Climate risk report for the Southeast Asia region: Technical Reference Document

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A: Methods and Data

Methodological approach

This report presents an analysis of climate risk in the Southeast Asia region, combining climate with social and economic analysis to identify key challenges to production systems, resources, economies, services, and livelihoods. The report aims to guide development planners to areas requiring attention, providing an overview of key risks and uncertainties, highlighting prominent regional risks.

The climate has been analysed for distinct geographical regions (zones) which were determined using the following criteria:

- Similar climate characteristics e.g., timing of rainy seasons or similar seasonal temperatures (see TRD Section C for further detail on Köppen-Geiger climate classifications).
- Zone size was tailored to the resolution of the climate data and to capture large regional features such as e.g., mountain ranges.
- Zone boundary selection was balanced between Köppen-Geiger climate zones, river basins, and elevation changes.

This tailored zonal climate analysis is combined with regional socio-economic information to assess potential impacts of future regional climate change on the following:

- Agriculture and food security
- Water resources and water-dependent services
- Health
- Infrastructure and settlements
- Energy
- Environment
- Blue economy and the marine environment

Further information regarding the data used and detailed methodology can be found in Section A of the Technical Reference Document (TRD) and on the Met Office website[1].

[1] https://www.metoffice.gov.uk/services/government/international-development/climate-risk-reports

Climate in context methodological approach

The key stages in the methodology and division of responsibilities across the project team are presented in a schematic in Figure A1 and described in more detail below.

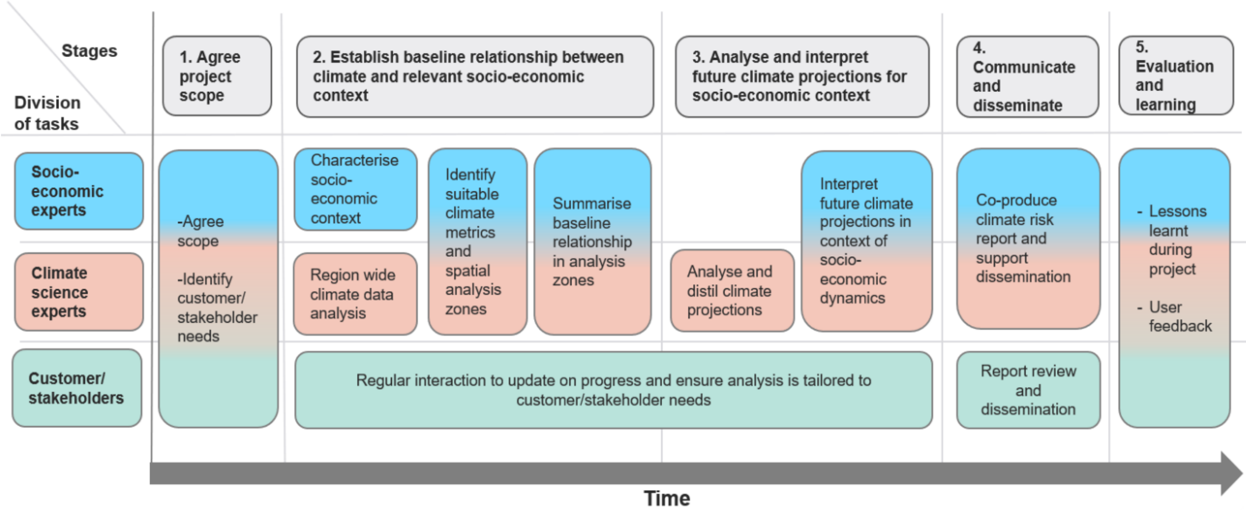

Figure A1: Schematic diagram of the key stages of the methodology and division of tasks between the socio-economic experts (ODI), climate science experts (Met Office) and customer (FCDO) roles of the project team (Richardson et al., 2022)

Stage 1 involves agreement on the scope of the work and the format of the outputs through iterative discussions across the project team. Consultations with the customer (FCDO) are conducted to identify the socio-economic themes relevant to their decision context.

Stage 2 involves establishing the baseline relationship between climate and the key socioeconomic themes identified in Stage 1. This includes:

- Preliminary analysis is conducted to characterise the regional socio-economic context and regional climate through a combination of literature review and processing climate reanalysis data by the relevant experts.
- Identification of suitable climate metrics and spatial analysis zones via an iterative process between the experts, drawing on the outcomes of the preliminary analysis.
- Characterisation of the baseline climate, the key climate-related vulnerabilities and exposure to climate-related hazards in each of the spatial analysis zones.

Stage 3 involves analysis of future climate projections and interpretation in the context of the key vulnerabilities and baseline assessments developed in Stage 2. This includes:

- Selection of appropriate climate model simulations for the region and quantitative analysis of projected changes in relevant climate variables in each of the spatial analysis zones.
- Distillation of the future climate projections into narrative summaries for the relevant climate metrics in each spatial analysis zone.
- Translation of the future climate summaries into climate risk impacts with a focus on the key socio-economic themes.

Stage 4 involves the co-production of a report summarising the analysis and outcomes, tailored to the needs of the customer.

Stage 5 involves evaluation and learning of the process to support future applications of the methodology.

Climate data and analysis methods

This report uses spatial analysis zones (which were selected using criteria, as mentioned on TRD page 1, to process ERA5 reanalysis[2,3] data; Hersbach et al., 2020) to characterise the current climate over the 1981-2010 baseline period. Global and regional climate model simulations were used to assess the projected change in temperature and precipitation for the 2050s (2041-2070- consistent with IPCC AR6).

To model and predict future climate it is necessary to make assumptions about the economic, social and physical changes to our environment that will influence climate change. Representative Concentration Pathways (RCPs) used in IPCC AR5, and Shared Socio-Economic Pathways (SSPs) used in IPCC AR6 are both methods for capturing those assumptions within a set of scenarios. The conditions of each scenario are used in the process of modelling possible future climate evolution.

In this study, we use RCP8.5[4,5] (radiative forcing of 8.5 Watts m^{-2} by 2100)- a pathway where greenhouse gas emissions are not substantially reduced, and SSP5-8.5, a fossil-fuel driven development scenario. RCP4.5 (a stabilisation pathway where greenhouse gas emissions are limited to 4.5 Watts m^{-2} by 2100) has also been analysed but only mentioned where it differs substantially from RCP8.5. Both RCP8.5 and SSP5-8.5 represent an increase in global average temperature of around 2.5˚C compared to pre-industrial levels, (van Vurren et al. 2011), which is higher than the target of limiting warming to well below 2˚C set by the United Nations Framework Convention on Climate Change (UNFCCC) Paris Agreement. The

[2] A gridded dataset that blends climate observations and model data to present the current climate for use as a baseline in future climate assessments.

[3] All observational and reanalysis datasets have associated uncertainties and limitations. For example, reanalysis datasets may underestimate observed extremes, and cannot fully represent localised features such as intense precipitation caused by complex topography, partly due to their limited resolution in space and time. Additionally, ERA5 precipitation fields are derived from ‘forecast’ output and are therefore more affected by imperfections within the underlying model. The benefit, however, of using reanalyses is that they provide a systematic approach to producing gridded, dynamically consistent datasets for climate monitoring, particularly over data-scarce regions. However, the use of these data to characterise climatological means for the purpose of this analysis is largely uninfluenced by these biases, and the benefits of using a dataset that is globally consistent and consistent with other climate information products outweighs this.

[4] The RCP8.5 Representative Concentration Pathway represents the highest emission scenario/future pathway of ongoing and substantial increases in future global greenhouse gas concentrations. Other pathways represent stabilisation or eventual reduction of greenhouse gas concentrations with the lowest projecting less additional climate change in the 2050s compared to RCP8.5. Analysis of the RCP4.5 scenario was also conducted, and results were broadly consistent with those presented here for RCP8.5.

[5] The SSP5-8.5 scenario was used for the CMIP6 generation of climate models.

baseline period of 1981-2010 considered in this report represents an observed increase of around 1°C in global average temperature compared to pre-industrial levels.

The climate projections in this report comprise a 47-member ensemble; 22 World Climate Research Project (WCRP) Coupled Model Intercomparison Project Phase 5 (CMIP5; Taylor et al., 2012) global climate model simulations (see Table A1), 19 WCRP CMIP Phase 6 (CMIP6; Eyring et al., 2016) global climate model simulations (see Table A2), and 6 regional climate model simulations from the WCRP CoOrdinated Regional climate modelling Downscaling EXperiment (CORDEX; Giorgi and Gutowski, 2015) project (see Table A3).

CMIP5 models were used to inform the Intergovernmental Panel on Climate Change (IPCC) 5 the Assessment Report (AR5; IPCC, 2013), with horizontal model resolution ranging from 100- 300 km. CMIP6 models informed the latest Assessment Report (AR6; IPCC, 2021). Like CMIP5, the horizontal resolution of the CMIP6 models varies by model with some at a higher resolution than CMIP5 and some unchanged. The regional climate models are downscaled CMIP5 simulations over the CORDEX Southeast Asia domain (SEA-22) at a resolution of ~25km.

The models selected are those that were available to access at the time of analysis. Model suitability was evaluated by comparing baseline periods from model simulations with reanalysis data. This model evaluation was taken into consideration when interpreting the future model projections. More detail on evaluation of these model simulations and known biases is available in IPCC (2021).

The climate data analysis focuses on quantifying projected changes in annual, and seasonal means in temperature and precipitation in the spatial analysis zones. This is supplemented with information from literature and analysis contained within the Intergovernmental Panel on Climate Change (IPCC) 6th Assessment Report (AR6) and the IPCC Interactive Atlas (Gutiérrez et al., 2021). Information on the projected changes in other relevant climate variables and indicators – such as sea surface temperatures, sea level rise and relevant climate extremes – is drawn from appropriate scientific literature and from the IPCC Interactive Atlas (Gutiérrez et al., 2021).

Table A1: GCM simulations from CMIP5 used in the climate data analysis, from https://pcmdi.llnl.gov/mips/cmip5/availability.html.

Modelling Centre	Model	Institution
BCC	BCC-CSM1-1-m	Beijing Climate Center, China Meteorological Administration
CSIRO-BOM	ACCESS1-0	CSIRO (Commonwealth Scientific and Industrial Research Organisation, Australia), and BOM (Bureau of Meteorology, Australia)
	ACCESS1-3	
NCAR	CCSM4	National Center for Atmospheric Research
NSF-DOE-NCAR	CESM1-CAM5	National Science Foundation, Department of Energy, National Center for Atmospheric Research
CMCC	CMCC-CM	Centro Euro-Mediterraneo per I Cambiamenti Climatici
	CMCC-CMS	
CNRM-CERFACS	CNRM-CM5	Centre National de Recherches Meteorologiques / Centre Europeen de Recherche et Formation Avancees en Calcul Scientifique

CSIRO-QCCCE	CSIRO-Mk3-6-0	Commonwealth Scientific and Industrial Research Organisation in collaboration with the Queensland Climate Change Centre of Excellence
EC-EARTH	EC-EARTH	EC-EARTH consortium
NOAA-GFDL	GFDL-CM3	NASA Goddard Institute for Space Studies
	GFDL-ESM2G	
	GFDL-ESM2M	
MOHC	HadGEM2-AO	Met Office Hadley Centre
	HadGEM2-CC	
	HadGEM2-ES	
INM	INMCM4	Institute for Numerical Mathematics
MIROC	MIROC5	Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies
MPI-M	MPI-ESM-LR	Max Planck Institute for Meteorology
	MPI-ESM-MR	
MRI	MRI-CGCM3	Meteorological Research Institute
NCC	NorESM1-M	Norwegian Climate Centre

Table A2: GCM simulations from CMIP6 used in the climate data analysis, from https://pcmdi.llnl.gov/CMIP6/ArchiveStatistics/esgf_data_holdings/

Modelling Centre	**Model**	**Institution**
BCC	BCC-CSM2-MR	Beijing Climate Center, China Meteorological Administration
CNRM-CERFACS	CNRM-CM6-1	Centre National de Recherches Meteorologiques / Centre Europeen de Recherche et Formation Avancees en Calcul Scientifique
	CNRM-CM6-1-HR	
	CNRM-ESM2-1	
CSIRO	ACCESS-ESM1-5	CSIRO (Commonwealth Scientific and Industrial Research Organisation, Australia)
EC-EARTH Consortium	EC-Earth3	EC-EARTH consortium
	EC-Earth-Veg	
INM	INM-CM4-8	Institute for Numerical Mathematics
	INM-CM5-0	
IPSL	IPSL-CM6A-LR	Institut Pierre-Simon Laplace
MIROC	MIROC6	Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies
MOHC	HadGEM3-GC31-LL	Met Office Hadley Centre
	UKESM1-0-LL	
MPI-M	MPI-ESM1-2-LR	Max Planck Institute for Meteorology
MRI	MRI-ESM2-0	Meteorological Research Institute
NCC	NorESM2-MM	Norwegian Climate Centre
NOAA-GFDL	GFDL-ESM4	NASA Goddard Institute for Space Studies
	GFDL-CM4	
NUIST	NESM3	Nanjing University of Information Science and Technology

Table A3: Regional Climate Model (RCM) simulations from CORDEX SEA-22 used in the climate data analysis. These are downscaled simulations of a subset of the Global Climate Model (GCM) CMIP5 models in Table A1 at ~25km resolution.

Modelling Centre	RCM	Driving GCM	Institution
SMHI	RCA4	CNRM-CM5	Swedish Meteorological and Hydrological Institute
		HadGEM2-ES	
GERICS	REMO2015	HadGEM2-ES	Helmholtz-Zentrum Geesthacht, Climate Service Center Germany
		MPI-ESM-LR	
		NorESM1-M	
ICTP	RegCM4-7	NorESM1-M	International Centre for Theoretical Physics

B: Climate risk in Southeast Asia

Focus box B1: Risk-informed development

There is an increasing recognition that development objectives face multiple, intersecting threats, beyond just the risks associated with environmental and climate factors. The full implications for development programming will not be captured by traditional single threat analysis. In order to be risk-informed, programme decision making must undertake multi-threat analysis that considers how different threats merge with existing and changing socioeconomic contexts to create complex risk. In practice, this means that climate-resilient development must not only consider threats to programme outcomes from climate and environmental degradation, but also political, economic and financial instability, cyber and technology, transboundary crime and terrorism, geopolitical volatility, conflict and global health pandemics.

