead to the formation of cloud droplets. A subset of aerosols that are of a particular size.

CMIP5 Coupled Model Intercomparison Project, Phase 5. CMIP5 is a coordinated climate modelling exercise involving 20 climate-modelling groups from around the world. It has provided a standard

experimental protocol for producing and studying the output of many different global climate models. The output from CMIP5 ensemble experiments is used to inform international climate assessment reports, such as those from the IPCC.

CMIP6 Coupled Model Intercomparison Project Phase 6

CO2 See carbon dioxide

Confidence The validity of a finding based on the type, amount, quality, and consistency of evidence (e.g. mechanistic understanding, theory, data, models, expert judgment) and on the degree of agreement. IPCC uses standard confidence thresholds such as "*low*", "*medium*" and "*high*" to indicate probabilities of occurrence of projected changes to "*very unlikely*" (<10 Percent), "*likely*" (17 – 83 Percent) and "*Very likely*" (>90 Percent).

Contemporary Mass Redistribution (CMR) sea-level change Satellite altimetry sea-level without sterodynamic and GIA-induced sea-level. 2. Composed of barystatic sea-level change and GRD fingerprints.

CORDEX Coordinated Regional Climate Downscaling Experiment.

D

Dangerous climate change A term referring to severe climate change that will have a negative effect on societies, economies, and the environment as a whole. The phrase was introduced by the 1992 UN Framework Convention on Climate Change, which aims to prevent "dangerous" human interference with the climate system.

Decadal variability Fluctuations, or ups-and-downs of a climate feature or variable at the scale of approximately a decade (typically taken as longer than a few years such as ENSO, but shorter than the 20-30 years of the IPO).

Deforestation The permanent removal of standing forests that can lead to significant levels of carbon dioxide emissions.

Delta Difference between the future value and the reference period (or baseline) value of a climate variable, as simulated by a climate model.

Detection and attribution Detection of change is defined as the process of demonstrating that climate or a system affected by climate has changed in some defined statistical sense, without providing a reason for that change. An identified change is detected in observations if its likelihood of occurrence by chance due to internal variability alone is determined to be small, for example, less than 10 per cent. Attribution is defined as the process of evaluating the relative contributions of multiple causal factors to a change or event with an assignment of statistical confidence.

Downscaling A method that can provide climate model outputs at a finer resolution than their original resolution. Two different approaches are prioritised: statistical downscaling and dynamical downscaling.

Dynamical downscaling This type of downscaling relies on the use of regional climate models that are driven at their boundaries by global climate models.

E

Earth Science Earth science is the study of the Earth's structure, properties, processes, and four and a half billion years of biotic evolution. Understanding these phenomena is essential to maintenance of life on the planet.

El Niño Southern Oscillation (ENSO) A fluctuation in global scale tropical and subtropical surface pressure, wind, sea surface temperature, and rainfall, and an exchange of air between the south-east Pacific subtropical high and the Indonesian equatorial low. Often measured by the surface pressure anomaly difference between Tahiti and Darwin or the sea surface temperatures in the central and eastern equatorial Pacific. There are three phases: neutral, El Niño and La Niña. During an El Niño event the prevailing trade winds weaken, reducing upwelling and altering ocean currents such that the eastern tropical surface temperatures warm, further weakening the trade winds. The opposite occurs during a La Niña event.

Emissions scenario A plausible representation of the future development of emissions of substances that are potentially radiatively active (e.g. greenhouse gases, aerosols) based on a coherent and internally consistent set of assumptions about driving forces (such as demographic and socioeconomic development, technological change) and their key relationships.

Ensemble Term used to refer to the complete set of climate simulations or climate scenarios used for a given study. Because no one model can be considered best, it is standard practice in climate change studies to use the outputs of many models when studying the projected changes. Consequently, ensemble is usually a synonym for the term multimodel ensemble. Note, however, that other, more restrictive, definitions exist for ensembles designed to study very specific scientific questions (for example, an ensemble could represent a set of simulations made with the same climate model, using the same emissions scenario, but initialised using different starting conditions).

Extreme weather An extreme weather event is an event that is rare at a particular place and time of year. Definitions of rare vary, but an extreme

weather event would normally be as rare as or rarer than the 10th or 90th percentile of a probability density function estimated from observations.

F

Feedback loop In a feedback loop, rising temperatures on the Earth change the environment in ways that affect the rate of warming. Feedback loops can be positive (adding to the rate of warming), or negative (reducing it). The melting of Arctic ice provides an example of a positive feedback process. As the ice on the surface of the Arctic Ocean melts away, there is a smaller area of white ice to reflect the Sun\'s heat back into space and more open, dark water to absorb it. The less ice there is, the more the water heats up, and the faster the remaining ice melts.