Risk-informed development requires us to think about risks to development as well as risks from development. Development outcomes are uneven, creating opportunities for some, and risks for others. Risk-informed development must account for trade-offs inherent in development choices, including climate adaptation and mitigation. Such decisions are inherently political, involving the redistribution of resources and navigating unequal power structures.

Source: Opitz-Stapleton et al. (2019); Eriksen et al. (2015).

Climate risk rankings and comparisons

Figure B1 presents a snapshot of climate risk across the region using widely used ND-GAIN[6] country rankings for 2021 – the most recent year for which data are available. The ND-GAIN country index uses a range of metrics to assess both a country's vulnerability to climate change and other global challenges and its readiness to build resilience. Vulnerability is measured by assessing a country's exposure, sensitivity, and capacity to adapt to the negative effects of climate change, looking at seven sectoral themes: agriculture and food security, water resources and water-dependent services, health, infrastructure and settlements, energy, environment, and blue economy and the marine environment. Readiness is measured by assessing a country's ability to leverage investments and convert them into adaptation actions, looking at three components: economic readiness, governance readiness, and social readiness. Figure B1 presents a snapshot of climate risk across the region using widely used ND-GAIN[7] country rankings for 2021 – the most recent year for which data are available. The ND-GAIN country index uses a range of metrics to assess both a country's vulnerability to climate change and other global challenges and its readiness to build resilience.

[6] Notre Dame Global Adaptation Initiative: https://gain.nd.edu/ ND-GAIN country scores and rankings are used by, amongst others, the World Bank in their climate risk country profiles – see https://climateknowledgeportal.worldbank.org/. Scores are available for a total of 182 countries based on data for 2021.

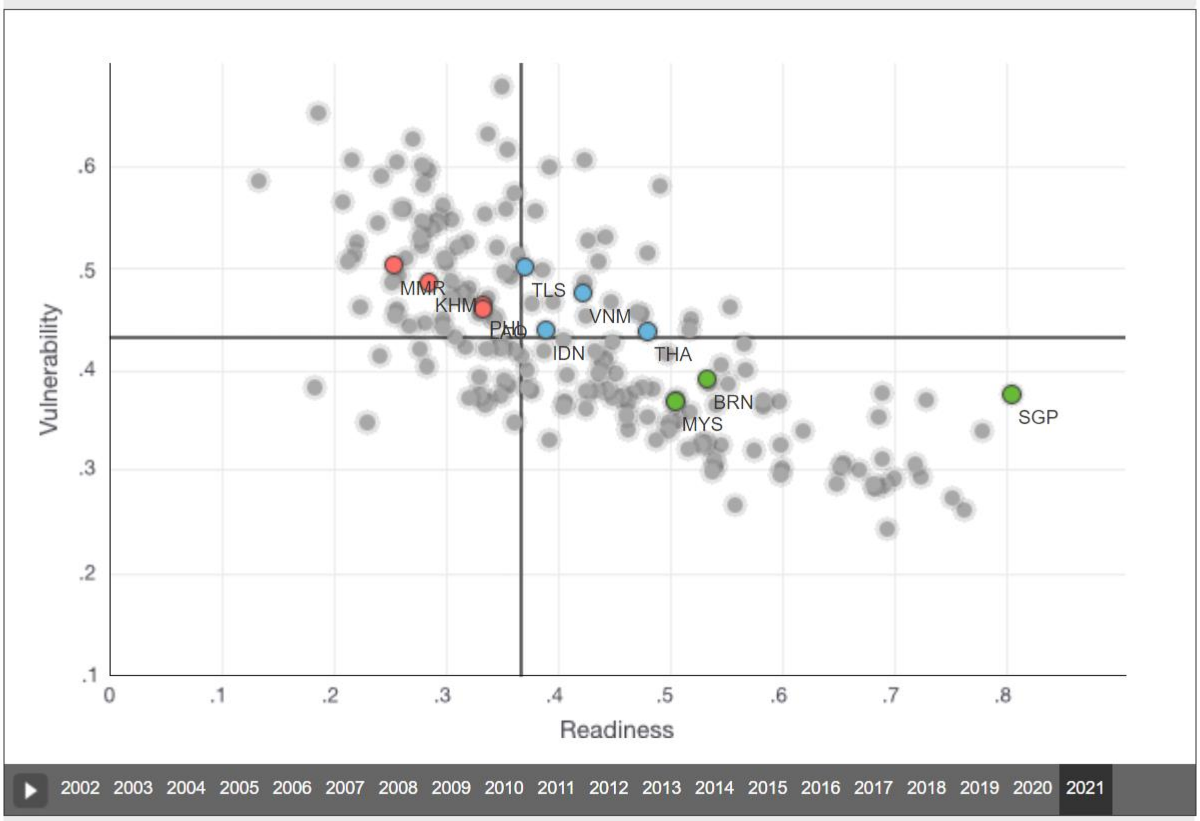

Figure B1: ND-GAIN country scores for the Southeast Asia region. Red denotes high vulnerability and low readiness (Myanmar as MMR, Cambodia as KHM, Philippines as PHL, and Lao PDR as LAO). Yellow denotes low vulnerability and low readiness (none for this region). Blue denotes high vulnerability and high readiness (Timor-Leste as TLS, Viet Nam as VNM, Indonesia as IDN, and Thailand as THA). Green denotes low vulnerability and high readiness (Malaysia as MYS, Brunei Darussalam as BRN, and Singapore as SGP). Source: https://gain.nd.edu/.

Four of the 11 Southeast Asian countries considered in this report occupy the top left quadrant of the ND-GAIN matrix (Figure B1; red dots). These countries are Myanmar, Cambodia, Philippines, and Lao PDR. Countries in this quadrant combine high vulnerability with low levels of readiness, indicating an urgent need for adaptation action. All four countries are classified as lower-middle income in the latest World Bank ranking[8]. Collectively, these 'high risk' countries account for 28.5% (193.9 million people, with Philippines accounting for 60% of that number) of the whole region's population (680.3 million people)[9]. No countries fall into the bottom-left quadrant (yellow dots; low vulnerability, low readiness).

Lower-middle income Timor-Leste and Viet Nam and upper-middle income Indonesia and Thailand[8] (blue dots) occupy the top right quadrant, high vulnerability, and high readiness quadrant. These are countries with exposed populations and assets, but demonstrable

[8] https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups
[9] https://data.worldbank.org/indicator/SP.POP.TOTL?view=map

capacity to act and adapt. Collectively, these four countries account for 65.6% (446.6 million people, with Indonesia accounting for 61% of that number) of the whole region's population (680.3 million people)[9].

Upper-middle income Malaysia and high-income Brunei Darussalam and Singapore[8] occupy the bottom right quadrant (green dots) i.e., in the low vulnerability and high readiness quadrant. These three countries collectively account for 5.8% (40 million people, with Malaysia accounting for 85% of that number) of the whole region's population (680.3 million people)[9].

C: Climate projections and drivers of climate variability

Climate stripes

Figures C1 and C2 show climate stripes for temperature and precipitation for the one IPCC region which forms Southeast Asia for the period 1950-2100 (centred around a 1981-2010 baseline). This gives an indication of inter-model agreement, an important factor in establishing confidence in future projections. There is more consistency (although, still variation between models) in the projected magnitude and rate of temperature change (warming) by the end of the century, compared to less confidence in magnitude and rate of precipitation changes.

It should be noted that climate stripes are generated from a different subset of model configurations compared to the bespoke zonal analysis conducted for this research. Whilst the number of models used within the zonal analysis is lower than is used within the IPCC Interactive Atlas data, there is a significant number (see Tables 1-3) which is considered representative of the range of climate outcomes. In addition, the climate stripes represent the whole Southeast Asia region, so are not suited for comparison between the bespoke zonal analysis. **Instead, climate stripes are a useful tool for visualising broader regional trends and associated inter-model variability.**

Observed precipitation datasets

There are considerable differences in the observed annual precipitation trend between observational datasets (GPCC from Becker et al., 2013 and APHRODITE from Yatagai et al., 2012) available in the IPCC Interactive Atlas (Gutiérrez et al., 2021a) across the southern Maritime Continent. This is due to the sparse availability of rainfall gauge data over this region (which forms the basis of the APHRODITE dataset) (Ma et al., 2022) and, therefore, GPCC has been used as the basis of analysis in this region.

Precipitation Projections

Of the key variables within climate modelling (temperature, precipitation, sea surface temperature and sea level), precipitation, by a significant margin, exhibits the most uncertainty in respect to spatial climate trends across Southeast Asia. **Projected changes for 2050 in rainfall over Southeast Asia vary, depending on model, sub-region, and season (*high confidence*)** (Gutiérrez et al., 2021b).

Taken in this context, there are regions and seasons which show stronger evidence, and therefore higher confidence, for either a positive or negative trend and these are listed below:

- Across all regions, the number of days where extreme rainfall occurs will increase.
- Across Myanmar, Lao PDR, Viet Nam, Thailand and Cambodia, rainfall will increase during the SW monsoon season (June-October), in the region of 5-10%. In addition, a higher level of warming will impact the start of the SW monsoon across these countries – higher levels will delay onset, lower levels will bring forward the start time.
- The far south of the Maritime Continent (South Sumatra, Java, the Lesser Sunda Islands and Timor-Leste) are expected to see minimal increases to annual rainfall, and may even see an overall decrease, driven by a longer drier season between April and October (Gutiérrez et al., 2021).

- Typhoons will become more water-laden, bringing higher rainfall rates, both instantaneous and throughout the event. However, as a result of the background increase in annual rainfall, typhoons will represent a lower contribution (Ma et al., 2023). In other words, the underlying wetting trend is greater than the additional contribution from typhoons.

The ensemble mean of global coupled models (GCMs), which are relatively coarse in spatial and temporal resolution, present wetting trend across the majority of Southeast Asia. Uncoupled, but higher resolution Regional Climate Models (RCMs), exhibit this wetting trend across northern Indochina but otherwise project a general drying trend, particularly through September to December, across the Maritime Continent (Gutiérrez et al., 2021; Tangang et al., 2020).

It has been found that RCMs better represent climatic patterns of precipitation across the Southeast Asia region compared to GCMs, with the RCM ensemble mean outperforming individual models (Gutiérrez et al., 2021). However, whilst this can be said at a regional scale, there is more nuance on a sub-regional level – such as the zones used in this analysis – where the same cannot be said. Therefore, the climate analysis within this report presents the full ensemble (GCM and RCM) of solutions as plausible outcomes but gives greater weight to the GCM solutions.

Across the Maritime Continent through the summer months (June-October in the north, November-March in the south), a highly variable drying trend (between 0-750mm by 2050) is apparent in RCM ensemble members which is not evident in their GCM counterparts. Whilst this presents contradictory evidence for future trends across the Maritime Continent, this analysis considers that the GCM outcomes are most plausible and flags a low probability of an alternative scenario occurring and highlights that this is an area ripe for further research.

Typhoons

Due primarily to ocean warming, it has been observed over the past four decades that it is *very likely* that typhoons in the western North Pacific reach their peak intensity at higher latitudes. This trend is expected to continue, possibly reducing typhoon frequency at lower latitude locations, such as Philippines (Seneviratne et al., 2021). The average and maximum rain rates associated with typhoons increase in a warming world (*high confidence*)[10] (Seneviratne et al., 2021). Additionally, across the western North Pacific basin, a significant slowdown in typhoon translation speed (movement) has been found (Yamaguchi and Maeda, 2020), amplifying the impact of increased rain rates. Globally over the past 40 years, intensification rates and frequency of rapid intensification of typhoons has increased (Kishtawal et al., 2012; Bhatia et al., 2018). This trend is expected to continue so it is *very likely* that both average peak wind speeds in typhoons and overall proportion of category 4 and 5 typhoons will increase globally. It is *likely* that the frequency of category 4 and 5 typhoons will increase across the western North Pacific (Seneviratne et al., 2021), primarily impacting on north-central Philippines as well as Viet Nam, Cambodia and Thailand (Qin et al., 2023). Peak intensity (and therefore highest wind speed) will also increase (Wehner et al., 2018; Knutson et al., 2020). Due to the low spatial resolution of most climate models, typhoons

[10] Annual maximum 1-day rain rates in the western Pacific may remain unchanged, but this is likely a function of reduced frequency rather than reduced moisture availability (Kitoh and Endo, 2019).

are not well represented and therefore their projections generally hold lower confidence compared to other parameters such as temperature.

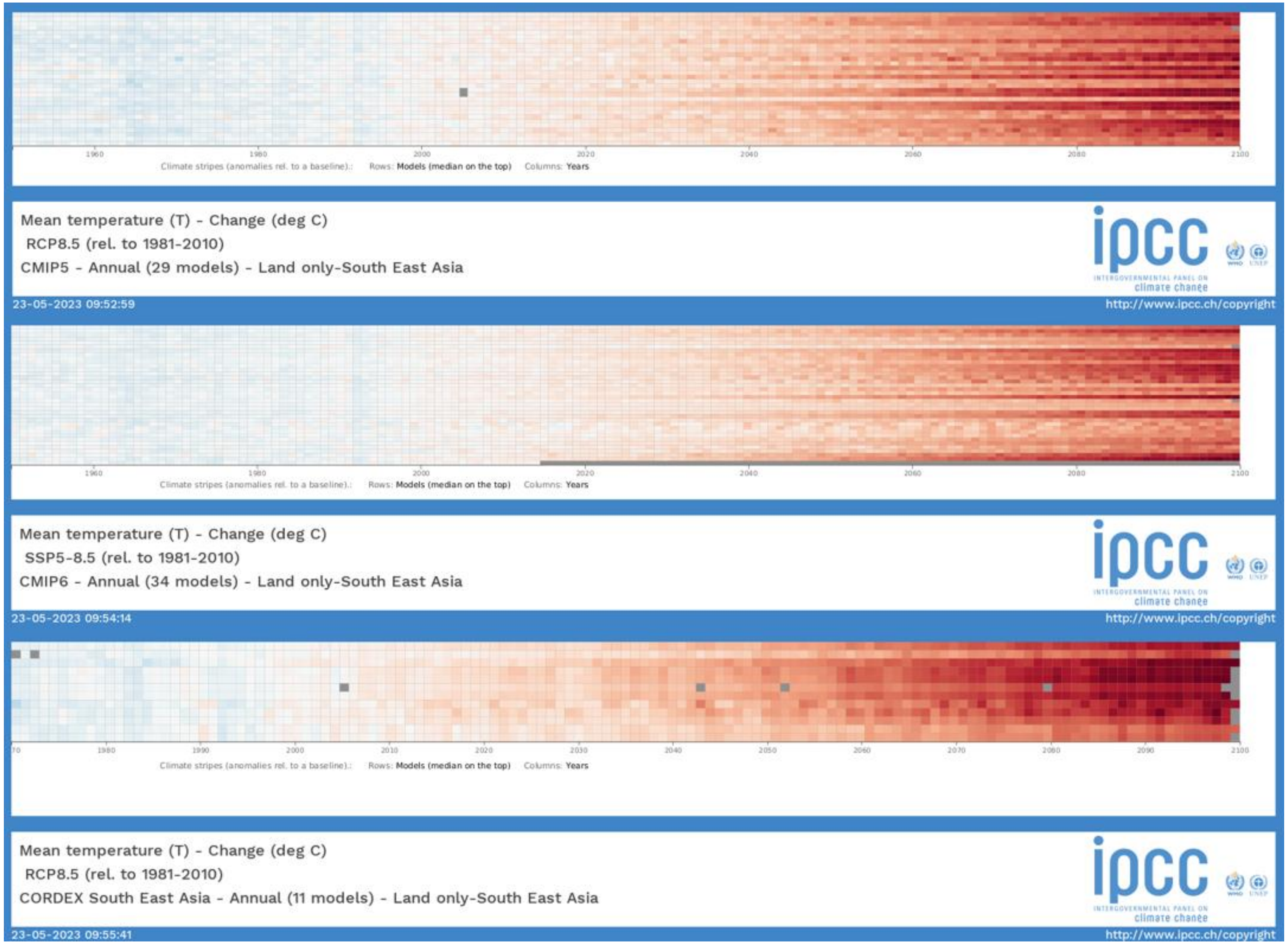

Figure C1: Climate time series for Southeast Asia (land only) showing RCP8.5 projections of mean temperature anomaly from individual models within each ensemble from 1950-2100, relative to a 1981-2010 baseline. Each box represents the average projected temperature for a single year, relative to the average temperature over the period as a whole. Shades of blue indicate cooler-than-average years, while red shows years that were hotter than average. The stark band of deep red stripes on the right-hand side of the graphic show the rapid warming that is projected. Three model configurations are shown: CMIP5 (top), CMIP6 (middle) and CORDEX SE Asia (bottom). Each stripe running left to right represents an individual model run, and therefore a plausible outcome. Grey squares represent areas of missing data. Projection confidence is discussed further within the TRD.

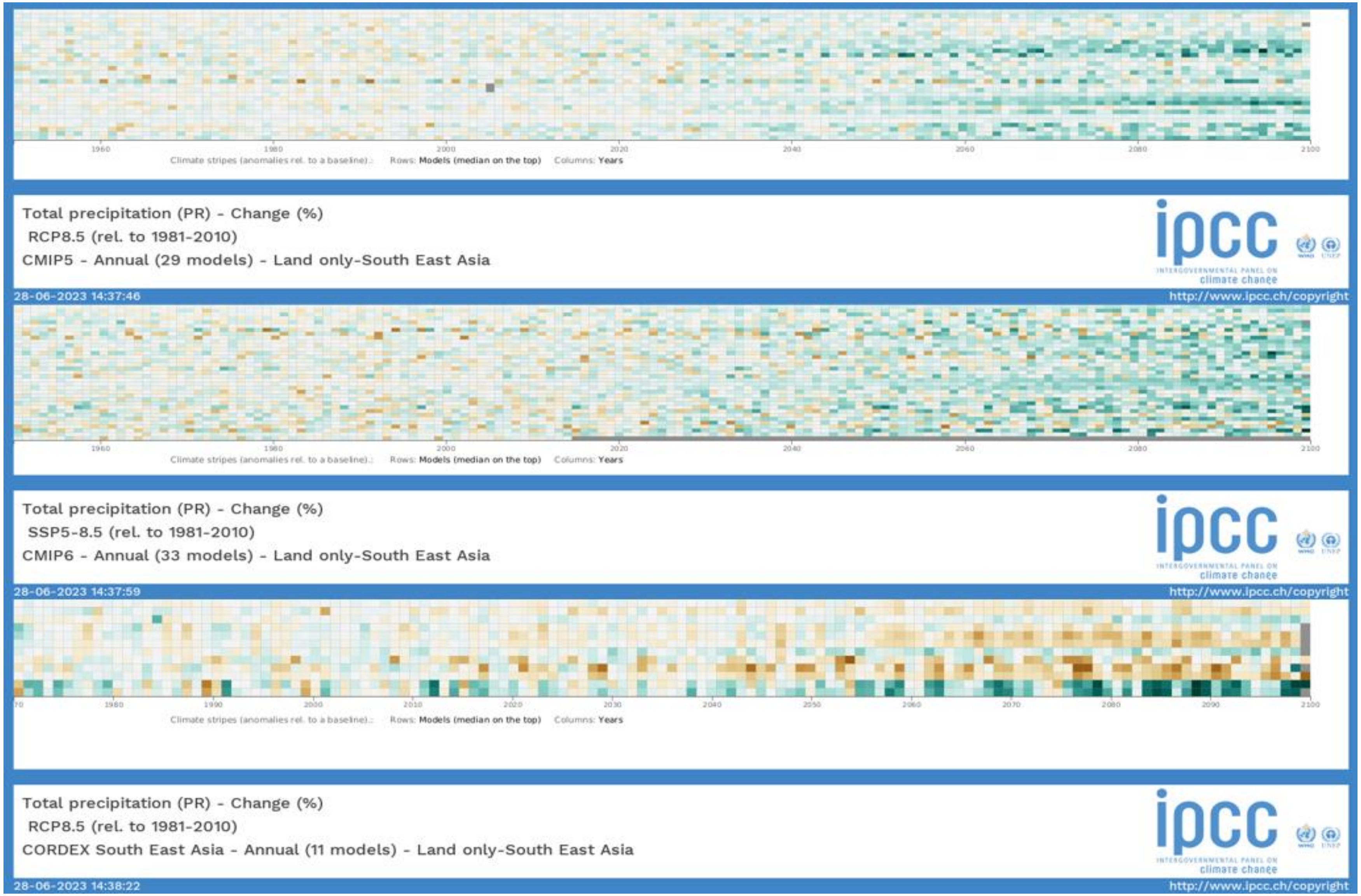

Figure C2: Climate Stripes for Southeast Asia (land only) showing RCP8.5 projections of total precipitation anomaly from individual models within each ensemble from 1950-2100, relative to a 1981-2010 baseline. Each box represents the average projected precipitation for a single year, relative to the average precipitation over the period. Each stripe running left to right represents an individual model run, and therefore a plausible outcome. Shades of brown indicate drier-than-average years, while blue shows years that were wetter than average. Three model configurations are shown: CMIP5 (top), CMIP6 (middle) and CORDEX SE Asia (bottom). Grey squares represent areas of missing data.

Climate, climate change and drivers of climate variability

What is weather? The weather varies from day to day and season to season, with long-term statistics of the weather defining a region's climate. These statistics are typically defined over a 30-year period. They will include quantities such as monthly averages of minimum and maximum temperature, the frequency, intensity, and duration of heavy rainfall or extreme wind-speeds and daily averages of evaporation or solar radiation. Climate change can then be characterised as the difference in these statistics between two 30-year climate periods.

Climate varies naturally over shorter periods of several years, and this natural variability can accentuate or dampen longer-term climate change signals. Both average conditions and the variability around that average can change and can result in increases in events that in the past were rare or extreme. It can also lead to situations where climate change increases the frequency of both heavy rainfall events and the occurrence of very dry conditions (IPCC, 2021).

The actual annual and seasonal rainfall and temperature values vary from year to year, resulting in hotter, drier, cooler, and wetter periods in relation to the climatological mean. This happens because the local weather is influenced by larger-scale processes in the climate, known as climate drivers, which influence regional and local climate over different timescales.

The El Niño-Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD) are two main drivers of climate variability in Southeast Asia. These refer to oscillations of sea surface temperatures and leads to variations in associated atmosphere and ocean circulations. In Southeast Asia, El Niño (one phase of ENSO) is linked with reduced rainfall while La Niña (another phase of ENSO) is linked with enhanced rainfall. Positive IOD events are associated with suppressed rainfall in Southeast Asia and subsequent regional drought and forest fires. Negative IOD events are often associated with regional enhanced rainfall, flooding, and marine heatwaves.

In addition to the mean trends, year-to-year variability in precipitation amounts and timings will continue in the future as the larger-scale influences on climate continue to remain active. In climate model projections, extreme ENSO events become more frequent and ENSO rainfall variability also increases (Cai et al., 2014). This could result in an increase in wetter and drier years relative to the mean despite a lack of a clear signal in average precipitation. However, observed trends over the past 50-100 years do not necessarily support these climate model projections of ENSO changes so future changes in tropical rainfall variability remain uncertain. Addition drivers of climate variability for Southeast Asia are provide in Table C1.

Table C1: Summary of the drivers of rainfall and temperature variability in Southeast Asia and the influence they have on seasonal climate. Definitions of the drivers of variability are provided in the glossary in TRD Section G.

Drivers of variability	Influence on seasonal climate	Regional relevance
Madden-Julien Oscillation (MJO)	The MJO is an eastward-moving pattern of enhanced and suppressed rainfall. The MJO can influence the timing and intensity of the Indian and Australian summer monsoons. Typhoons are more likely to develop during active MJO phases and the presence of MJO can sustain a typhoon. The MJO can also weaken trade winds over the eastern Pacific which can trigger or strengthen El Niño events or weaken or disrupt La Niña events.	Whole region.

Typhoons (TCs)	TCs are deep areas of low pressure, bringing catastrophic impacts to an area through wind, rain and storm surges. Strong winds cause damage to infrastructure and the environment and danger to life. Heavy rain causes flooding, landslide risk, and increased disease prevalence due to flooding. Storm surges cause coastal inundation, danger to life and infrastructure, and coastal erosion.	All regions except Indonesia and Timor-Leste.
Asian Monsoon	A monsoon climate is characterised by a dramatic seasonal change in direction of prevailing winds, bringing a marked change in rainfall. The Asian Monsoon is a huge monsoon wind system and can cause flooding in summer but provides freshwater supply from increased rainfall which can also supply agriculture. The Indo-Australian Monsoon is another huge monsoon wind system which, during the Austral Summer, leads to heavy rainfall across much of the Maritime Continent of Southeast Asia. During Austral Winter, rainfall is suppressed, especially for Java and Timor-Leste.	Whole region.

D: Attribution of weather and climate-related events

Attribution Context

Climate attribution can tell us how changes to the physical climate system from human-caused greenhouse gas emissions are influencing weather and climate. This is physics based and typically uses observations of physical climate metrics (rainfall, temperature, etc) and compares these against events in climate models. Where observations are deficient this is more difficult. Modelled worlds with and without human greenhouse gas emissions are compared to quantify the influence of human-caused climate change on extreme weather and climate events, as well as on slower onset changes in the climate such as sea level rise (known as **Trend Attribution**). For individual extreme events, **Extreme Event Attribution (EEA)** can be performed rapidly in the days following an event by research groups such as the World Weather Attribution collaboration. The UK also has capability to perform climate event attribution assessments. These extreme event attribution studies aim to quantify the extent to which human-induced climate change has altered the likelihood or intensity of a specific event, such as a heatwave, a flood, or a drought.

Impact attribution takes into consideration the economic and social impacts arising from an individual climate event (loss of life, damage to property, etc). So, this includes aspects of exposure and vulnerability. This is more complicated as it requires socioeconomic information (in addition to the assessment of the physical climate event attribution). So, the science can tell us about whether an individual event was made more likely or more intense due to human-caused climate change. The quantification of any impacts from an individual event requires additional information.

The following paragraphs and table provide a summary of the main findings and limitations of attribution studies of weather and climate-related events in Southeast Asia, based on the literature review conducted for this report.

Relevant studies to Southeast Asia

In general, many of the available attribution studies for Southeast Asia show a positive causation between human influences (primarily via increased greenhouse gas contribution) and notable weather events such as flooding and heatwaves. There are however still a significant number of studies which do not find this link and show that the event is explained solely by natural climate variability. Weather events which have not been shown to have been exacerbated by climate change are equally important to understand because they show where adaptation and mitigation measures are required, regardless of future climate scenarios.

The majority of attribution studies across Southeast Asia are focused on flooding. Not all flooding events, however, have been shown to be attributed to climate change and as such, would be expected to occur in an un-altered climate state. Most studies that assessed flooding highlighted a combination of events which led to the flooding, such as a delayed withdrawal of monsoon rains leading to conditions more conducive to flooding.

Across continental Southeast Asia, available attribution studies on rainfall events have generally not found strong links to anthropogenic climate change due to either a lack of sufficient observational data or no clear trends evident within the data. This highlights one of the key challenges facing attribution science in the region where the spatial and temporal coverage of climate observations is limited, unavailable (due to lack of digitisation) or non-existent. One study (Yun et al., 2020) does find that flooding along the Mekong River between 2008-2016 increased both the magnitude and frequency by 14% and 45%, respectively. Conversely, Alifu et al., (2022) showed that human-induced climate change *suppressed* the magnitude of flooding along the Mekong River during 2010. This demonstrates that each event must be treated in isolation and there is an insufficient evidence base to support region-wide statements of multi-event attribution to anthropogenic climate change.

Across the Maritime Continent, Oliver et al., (2018) showed that the 2016 marine heatwave surrounding Java, the Lesser Sunda Islands and Timor-Leste was up to 50 times more likely due to anthropogenic climate change. King et al., (2016) concluded that the heatwave and associated drought which affected Indonesia during 2015 was made significantly more likely as a result of anthropogenic climate change, but also acknowledged the contributing role of El Niño during this event. Conversely, Siswanto et al., (2015) found that intense rainfall that led to severe flooding across Jakarta in 2014 was not unusual and was unlikely linked to climate change.

Table D1: Cases of event attribution, ordered by date (recent events at top). This list is non-exhaustive. Red rows represent events that are attributed to anthropogenic climate change. Blue rows represent events that are not attributed to anthropogenic climate change. Blank rows (white) represent studies that are inconclusive or lacking in data.