Fossil fuels Natural resources, such as coal, oil and natural gas, containing hydrocarbons. These fuels are formed in the Earth over millions of years and produce carbon dioxide when burnt.

G

GCM Global Climate Model

Geocentric sea-level change The change in local mean sea level with respect to the terrestrial reference frame. This does not include effects of vertical land movement.

GIA-induced sea-level change GRD due to ongoing changes in the solid Earth caused by past changes in land ice (i.e., during the Last Glacial Maxima).

Global average temperature The mean surface temperature of the Earth measured from three main sources: satellites, monthly readings from a network of over 3,000 surface temperature observation stations and sea surface temperature measurements taken mainly from the fleet of merchant ships, naval ships and data buoys.

Global climate model (GCM) A global climate model (GCM) is a complex computer-based representation of the Earth’s climate system. It incorporates mathematical equations to simulate and predict the behaviour of various components of the climate system, including the atmosphere, oceans, land surface, and sea ice. GCMs are used to study and understand past climate patterns, as well as to project and predict future climate changes. They consider factors such as greenhouse gas concentrations, solar radiation, atmospheric circulation patterns, and interactions between different components of the climate system. GCMs help scientists make predictions about how the Earth’s climate might respond to different scenarios, such as changes in greenhouse gas emissions or land use patterns.

Global dimming An observed widespread reduction in sunlight at the surface of the Earth, which varies significantly between regions. The most likely cause of global dimming is an interaction between sunlight and microscopic aerosol particles from human activities. In some regions, such as Europe, global dimming no longer occurs, thanks to clean air regulations.

Global energy budget The global energy budget refers to the balance between the incoming and outgoing energy on Earth. It represents the distribution and flow of energy throughout the Earth’s atmosphere, oceans, land, and ice. The incoming energy is primarily in the form of solar radiation, while the outgoing energy is in the form of reflected sunlight, emitted infrared radiation, and heat transfer. The global energy budget plays a crucial role in understanding Earth’s climate system and its changes over time.

Global warming Global warming refers to the long-term increase in Earth’s average surface temperature due to human activities, primarily the emission of greenhouse gases, such as carbon dioxide, into the atmosphere. Global warming leads to various adverse effects, including climate change, rising sea levels, more frequent and severe extreme weather events, and disruptions to ecosystems.

Global-mean sea-level rise Global-mean sea-level rise for the global mean of relative sea-level change, due to the change in the volume of the ocean.

Global-mean thermosteric sea-level change Global-mean sea-level change due to thermal expansion

Gravitational, Earth's Rotational, viscoelastic solid-Earth Deformational (GRD) effects Changes in gravitation and rotation alter the geopotential field and hence the geoid, while deformation of the solid Earth changes the sea floor topography through vertical land movement.

Greenhouse effect The insulating effect of certain gases in the atmosphere, which allow solar radiation to warm the earth and then prevent some of the heat from escaping. See also Natural greenhouse effect.

Greenhouse gases (GHGs) Natural and industrial gases that trap heat from the Earth and warm the surface. The Kyoto Protocol restricts emissions of six greenhouse gases: natural (carbon dioxide, nitrous oxide, and methane) and industrial (perfluorocarbons, hydrofluorocarbons, and sulphur hexafluoride).

Grid (grid points) Discrete model "cells" which represent computational units of a climate model. The simplest model grids typically divide the globe

(or model domain) into constant angular grid spacing (i.e., a latitude / longitude grid). A climate model's horizontal resolution is often expressed as the size of a single grid cell (e.g., 1° x 1° grid or 10 km by 10 km grid).

H

Hadley Cell/Circulation A direct, thermally driven circulation in the atmosphere consisting of poleward flow in the upper troposphere, descending air into the subtropical high-pressure cells, return flow as part of the trade winds near the surface, and with rising air near the equator in the so-called Inter-Tropical Convergence zone.

Halosteric sea-level change Steric sea-level change due to changes in salinity in the ocean.

High emissions scenario This scenario assumes that greenhouse gas concentrations will continue to increase at approximately the same rate as they are increasing today. Under this scenario, the planet's radiative forcing will have increased by 8.5 W/m^2 by the year 2100, relative to 1750 (and continues to rise well after 2100). In the scientific literature, this scenario is referred to as "RCP8.5". Of the four greenhouse gas pathways (RCP8.5, RCP6.0, RCP4.5, RCP2.6) used by the IPCC for its 5th Assessment Report, this pathway results in the most severe global warming and climate change.