Month / Year	Country	Variables	Study statement	Attribution	Study reference
April 2023	Thailand, Lao PDR	Heatwave	"In the current climate, which has warmed by 1.2°C since pre-industrial times due to human activities, the humid heat event (defined using the heat index) is estimated to be rare in Thailand and Lao PDR."	Attributed to anthropogenic climate change	Zachariah et al. (2023)
October 2020	Vietnam	Rainfall	"The effect of human-induced climate change contributing to this persistent extreme rainfall event is small compared to natural variability."	Not attributed to anthropogenic climate change	Luu (2021)
2016	Southern Indonesia, Northern Australia	Marine Heatwave	"The marine heatwave of 2016 was up to fifty times more likely due to anthropogenic climate change. Natural variability also played a role, especially the influence of the negative IOD phase."	Attributed to anthropogenic climate change	Oliver et al. (2018)
July-October 2015	Indonesia	Heatwave and Drought	"El Niño and human-induced climate change have substantially increased the likelihood of rainfall deficits and high temperatures, respectively, in Indonesia such as those	Attributed to anthropogenic climate change	King et al. (2016)

			experienced in the drought conditions of July–October 2015.”		
2014	Singapore and Malaysia	Lack of Rainfall	“The record dry spell over Singapore–Malaysia was caused by the southward contraction of the intertropical convergence zone. Within present evidence, there is no clear attribution to climate change.”	Not attributed to anthropogenic climate change	McBride et al. (2015)
2014	Jakarta, Indonesia	Flooding	“The January 2014 floods paralyzed nearly all of Jakarta, Indonesia. The precipitation events that lead to these floods were not very unusual but show positive trends in the observed record.”	Inconclusive	Siswanto et al. (2015)
2013	Philippines	Storm Surge	Typhoon Haiyan. “The result indicates that the worst-case scenario of a storm surge in the Gulf of Leyte may be worse by 20%, though changes in frequency of such events are not accounted for here.”	Attributed to anthropogenic climate change	Takayabu et al. (2015)
2011	Thailand	Flooding	“Neither in the precipitation observations nor in climate models is there a trend in mean or variability up to now, so climate change cannot be shown to have played any role in this event.”	Not attributed to anthropogenic climate change	van Oldenborgh et al. (2012)

2010	Thailand	Flooding	"Compared to pre-industrial times (1880), the frequency of such events [2010 floods] has likely increased; however, due to the limited length of the observational series, the trend is not statistically distinguishable above natural climate variability. "	Insufficient data	Otto et al. (2018)
2008-2016	Mekong River Basin	Flooding	"Compared with the baseline period of 1985–2007…climate change increased the magnitude and frequency of the flood by up to 14% and 45%, respectively."	Attributed to anthropogenic climate change	Yun et al. (2020)
1996	Mekong River	Flooding	One study showed that human induced climate change was likely to have *suppressed* flooding due to higher evapotranspiration or lower volume of snow melt.	Not attributed to anthropogenic climate change	Alifu et al. (2022)

Extreme rainfall, rather than flooding, is regarded as easier to assess due to the lack of the additional layer of complexity that the flooding hazard and associated impact reporting brings. For example, a flooding assessment requires consideration of hydrology and human water management in addition to the rainfall.

Gaps

One of the main challenges that climate attribution studies face in Southeast Asia is the scarcity and quality of observational data, both for historical and current events. This limits the ability to establish reliable baselines, trends, and causal relationships between climate change and individual extreme weather events. This is also true for impact attribution (which this study has not focused on) as events are influenced by multiple factors, such as land use change, availability of water and its management, health data availability which all complicate and often weaken the attribution analysis.

E: Climate analysis in the zones

Selection of spatial analysis zones

To assess the magnitude and direction of projected climate trends at a sub-regional scale it is useful to spatially aggregate gridded climate data over climatologically similar regions. As the Southeast Asian region represents a large, climatologically diverse area, it is also important to reflect this. Averaging the climate data by country borders is often not useful, as these do not reflect the climate and some countries may experience a range of climate types. Therefore, the region is divided into five spatial analysis zones that reflect the different climate types.

As mentioned in TRD Section A, the climate analysis was conducted at a sub-regional scale using five zones displayed in Figure E4. The IPCC AR6 WGI sub-continental analysis boxes for comparison are provided in Figure E2. This zonal approach uses a multidisciplinary integrated analysis which allows for transboundary climate-related risks to be examined at a sub-regional and regional scale within consideration of pre-existing socio-economic and environmental stressors which may act to amplify future climate risks. In this way, additional and new insights on climate-related risks for the region are described, beyond the information available from using the IPCC AR6 WGI reference regions. The following criteria were considered during selection of the zones:

1. **Political borders:** By considering political borders we can pair climatological data with socio-economic data for each country for the integrated analysis. However, where political boundaries traverse multiple geographical or climate features, the risk report zone boundary is informed by other criteria.
2. **Köppen-Geiger climate zones (Figure E1):** Ensures the climatological analysis is consistent across the zone and not averaged over many different climatological zones. The Risk Report zone selection distinguishes between these climatological zones in order to provide more tailored climate information for specific climate zones, regardless of political borders (e.g., Zones 1 and 2 share Myanmar, Lao PDR and Viet Nam).
3. **Major river basins and catchment areas:** Given the critical interest in water resources in this region, it is essential to account for changing climate to the entirety of the river basin. Zone 1 was extended north and east from Myanmar into China to capture the entire catchment of the upper Mekong River (known locally as Lancang River).
4. **Elevation:** Elevation is not captured in detail in the IPCC regions.

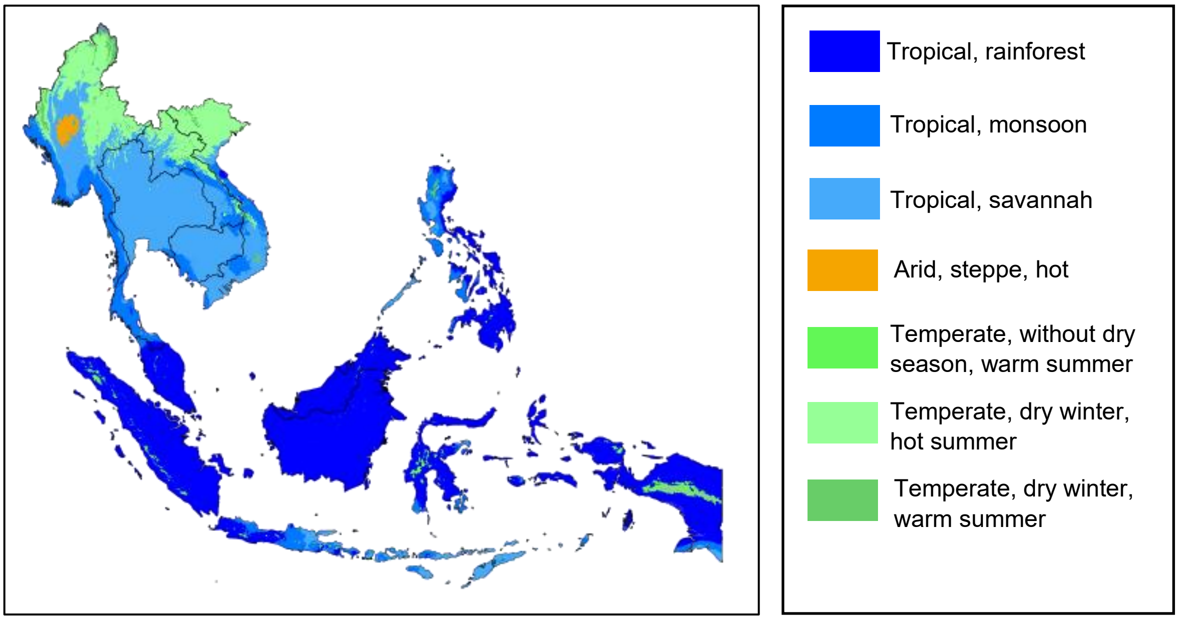

Figure E1: Köppen-Geiger climate classification map for the Southeast Asia region, adapted from Beck et al. (2018).

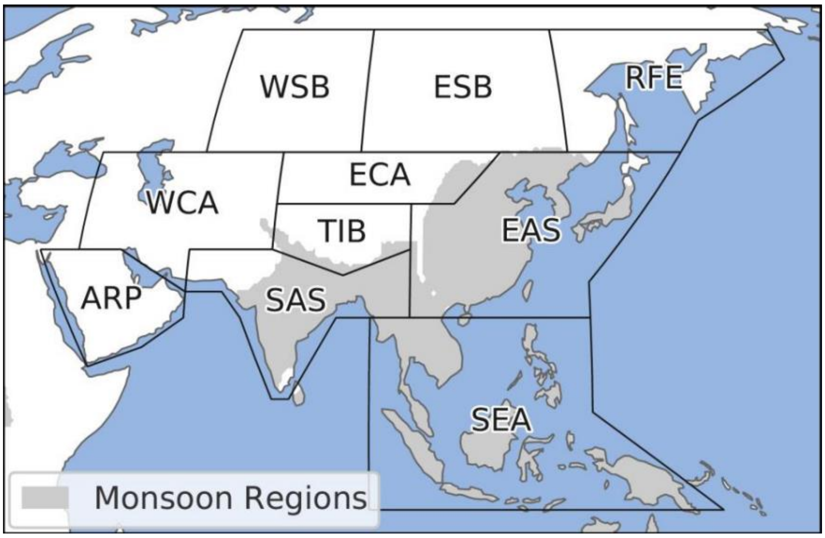

Figure E2: IPCC AR6 reference regions, as defined by WGI. Source: IPCC AR6 Regional Factsheet (2021) - Asia[11]

[11]IPCC Asia Factsheet (2021); https://www.ipcc.ch/report/ar6/wg1/downloads/factsheets/IPCC_AR6_WGI_Regional_Fact_Sheet_Asia.pdf

Table E1: Countries in the Southeast Asia region and the relevant spatial analysis zones.

Country	Climate analysis zones that cover that country
Brunei Darussalam	Zone 4
Cambodia	Zone 2
Indonesia	Zones 4 and 5
Lao PDR	Zones 1 and 2
Malaysia	Zone 4
Myanmar	Zones 1 and 2
Philippines	Zone 3
Singapore	Zone 4
Thailand	Zone 2
Timor-Leste	Zone 5
Viet Nam	Zones 1 and 2

Results from the zonal analysis

The bespoke climate data analysis conducted in the spatial analysis zones (Figure E4) focuses only on characterising the baseline climate of each zone and assessing the projected trends in annual and seasonal mean temperature and precipitation for the 2050s relative to the baseline period (1981-2010; see TRD Section A for detail on the data and methods). The current climate is represented by a baseline climatology for the period 1981 – 2010 (hereafter referred to as the 'baseline climate').

Maps of the baseline climatology with the zones overlaid are shown in Figure E3 below.

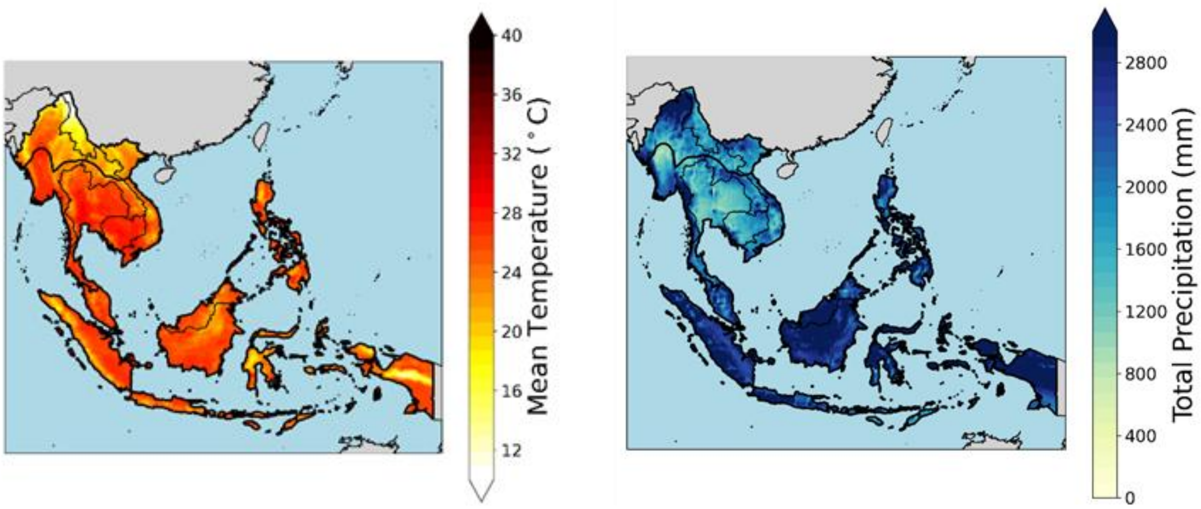

Figure E3: Baseline climate for the Southeast Asia region for the period 1981-2010 with the spatial analysis zones overlaid. Maps show climatological average values of annual mean total precipitation (mm/year; right panel) and annual mean temperature (°C; left panel). Temperature and precipitation data come from the ERA5 reanalysis dataset.

Other outputs from the bespoke zonal data analysis are presented in the following zone-specific sections. This includes time series plots for the baseline climate and scatter plots of the future climate model projections for the 2050s under RCP8.5 (see TRD Section A for detail on the data and methods).

The climate in context assessment at the zone scale includes this bespoke zonal data analysis, supplemented by regional findings from IPCC (2021), and the IPCC Interactive Atlas (Gutiérrez et al., 2021; as presented in the main report), and the socio-economic and geographic context to identify relevant impacts in each of the zones. Summaries of this assessment are provided in Tables E2-E6 in the following sections.

Climate analysis by zone

To assess the magnitude and direction of projected climate trends at a sub-regional scale the region is divided into five sub-regional spatial analysis zones that reflect the different climate types, as shown in Figure E4. The projected trends in these zones are summarised in Table E2.

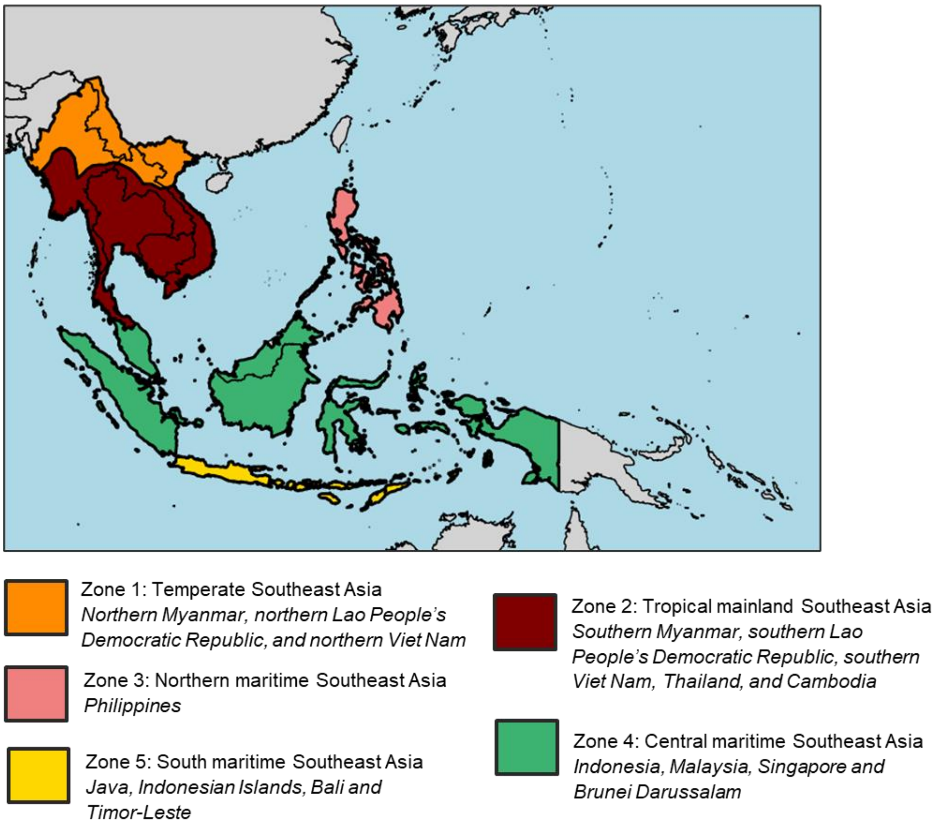

Figure E4: The five spatial analysis zones across the Southeast Asia region. Region countries as well as some Indonesian islands are listed.

Table E2: Summary of the zonal analysis for Southeast Asia. More detail is provided in Section E of the TRD. Climate types are defined in the TRD Section G – Technical Terms.

Zone	Countries included	Climate type	Future projections for the 2050s Headline Messages
Zone 1	Northern Myanmar, northern Lao PDR, and northern Viet Nam	Temperate climate	• Warming between 1 to 3.5 °C as annual temperatures increase with an increased frequency and intensity of heatwaves. • Medium confidence that the zone will become wetter on average primarily during SW monsoon (June-October). • Typhoons will continue to be a significant feature of the climate, although there may be a small reduction in frequency, but an increase in the intensity of the strongest typhoons.
Zone 2	Southern Myanmar, southern Lao PDR, southern Viet Nam, Thailand, and Cambodia	Tropical climate	• Warming between 1 to 3.5 °C as annual temperatures increase with an increased frequency and intensity of heatwaves. • Medium confidence that the zone will become wetter on average, mainly through the SW monsoon (June-October). • Typhoons will continue to be a significant feature of the climate, although there may be a small reduction in frequency, but an increase in the intensity of the strongest typhoons.
Zone 3	Philippines	Northern maritime climate	• Warming between 1 and 3 °C as annual temperatures increase with an increased frequency and intensity of heatwaves. • Consistent signal that the zone will be wetter on average during SW monsoon (June-October). • The high level of seasonal and interannual variability of precipitation is expected to continue. • Typhoons will continue to be a significant feature of the climate, although there may be a small reduction in frequency, but an increase in the intensity of the strongest typhoons.
Zone 4	Indonesia, Malaysia, Singapore and Brunei Darussalam	Central maritime climate	• Warming between 1 and 3 °C as annual temperatures increase with an increased frequency and intensity of heatwaves. • The zone will be wetter on average throughout year.

			• The high level of seasonal and interannual variability in precipitation is expected to continue. • Typhoons will continue to be a significant feature of the climate outside the near-equatorial zone, although there may be a small reduction in frequency, but an increase in the intensity of the strongest typhoons.
Zone 5	Indonesia, Timor-Leste	South maritime climate	• Warming between 1 and 3 °C as annual temperatures increase with an increased frequency and intensity of heatwaves. • Some evidence for the zone to become wetter on average during November to March but there is a lack of model consensus during June to October with both wetter and drier scenarios plausible. • Typhoons will continue to be a significant feature of the climate outside the near-equatorial zone, although there may be a small reduction in frequency, but an increase in the intensity of the strongest typhoons.

Zone 1: Temperate Southeast Asia

Zone 1 includes northern Myanmar, northern Lao PDR, and northern Viet Nam (Figure E5) and experiences a temperate climate. Plots of the baseline climate are shown in Figures E3 and E7. Scatter plots of the future projections are shown in Figure E7. The climate in context assessment for Zone 1 is summarised in Table E3.

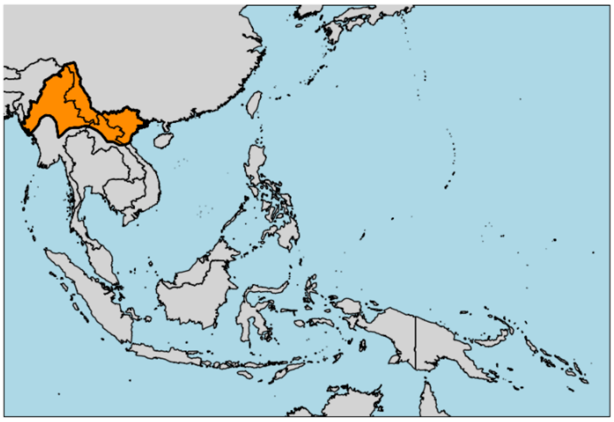

Figure E5: Zone 1.

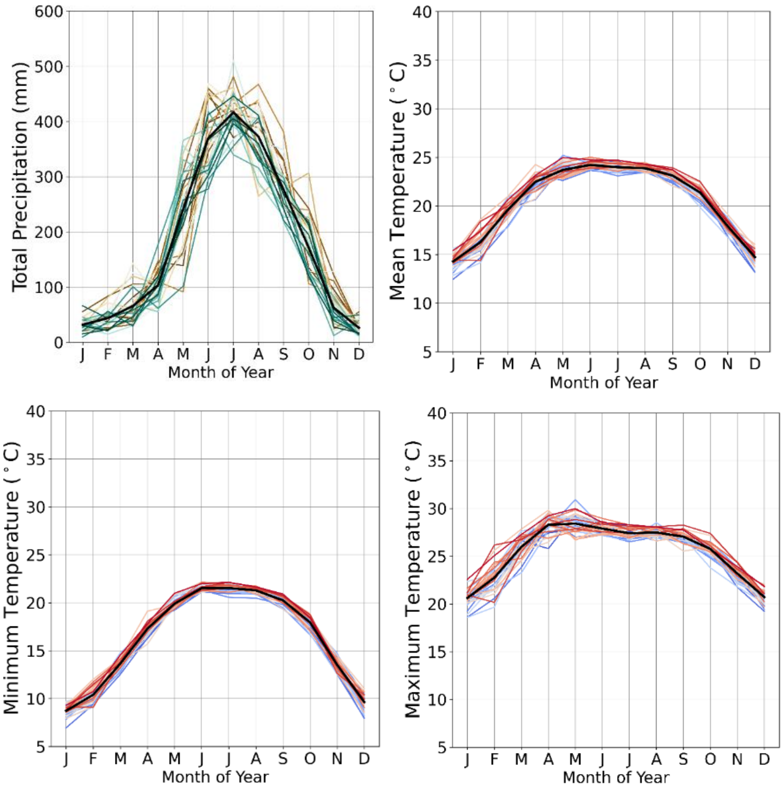

Figure E6: Observations of total monthly precipitation (a) and average daily mean (b), minimum (c) and maximum (d) temperature through 1981-2010 (baseline climate) for Zone 1. Each line is one individual year. Colours show the ordering of years from brown-green (total precipitation) and blue-red (mean temperature) – this highlights the presence, or lack of, a trend over the baseline climate. The bold black line indicates the average of the 30-year period.

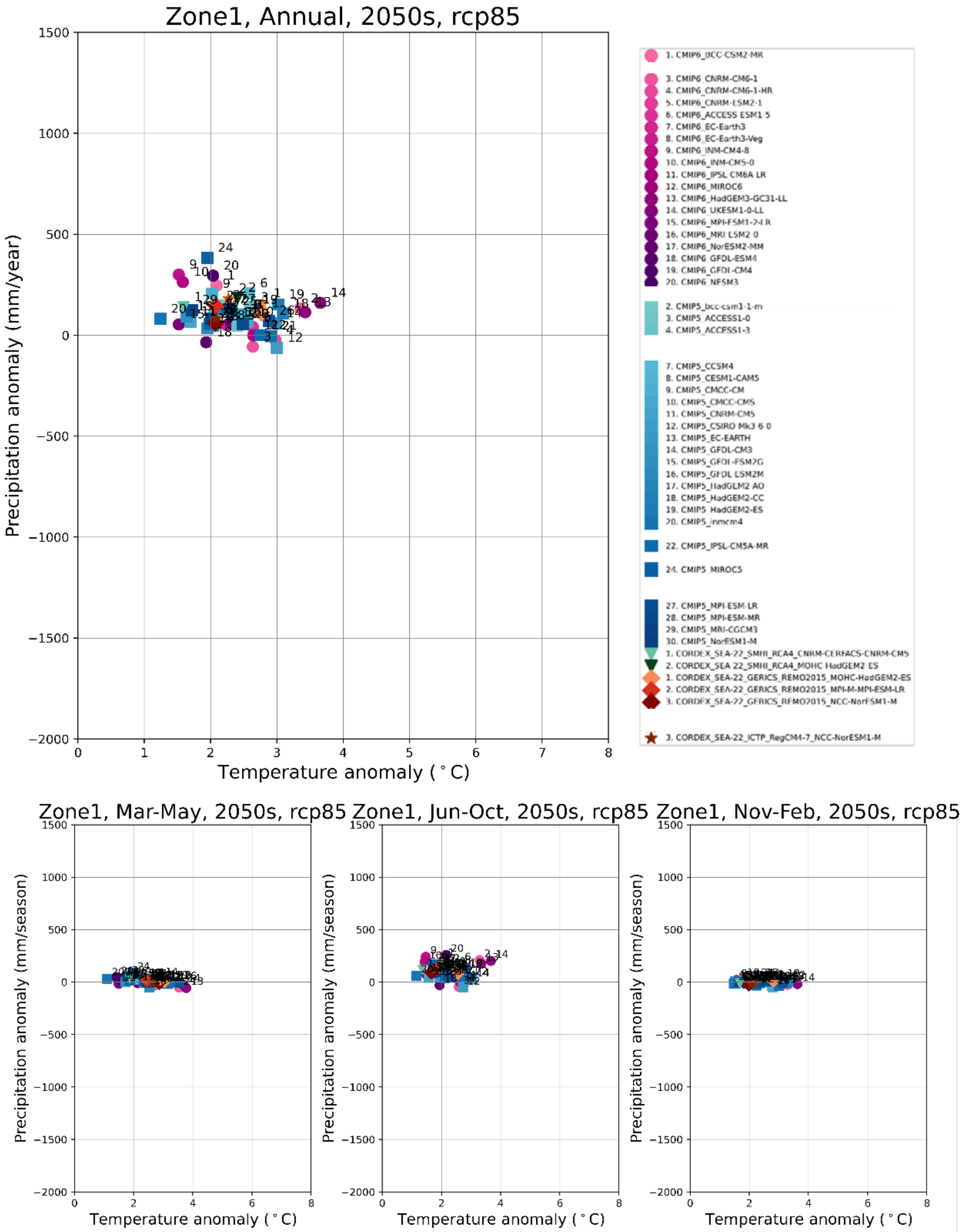

Figure E7: Projected change in average annual (top panel) and seasonal (bottom panels) precipitation and temperature in Zone 1. Each dot shows the difference between the average projected values in the 2050s and the average values in the current climate, for each climate model. Individual models are identified by the icon and number in the legend.

Table E3: Climate in context analysis for Zone 1		
Baseline (1981-2010)	Current climate	• Daily mean temperatures typically range from 12°C to 25°C through the year with daily maximums exceeding 27°C during the hottest months (April to June). • Zone 1 receives 300-400mm of precipitation between May and September. • There is a very pronounced annual cycle for precipitation whereas temperature ranges are less variable. • Zone 1 has experienced a warming trend with the largest increases during the dry season (November to March) and a drying trend, particularly over higher altitude areas.
	Context	• Zone 1 includes the South China Sea to the east and Bay of Bengal to the west. The north of the zone is mountainous. The Red River occupies east of the zone and the Irrawaddy River the west. The Salween and Mekong rivers run through the middle of the zone. • Key climate sensitivities include the impact of heat extremes and rainfall variability on crops, heat stress on humans and the environment, and the impact of rising sea surface temperatures on coral reef habitats.
In the 2050s Zone 1 is projected to be warmer and wetter on average		
Future projections (2050s)	Climate trends	• There is high confidence for a warming trend between 1°C and 3.5°C in the future. • There is medium confidence that the zone will become wetter on average, primarily during the Southwest Monsoon months (June to October). • It is virtually certain that sea levels will continue to rise. • Extreme rainfall is expected to increase across the zone while the trend in number of consecutive dry days shows a reduction across most of the region except across Vietnam where an increase is expected. • Typhoons will continue to be a significant feature of the climate, although there may be a small reduction in frequency and an increase in the intensity of the strongest typhoons.
	Relevant impacts	• Rice agriculture will become more vulnerable due to increasing temperatures and increasing rainfall variability, in particular for locations where crops are rainfed rather than irrigated, (Myanmar, Lao PDR, Viet Nam). • Increased risk to aquaculture from typhoons, storm surges, flooding and heatwaves possibly including marine heatwaves (Myanmar, Viet Nam). • Increased risk to water quality from climate-induced changes, exacerbated by flooding and rising temperatures (Myanmar, Lao PDR). • Increased risk of diarrhoeal disease due to reduced water quality caused by rising temperatures and changes in rainfall (Myanmar, Lao PDR). • Increased risk of high heat-humidity stress as temperatures rise. Impacts will fall disproportionately on women (particularly Lao PDR) and the elderly (particularly Viet Nam). • Increased risk of summer nighttime hot extremes (‘tropical nights’) posing significant risks to health (Myanmar, Lao PDR, Viet Nam). • Increased climate risks and poverty as informal settlements increase in number and increasingly overlap with urban areas (Myanmar). • Reduced efficiency of solar energy outputs due to hotter conditions generally reducing efficiency of PV panels (Myanmar). • Increased economic and social risk due to climate-related hydropower insecurity (Myanmar, Lao PDR, Viet Nam). • Increased risk to coral reef habitats and biodiversity due to rising sea surface temperatures and extreme weather events (Myanmar, Lao PDR, Viet Nam).