Hockey stick The name given to a graph published in 1998 plotting the average temperature in the Northern hemisphere over the last 1,000 years. The line remains roughly flat until the last 100 years, when it bends sharply upwards. The graph has been cited as evidence to support the idea that global warming is a man-made phenomenon, but some scientists have challenged the data and methodology used to estimate historical temperatures. (It is also known as MBH98 after its creators, Michael E. Mann, Raymond S. Bradley and Malcolm K. Hughes.)

I

IDF curves Intensity-Duration-Frequency curves relate short-duration rainfall intensity with its frequency of occurrence and are often used for flood forecasting and urban drainage design.

Index (climate index) Term used to refer to properties of the climate that are not measured in the field or calculated by climate models but rather that are calculated or derived from climate variables such as temperature and precipitation. Examples include the number of growing degree-days, freeze-thaw cycles, and the drought code index. (see variable)

Indian Ocean Dipole (IOD) Large-scale mode of interannual variability of sea surface temperature in the Indian Ocean. This pattern manifests through a zonal gradient of tropical sea surface temperature, which in its positive phase in September to November shows cooling off Sumatra and warming off Somalia in the west, combined with anomalous easterlies along the equator.

Inter-decadal Pacific Oscillation A fluctuation in the sea surface temperature (SST) and mean sea level pressure (MSLP) of both the north and south Pacific Ocean with a cycle of 15-30 years. Unlike ENSO, the IPO may not be a single physical 'mode' of variability but be the result of a few processes with different origins. A related phenomenon, the Pacific Decadal Oscillation (PDO), is also an oscillation of SST that primarily affects the northern Pacific.

Inverse barometer effects on sea-level change Sea-level change due to atmospheric pressure variations.

IPCC The Intergovernmental Panel on Climate Change is a scientific body established by the United Nations Environment Programme and the World Meteorological Organization. It reviews and assesses the most recent scientific, technical, and socio-economic work relevant to climate change, but does not carry out its own research. The IPCC was honoured with the 2007 Nobel Peace Prize.

J

Jet stream A narrow and fast-moving westerly air current that circles the globe near the top of the troposphere. The jet streams are related to the global Hadley circulation.

K

L

Low emissions scenario This scenario assumes that greenhouse gas emissions will continue to increase until mid-century and then decline significantly. The IPCC refers to this scenario as a "peak and decline" scenario that increased the planet's radiative forcing to 2.6W/m2 by year 2100, relative to 1750.In the scientific literature, this scenario is referred to as "RCP2.6". Of the four greenhouse gas pathways (RCP8.5, RCP6.0, RCP4.5, RCP2.6) used by the IPCC for its 5th Assessment Report, this RCP results in the lowest level of global warming and climate change. This scenario is the only one that can ensure the success of the Paris Agreement.

LULUCF This refers to Land Use, Land-Use Change, and Forestry. Activities in LULUCF provide a method of offsetting emissions, either by increasing the removal of greenhouse gases from the atmosphere (i.e., by planting trees or managing

forests), or by reducing emissions (i.e. by curbing deforestation and the associated burning of wood).

M

Madden Julian Oscillation (MJO) The largest single component of tropical atmospheric intra-seasonal variability (periods from 30 to 90 days). The MJO propagates eastwards at around 5 m/s in the form of a large-scale coupling between atmospheric circulation and deep convection. As it progresses, it is associated with large regions of both enhanced and suppressed rainfall, mainly over the Indian and western Pacific Oceans.

Manometric sea level Change in the time-mean local mass of the ocean per unit area, assuming the density does not change

Mean sea level The time-mean of the sea surface.

Methane Methane is the second most important man-made greenhouse gas. Sources include both the natural world (wetlands, termites, wildfires) and human activity (agriculture, waste dumps, leaks from coal mining).

Mitigation Action that will reduce man-made climate change. This includes action to reduce greenhouse gas emissions or absorb greenhouse gases in the atmosphere.

Moderate emissions scenario This scenario assumes that greenhouse gas emissions will continue to increase (but more slowly than they are today) until mid-century and then stabilise until the end of the century. However, carbon dioxide concentrations will still end up being much higher than they are today. The IPCC describes this scenario as a "stabilisation pathway" that increases the planet's radiative forcing by 4.5 W/m2 by the year 2100, relative to 1750. In the scientific literature, this scenario is referred to as "RCP4.5". Of the four greenhouse gas pathways (RCP8.5, RCP6.0, RCP4.5, RCP2.6) used by the IPCC for its 5th Assessment Report, this RCP results in the second-lowest level of global warming and climate change.

Monsoon A monsoon is a tropical and subtropical seasonal reversal in both the surface winds and associated rainfall, caused by differential heating between a continental-scale land mass and the adjacent ocean. Monsoon rains occur mainly over land in summer.

MSS Meteorological Service Singapore

N

Natural greenhouse effect The natural level of greenhouse gases in our atmosphere, which keeps the planet about 30C warmer than it would otherwise be - essential for life as we know it. Water vapour is the most important component of the natural greenhouse effect.

Natural variability Variability that describes short-term changes in that take place over months, seasons and years. It is due to natural variations in external forces such as changes in the sun's radiation or volcanoes, as well variations in internal processes, such as those related to the interactions of the oceans and the atmosphere, that occur for example in the Pacific Ocean during an El Niño event.

NCCS National Climate Change Secretariat

NEA National Environment Agency

O

Ocean acidification The ocean absorbs approximately one-fourth of man-made CO2 from the atmosphere, which helps to reduce adverse climate change effects. However, when the CO2 dissolves in seawater, carbonic acid is formed. Carbon emissions in the industrial era have already lowered the pH of seawater by 0.1. Ocean acidification can decrease the ability of marine organisms to build their shells and skeletal structures and kill off coral reefs, with serious effects for people who rely on them as fishing grounds.

Ocean dynamic sea-level change The local height of the sea surface above the geoid, with the inverse barometer correction applied

P

Percentile A percentile is a value on a scale of one hundred that indicates the percentage of the dataset values that is equal to, or below it. The percentile is often used to estimate the extremes of a distribution. For example, the 90th (or 10th) percentile may be used to refer to the threshold for the upper (or lower) extremes.

ppm (350/450) An abbreviation for parts per million, usually used as short for ppmv (parts per million by volume). The Intergovernmental Panel on Climate Change (IPCC) suggested in 2007 that the world should aim to stabilise greenhouse gas levels at 450 ppm CO_2 equivalent to avert dangerous climate change. Some scientists, and many of the countries most vulnerable to climate change, argue that the safe upper limit is 350ppm. Current levels of CO_2 only are about 420ppm.

PRCPTOT Annual total precipitation from wet days (wet day defined as any day with daily precipitation >= 1mm).

Pre-industrial levels of carbon dioxide The levels of carbon dioxide in the atmosphere prior to the start of the Industrial Revolution. These levels are

estimated to be about 280 parts per million (by volume). The current level is around 420ppm.

Projection (climate projection) Projections represent the future portion of climate model simulations that take into account an emissions scenario. Consequently, a projection is based on assumptions such as those concerning future socioeconomic and technological developments that may or may not be realised and thus are subject to uncertainty.

Q

R

Radiative forcing Radiative forcing is the change in the net, downward minus upward, radiative flux (expressed in W/m^2) at the tropopause or top of atmosphere due to a change in an external driver of climate change, such as a change in the concentration of carbon dioxide or the output of the Sun.

Range The term range is used to represent the spectrum of output data from an ensemble of simulations or scenarios.

RCP2.6 See low emissions scenario.

RCP4.5 See moderate emissions scenario.

RCP8.5 See high emissions scenario.

Reference period In practice, it often refers to a period of time from the recent past used in the production of climate scenarios. Future period values produced by climate models are compared with those from this period to evaluate changes. The WMO recommends 30-year intervals as reference periods, such as 1971-2000; however there are exceptions. For example, the current reference period used by the IPCC is 1985-2005. A synonymous term is baseline period. Accordingly, the terms 'reference scenario' or 'baseline scenario' are used to refer to climate scenarios for a reference period.

Regional climate model (RCM) Just like a GCM, the regional climate model is a mathematical representation of the climate system, based on equations describing the physical processes governing the climate. RCMs have a finer resolution than GCMs and therefore contain a better representation of topography and can include processes and features, such as lakes, which are too small to resolve in GCMs. As a consequence they are more expensive to run and typically operate as 'limited domain' models, meaning that they cover only a portion of the globe.

Relative sea-level change The change in local mean sea level relative to the local solid surface, i.e., the sea floor. This includes effects of vertical land movement.

Renewable energy Renewable energy is energy created from sources that can be replenished in a short period of time. The five renewable sources used most often are: biomass (such as wood and biogas), the movement of water, geothermal (heat from within the earth), wind, and solar.