Zone 2: Tropical continental Southeast Asia

Zone 2 includes southern Myanmar, southern Lao PDR, southern Viet Nam, Thailand, and Cambodia (Figure E8) and experiences a tropical climate. Plots of the baseline climate are shown in Figures E3 and E9. Scatter plots of the future projections are shown in Figure E10. The climate in context assessment for Zone 2 is summarised in Table E4.

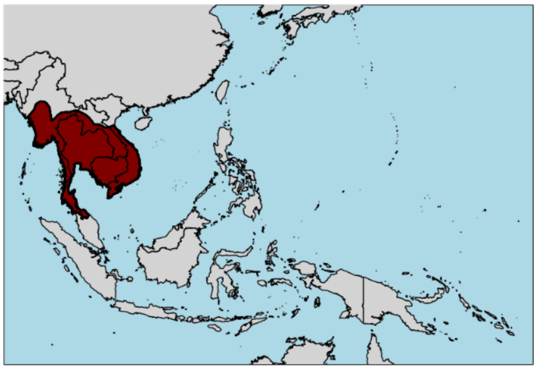

Figure E8: Zone 2.

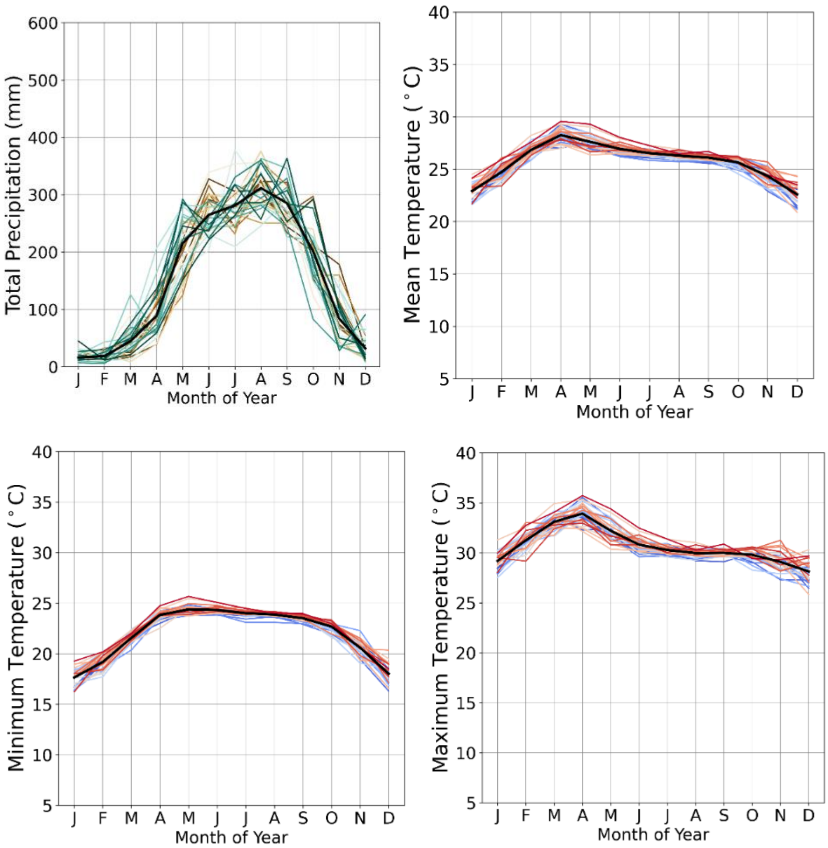

Figure E9: Observations of total monthly precipitation (a) and average daily mean (b), minimum (c) and maximum (d) temperature through 1981-2010 (baseline climate) for Zone 2. Each line is one individual year. Colours show the ordering of years from brown-green (total precipitation) and blue-red (mean temperature) – this highlights the presence, or lack of, a trend over the baseline climate. The bold black line indicates the average of the 30-year period.

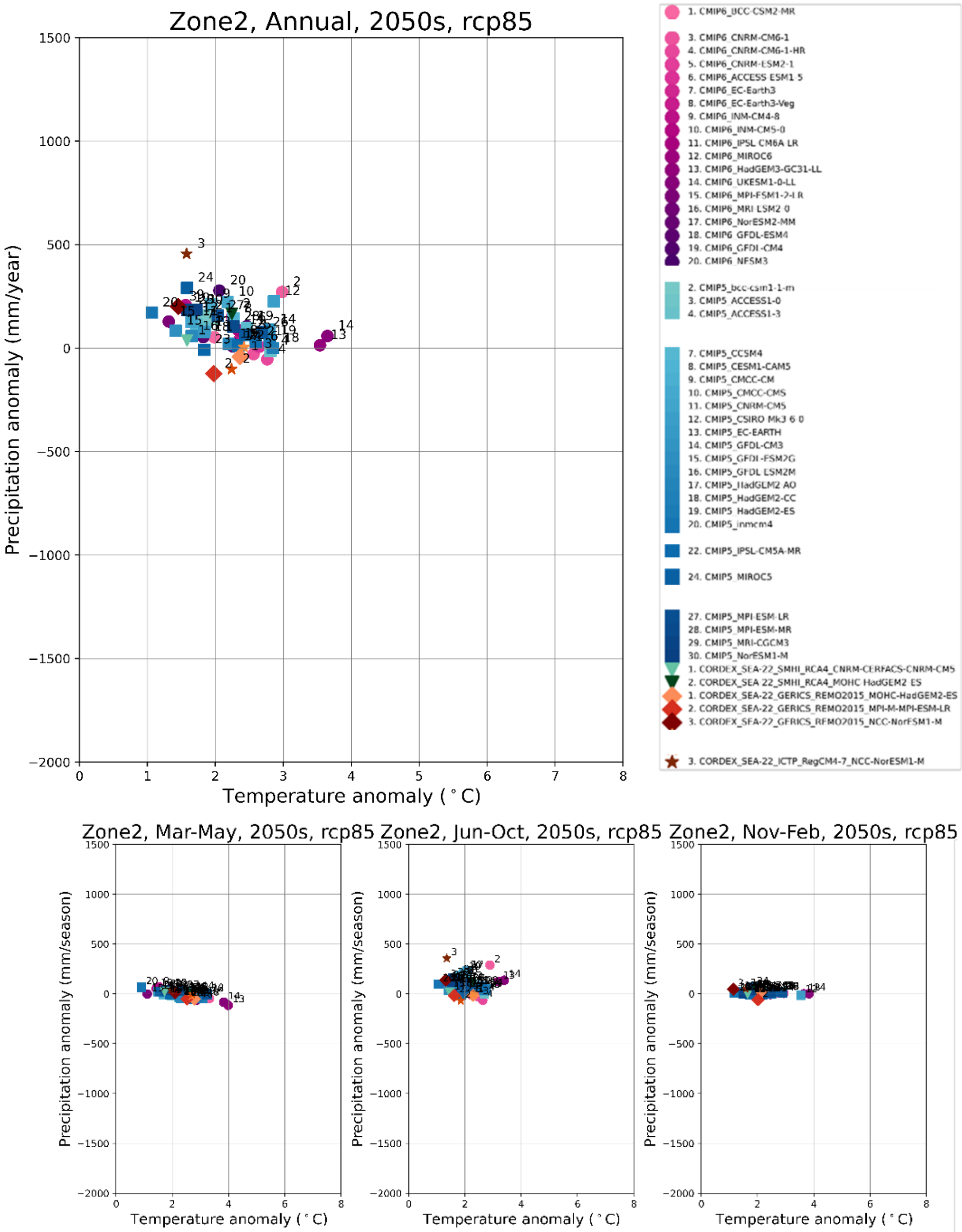

Figure E10: Projected change in average annual (top panel) and seasonal (bottom panels) precipitation and temperature in Zone 2. Each dot shows the difference between the average projected values in the 2050s and the average values in the current climate, for each climate model. Individual models are identified by the icon and number in the legend.

<table>
<tr><th colspan="3">Table E4: Climate in context analysis for Zone 2</th></tr>
<tr><td rowspan="2">Baseline (1981-2010)</td><td>Current climate</td><td>• Daily mean temperatures typically range from 22°C to 29°C through the year, with daily maximums regularly exceeding 30°C throughout the year and exceeding 35°C during the hottest month (April).
• Zone 2 receives 200-350mm of precipitation between the months May to October with a dry season which runs November to March.
• Zone 2 has experienced a warming trend through the year and a wetting trend over much of the zone except the central region of Cambodia and Thailand where there has been a drying trend.</td></tr>
<tr><td>Context</td><td>• Zone 1 includes the South China Sea to the east and Bay of Bengal to the west. There are some higher elevation areas on the outer extents of the zone and lower elevation areas in the middle of the zone. The Mekong River occupies east of the zone while the Salween and Irrawaddy rivers occupy west of the zone.
• Key climate sensitivities include the impact of heat extremes and rainfall variability on crops, heat stress on humans and the environment, and the impact of rising sea surface temperatures on coral reef habitats. Impacts are particularly prevalent for the Mekong delta.</td></tr>
<tr><th colspan="3">In the 2050s Zone 2 is projected to be warmer and wetter on average</th></tr>
<tr><td rowspan="2">Future projections (2050s)</td><td>Climate trends</td><td>• There is high confidence for a warming trend between 1°C and 3.5°C in the future.
• There is medium confidence that the zone will become wetter on average, mainly through the Southwest Monsoon months (June to October).
• Extreme rainfall is expected to increase across the zone while the trend in number of consecutive dry days shows a reduction across most of the region except across the Malay Peninsula where a small increase is expected.
• It is virtually certain that sea levels will continue to rise.
• Typhoons will continue to be a significant feature of the climate, although there may be a small reduction in their frequency but an increase in the intensity of the strongest typhoons.</td></tr>
<tr><td>Relevant impacts</td><td>• Rice agriculture will become more vulnerable due to increasing temperatures and rainfall changes (Myanmar, Lao PDR, Viet Nam, Cambodia, Thailand). For Viet Nam, this is particularly prevalent in the Mekong delta where most of the country's rice is produced.
• Agricultural droughts (lack of soil moisture) have a major impact on rainfed crop production (Myanmar, lower Mekong region).
• Increased risk to rice crop yields and economic returns resulting from higher temperatures and droughts in the lower Mekong basin (Lao PDR, Thailand, Cambodia, Viet Nam).
• Increased risk to aquaculture from typhoons, storm surges, flooding and heatwaves including marine heatwaves (Myanmar, Viet Nam).
• Increased risk to water quality due to extreme rainfall events exacerbated by flooding and rising temperatures (Myanmar, Lao PDR).
• Increased risk to river flows in the Mekong basin driven by dam construction will be amplified by rising temperatures and increased rainfall variability. These risks also drive increased water demand.
• Increased risk of summer nighttime hot extremes impacting health (Myanmar, Lao PDR, Viet Nam).
• Increased risk of riverine and coastal flooding in delta areas, such as the Mekong Delta.
• Reduced efficiency of solar energy outputs due to hotter conditions generally reducing efficiency of PV panels (Myanmar).
• Increased economic and social risk due to climate-related hydropower insecurity (Myanmar, Lao PDR, Viet Nam).
• Deforestation driven by agricultural expansion, bio-fuels and cutting timber, threaten forest cover, particularly the tropical dry forests of the Mekong region which are among the most fragmented, impacting biodiversity.
• Increased risk to coral reef habitats and biodiversity due to rising sea surface temperatures and extreme weather events (Myanmar, Lao PDR, Viet Nam).</td></tr>
</table>

Zone 3: Northern maritime Southeast Asia

Zone 3 includes Philippines (Figure E11) and experiences a tropical climate. Plots of the baseline climate are shown in Figures E3 and E12. Scatter plots of the future projections are shown in Figure E13. The climate in context assessment for Zone 3 is summarised in Table E5.

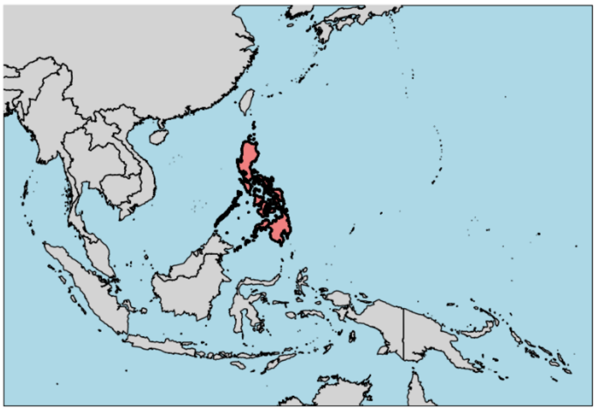

Figure E11: Zone 3.