Representative Concentration Pathways (RCPs) Representative Concentration Pathways follow a set of greenhouse gas, air pollution (e.g., aerosols) and land-use scenarios that are consistent with certain socio-economic assumptions of how the future may evolve over time. The well mixed concentrations of greenhouse gases and aerosols in the atmosphere are affected by emissions as well as absorption through land and ocean sinks. There are four Representative Concentration Pathways (RCPs) that represent the range of plausible futures from the published literature.

Resolution In climate models, this term refers to the physical distance (kilometres or degrees) between each point on the grid used to compute the equations. Temporal resolution refers to the time step or time elapsed between each model computation of the equations. See Grid.

Return period An estimate of the average time interval between occurrences of an event (e.g. flood or extreme rainfall) of a defined size or intensity.

Risk The potential for consequences where something of value is at stake and where the outcome is uncertain. Risk is often represented as a probability of occurrence of hazardous events or trends multiplied by the consequences if these events occur.

Risk management The plans, actions, or policies implemented to reduce the likelihood and/or consequences of risks or to respond to consequences.

Risk assessment The qualitative and/or quantitative scientific estimation of risks.

RWG Resilience Working Group

S

Sea level anomaly (SLA) Deviations of sea surface height from a mean level (i.e., variations from mean sea level).

Shared Socioeconomic Pathways (SSPs) A set of scenarios used to describe a range of possible trajectories for crucial factors like future economic development, population growth, technological advancement, energy use and greenhouse gas emissions. These scenarios allow researchers and

policymakers to understand and compare how different social, economic and environmental choices may lead to very different greenhouse gas emissions and thus global warming levels along with their potential impacts. Collectively, they span the range of plausible climate futures. In V3, future climate projections are made under SSP1-2.6 (Sustainability: Taking the Green Road), SSP2-4.5 ('Middle of the Road') and SSP5-8.5 (Fossil-Fuel Development: Taking the Highway) scenarios.

Simulation (Climate simulation) Climate simulations represent the outcome of running a climate model for a certain period of time. The time span of a simulation can range from a few years to thousands of years and will iteratively be computed at intervals of a few minutes. They are run for both the past and the future.

SINGV-RCM Singapore Variable Resolution-Regional Climate Model

SSP Shared Socioeconomic Pathway

Statistical downscaling This type of downscaling relies on the use of statistical relationship that relate large scale climate features, named predictors, to local climate variables (predictants).

Steric sea-level change Composed of thermosteric and halosteric sea-level change.

Sterodynamic sea-level change Composed of ocean dynamic sea level and global-mean thermosteric sea-level

T

Thermosteric sea-level change Steric sea-level change due to changes in ocean temperature.

Tipping point A tipping point is a threshold for change, which, when reached, results in a process that is difficult to reverse. Scientists say it is urgent that policy makers halve global carbon dioxide emissions over the next 50 years or risk triggering changes that could be irreversible.

U

Uncertainty A state of incomplete knowledge that can result from a lack of information or from disagreement about what is known or even knowable. It may have many types of sources, from imprecision in the data to ambiguously defined concepts or terminology, or uncertain projections of human behaviour. Uncertainty can therefore be represented by quantitative measures (e.g., a probability density function) or by qualitative statements (e.g., reflecting the judgment of a team of experts).

UNFCCC The United Nations Framework Convention on Climate Change is one of a series of international agreements on global environmental issues adopted at the 1992 Earth Summit in Rio de Janeiro. The UNFCCC aims to prevent "dangerous" human interference with the climate system. It entered into force on 21 March 1994 and has been ratified by 192 countries.

V

V2 Singapore's Second National Climate Change Study

V3 Singapore's Third National Climate Change Study

Variable The term climate variable is used to refer to a variable that can be measured directly in the field (at meteorological stations for example) or that is calculated by climate models. (See Index).

Vertical land movement (VLM) The change in the height of the sea floor or the land surface.

Vulnerability The degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change. It is a function of the character, magnitude and rate of change to which a system is exposed and the sensitivity and adaptive capacity of that system.

W

Walker Circulation An east-west circulation of the atmosphere above the tropical Pacific, with air rising above warmer ocean regions (normally in the west), and descending over the cooler ocean areas (normally in the east). Its strength fluctuates with that of the Southern Oscillation.

Weather The state of the atmosphere with regard to temperature, cloudiness, rainfall, wind and other meteorological conditions. It is not the same as climate which is the average weather over a much longer period.

X

Y

Z