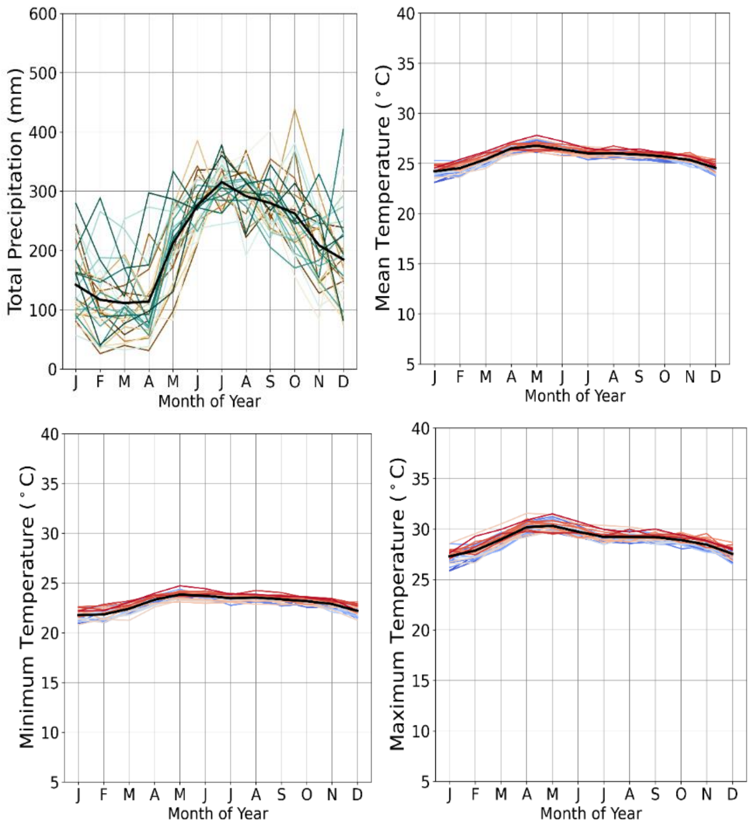

Figure E12: Observations of total monthly precipitation (a) and average daily mean (b), minimum (c) and maximum (d) temperature over the baseline period (1981-2010) for Zone 3. Figure E12: Observations of total monthly precipitation (a) and average daily mean (b), minimum (c) and maximum (d) temperature over through 1981-2010 (baseline climate) for Zone 3. Each line is one individual year. Colours show the ordering of years from brown-green (total precipitation) and blue-red (mean temperature) – this highlights the presence, or lack of, a trend over the baseline climate. The bold black line indicates the average of the 30-year period.

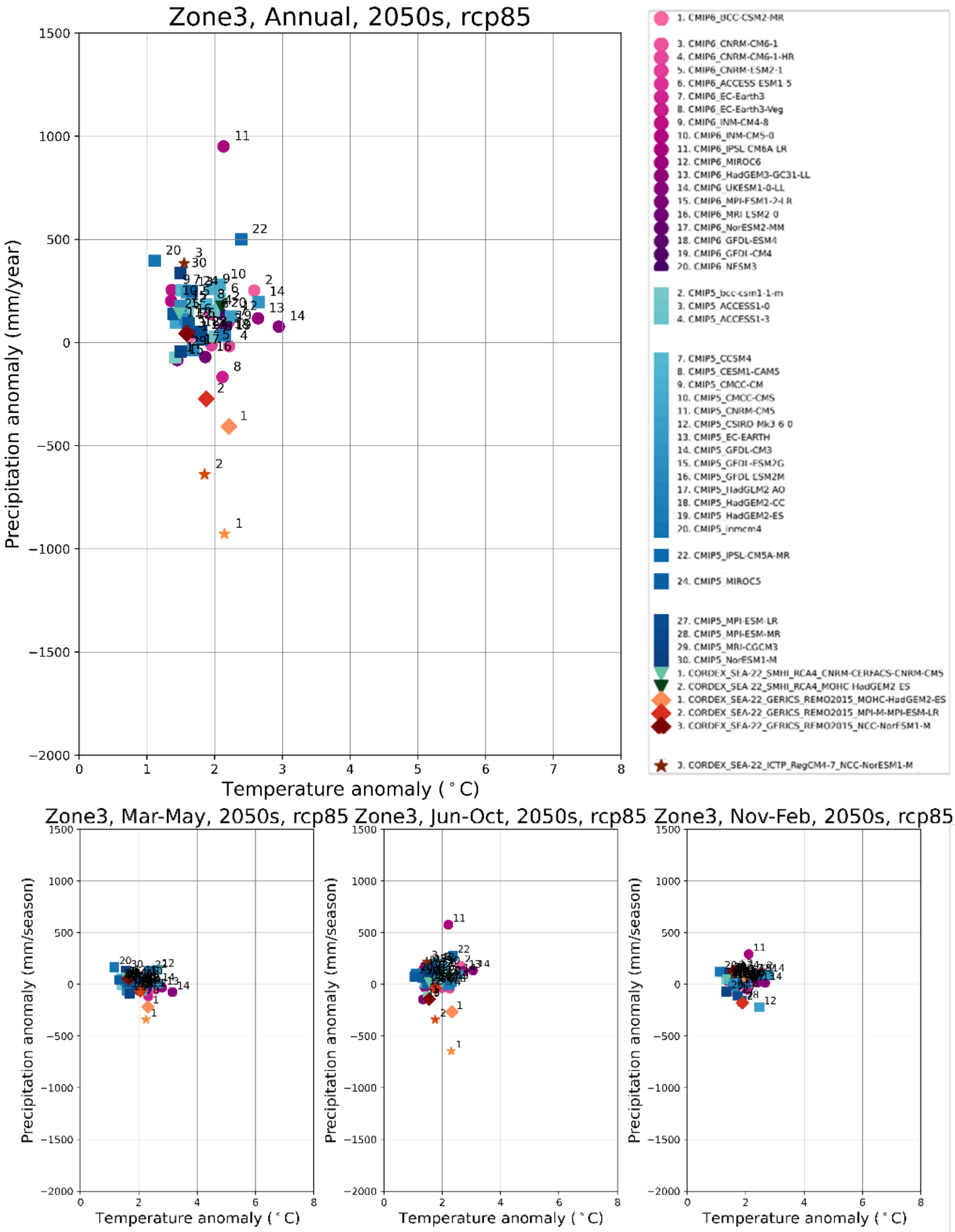

Figure E13: Projected change in average annual (top panel) and seasonal (bottom panels) precipitation and temperature in Zone 3. Each dot shows the difference between the average projected values in the 2050s and the average values in the current climate, for each climate model. Individual models are identified by the icon and number in the legend.

Table E5: Climate in context analysis for Zone 3		
Baseline (1981-2010)	Current climate	• Daily mean temperatures typically range from 23°C to 27°C through the year with daily maximums exceeding 30°C during the hottest months (April to June). • Zone 3 can receive as much as 400mm of precipitation annually but typically receives 250-350mm during the monsoon season between May to October. The seasonality of precipitation is pronounced but there is high variability from year to year. • Zone 3 has experienced a warming trend through the year and a drying tendency in the dry season and a significant wetting trend in the wet season (monsoon).
	Context	• Zone 3 includes the Philippine Sea to the east and the South China Sea to the west. Zone 3 includes Mount Pinatubo in the north, Mayon Volcano in the mid-north, and Mount Apo to the south. • Key climate sensitivities include heat stress to health and crops, variable rainfall and rising temperatures impacting water quality, hot extremes on health, sea level rise resulting in coastal flooding to infrastructure and the environment, and sea surface temperatures and typhoons negatively impacting the marine environment and biodiversity.
In the 2050s Zone 3 is projected to be warmer and most likely wetter on average		
Future projections (2050s)	Climate trends	• There is high confidence for a warming trend between 1°C and 3°C in the future. • There is medium confidence that the zone will become wetter on average, but in contrast to zones 1 and 2, this increase is spread more evening throughout the year. • The high level of seasonal and interannual rainfall variability is expected to continue due to Typhoon activity, which will also bring higher rainfall rates, both in intensity and in event totals over a given area. Due to the increase in background rainfall, typhoons are likely to represent a smaller proportion of the overall annual rainfall. • Extreme rainfall is expected to increase while the number of consecutive dry days is expected to also increase, although the latter signal is not very clear for Zone 3. • It is virtually certain that sea levels will continue to rise. • Typhoons will continue to be a significant feature of the climate, although there may be a small reduction in their frequency but an increase in the intensity of the strongest typhoons.
	Relevant impacts	• Increased risk to crop production, yields, and economy (particularly rice) due to heat stress. • Increased risk to production and income of aquaculture due to increasing sea surface temperatures, marine heatwaves, typhoons, storm surges, and flooding. • Increased risk of periodic hunger due to higher risks to crops, livestock and fisheries. • Increased risk to water quality due to more intense rainfall events and flooding, and potentially more hydrological droughts. • Rising temperatures and heavy rainfall will increase risks from diarrhoeal disease. • Increased risk of hot extremes and high overnight temperatures impacting health. • Increased climate risks and poverty as informal settlements increase in number and increasingly overlap with urban areas. • Increased risk to coastal cities (Manila) due to extreme events (floods and typhoons) which are expected to increase in intensity. • Increased risk from sea level rise, increasing the risk of coastal flooding, impacting coastal infrastructure such as roads and buildings. • Increased risk to electricity transmission due to extreme weather events including heavy rainfall and strong winds which may damage critical infrastructure. • Increased risk to habitats suitable for dominant tree species due to higher temperatures and other climatic impacts (e.g., rainfall variability). • Rising sea levels and extreme weather events threaten coral reef habitats. Rising sea levels could jeopardise mangrove survivability due to inundation of sea water. • Rising sea surface temperatures increase risk to seagrasses and thereby reduce the health of fisheries (Philippines relies on these habitats as nurseries for economically important fish). • Intensifying typhoons are likely to disproportionately affect smaller artisanal fishers due to their lower adaptive capacity and limited coastal protection compared with other larger fishing fleets with port infrastructure.

Zone 4: Central maritime Southeast Asia

Zone 4 includes Indonesia, Malaysia, Singapore, and Brunei Darussalam (Figure E14) and experiences a tropical climate. Plots of the baseline climate are shown in Figures E3 and E15. Scatter plots of the future projections are shown in Figure E16. The climate in context assessment for Zone 4 is summarised in Table E6.

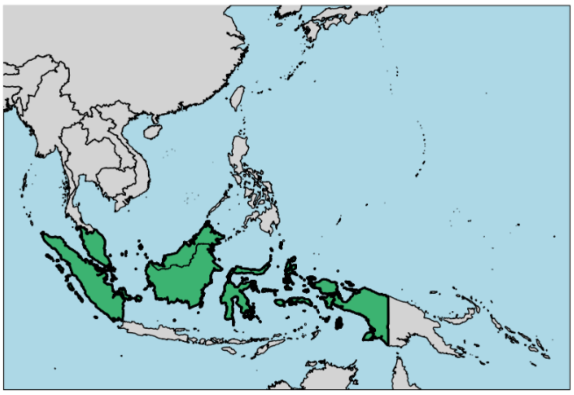

Figure E14: Zone 4.

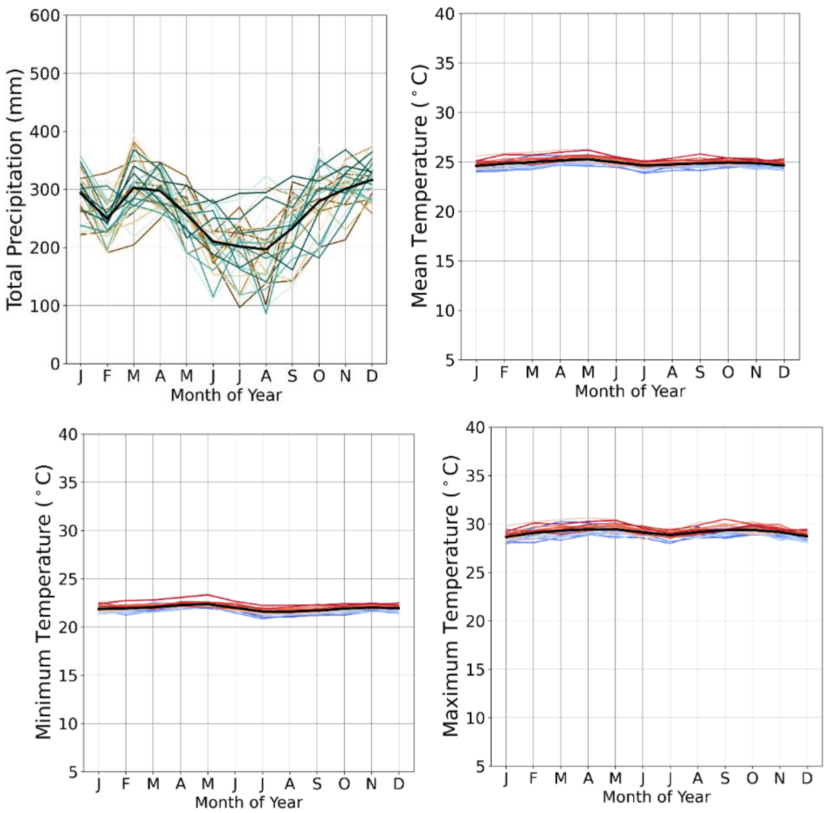

Figure E15: Observations of total monthly precipitation (a) and average daily mean (b), minimum (c) and maximum (d) temperature over the baseline period (1981-2010) for Zone 4. Figure E15: Observations of total monthly precipitation (a) and average daily mean (b), minimum (c) and maximum (d) temperature over through 1981-2010 (baseline climate) for Zone 4. Each line is one individual year. Colours show the ordering of years from brown-green (total precipitation) and blue-red (mean temperature) – this highlights the presence, or lack of, a trend over the baseline climate. The bold black line indicates the average of the 30-year period.

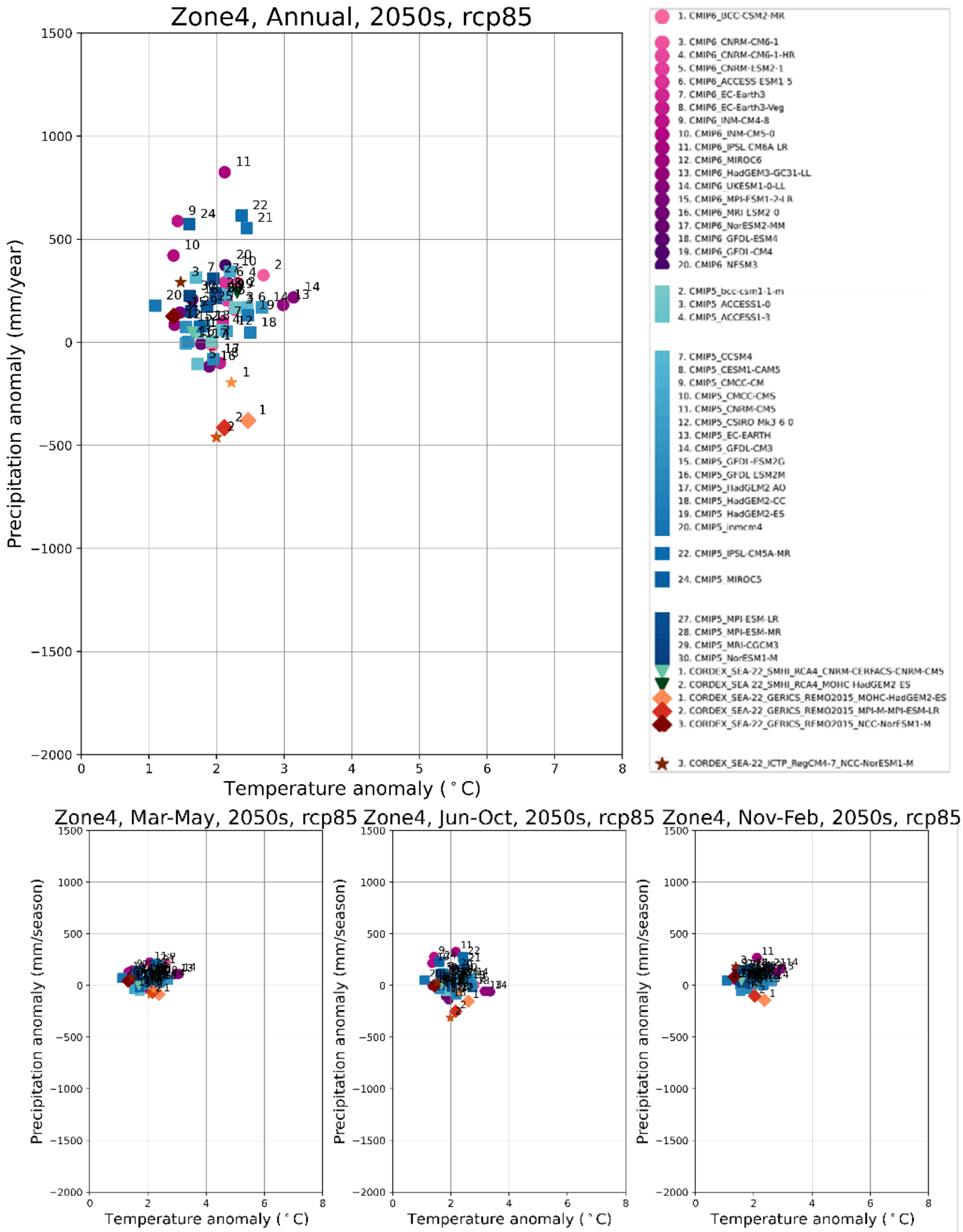

Figure E16: Projected change in average annual (top panel) and seasonal (bottom panels) precipitation and temperature in Zone 4. Each dot shows the difference between the average projected values in the 2050s and the average values in the current climate, for each climate model. Individual models are identified by the icon and number in the legend.

Table E6: Climate in context analysis for Zone 4		
Baseline (1981-2010)	Current climate	• Daily mean temperatures are close to 25°C throughout the year with daily maximums exceeding 30°C through the year. • Zone 4 receives 250-400mm of precipitation between October and April. The seasonality of precipitation is pronounced but there is high variability from year to year. • Zone 4 has experienced a warming trend and for precipitation, observational datasets show a wetting trend. The rate of increase in annual rainfall is greatest over eastern regions of Indonesia.
	Context	• Zone 4 includes the Java Sea, Banda Sea and Celebes Sea to the east and the Bay of Bengal and Indian Ocean to the west. Other points of interest include Mount Tahan, Taman Negara National Park, Cameron Highlands in the Malay Peninsula, Batu Hill in Sarawak in Borneo, and Mount Kinabalu which is the highest mountain in Borneo and Malaysia. • Key climate sensitivities include hot extremes on health, high sea surface temperatures and marine heatwaves on marine ecosystems and fisheries, sea level rise on coastal infrastructure, and rising temperatures on electricity and cooling systems demand.
In the 2050s Zone 4 is projected to be warmer on average		
Future projections (2050s)	Climate trends	• There is high confidence for a warming trend between 1°C and 3°C in the future. • Whilst there is uncertainty in the magnitude of increased annual precipitation (see 'Notes on precipitation projections' on page 10 of this report for further details), an overall increase is considered the most plausible outcome, especially from November to June. The high level of seasonal and interannual rainfall variability is expected to continue. • Extreme rainfall is expected to increase while the number of consecutive dry days are also expected to increase. • It is virtually certain that sea levels will continue to rise. • Typhoons will continue to occasionally threaten the far north of this zone (Malaysia and Brunei).
	Relevant impacts	• Increases in the intensity and frequency of hot extremes and high overnight temperatures pose significant risks to health (Indonesia, Malaysia, Singapore, Brunei Darussalam). • Increased risk to marine species, particularly corals, due to rising sea surface temperatures and marine heatwaves (Indonesia, Malaysia, Singapore, Brunei Darussalam). • Increased risk of seagrass mortality due to rising sea surface temperatures. • Increased risk to coastal settlements (Indonesia, Malaysia, Singapore). Agriculture, fishing, port and other coastal infrastructure are exposed to risks from storms and coastal floods from rising sea levels leading to subsequent economic losses. • Increased risk from marine heatwaves (Indonesia, Malaysia, Singapore, Brunei Darussalam) impacting marine species and biodiversity, especially corals. • Increase risk of diarrhoeal disease due to higher temperatures (Indonesia especially) producing more optimal conditions for diseases to thrive. This also increases demand for clean water. • Increase risk to undernutrition levels, especially of children (Indonesia especially) from decreased crop yields from rising temperatures and extreme rainfall events (droughts/flooding). • Increased climate risks and poverty as informal settlements increase in number and increasingly overlap with urban areas. • Increased demand for cooling as temperatures, droughts and heatwaves increase, increasing risks to electricity supplies and of blackouts. • Deforestation driven by agricultural expansion, demand for bio-fuels and cutting timber, threaten forest cover, impacting biodiversity (especially Indonesia which has the most tree species in the region). • Increased risks to wetlands and peatlands due to land-use changes for agriculture, and increased incidence of fires. • Rising sea levels and extreme weather events threaten coral reef habitats. Rising sea levels could jeopardise mangrove survivability due to inundation of sea water.

Zone 5: South maritime Southeast Asia

Zone 5 includes Timor-Leste (Figure E17) and experiences a tropical climate. Plots of the baseline climate are shown in Figures E3 and E18. Scatter plots of the future projections are shown in Figure E19. The climate in context assessment for Zone 5 is summarised in Table E7.

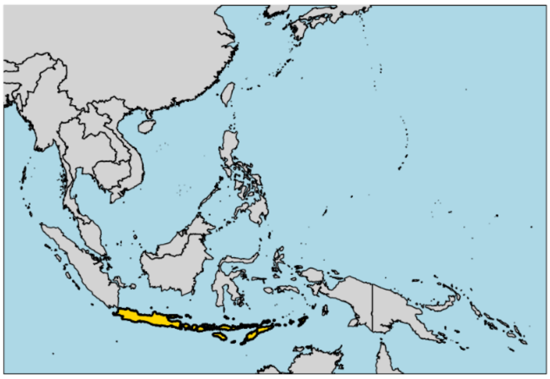

Figure E17: Zone 5.

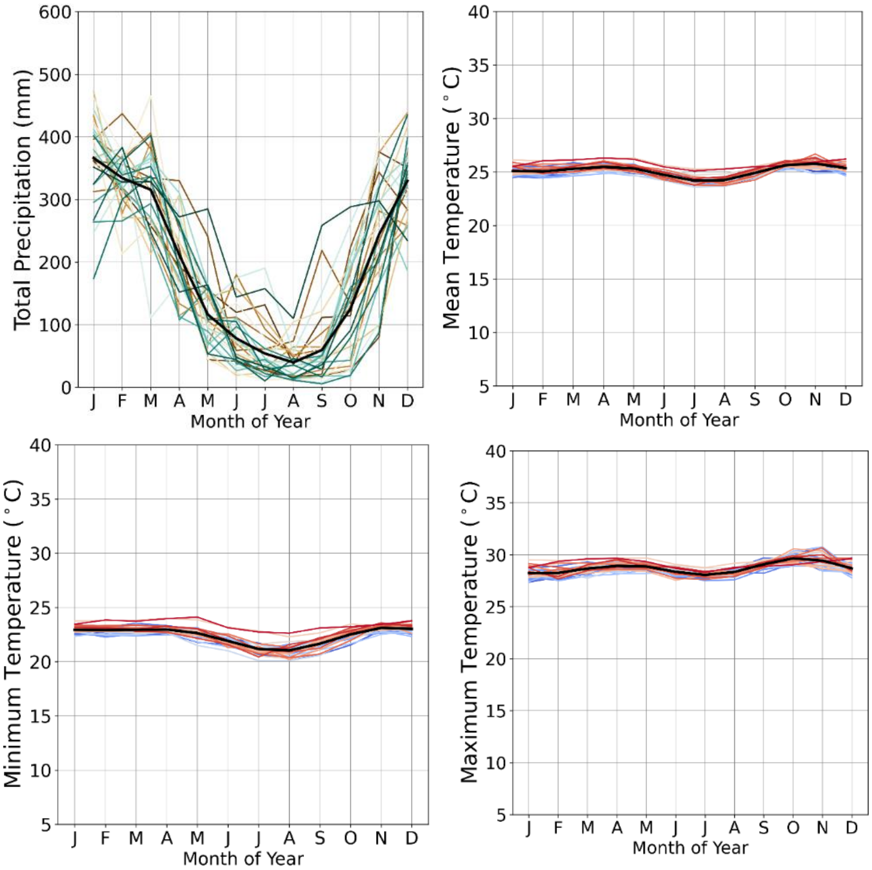

Figure E18: Observations of total monthly precipitation (a) and average daily mean (b), minimum (c) and maximum (d) temperature over the baseline period (1981-2010) for Zone 5. Figure E18: Observations of total monthly precipitation (a) and average daily mean (b), minimum (c) and maximum (d) temperature over through 1981-2010 (baseline climate) for Zone 5. Each line is one individual year. Colours show the ordering of years from brown-green (total precipitation) and blue-red (mean temperature) – this highlights the presence, or lack of, a trend over the baseline climate. The bold black line indicates the average of the 30-year period.

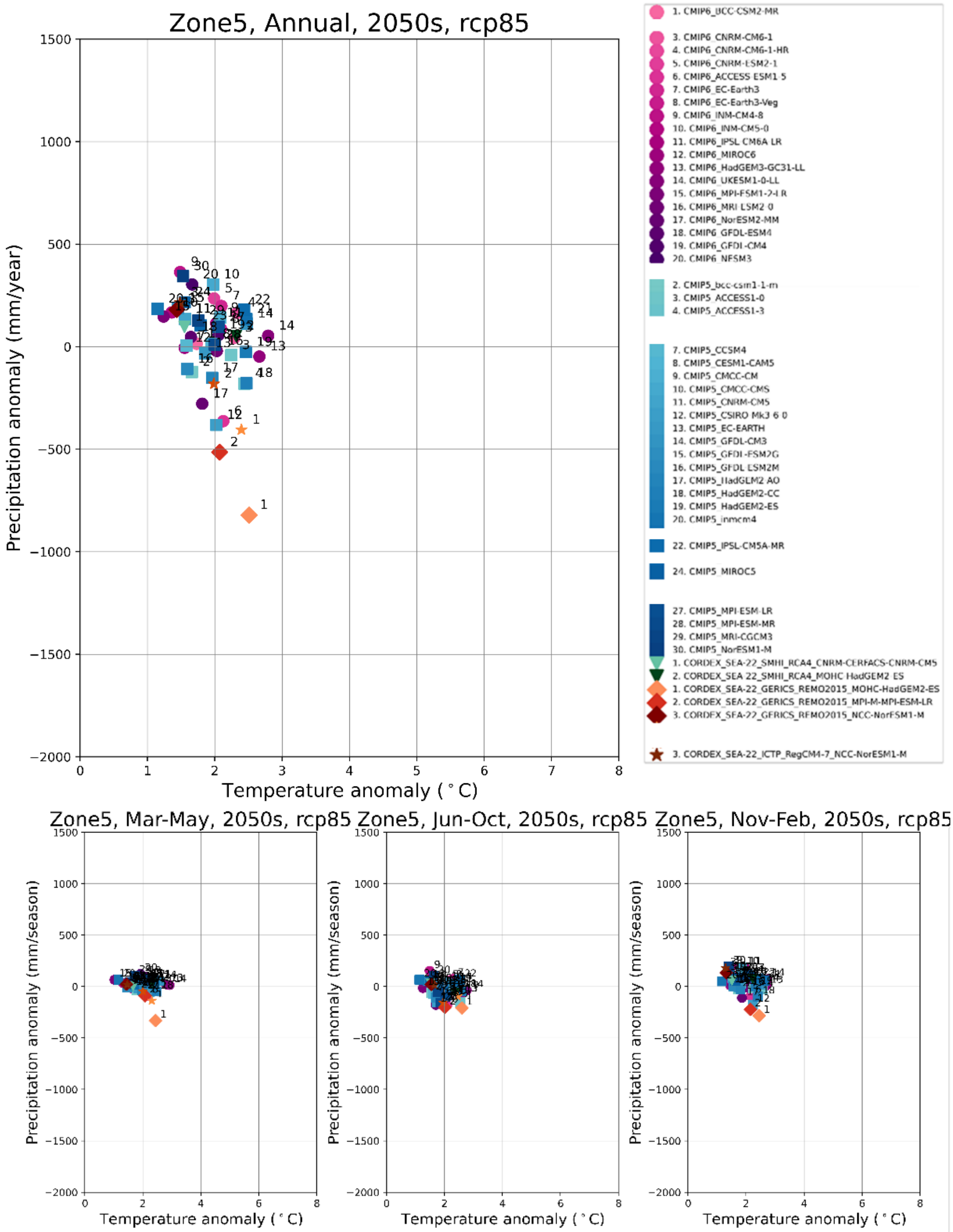

Figure E19: Projected change in average annual (top panel) and seasonal (bottom panels) precipitation and temperature in Zone 5. Each dot shows the difference between the average projected values in the 2050s and the average values in the current climate, for each climate model. Individual models are identified by the icon and number in the legend.

Table E7: Climate in context analysis for Zone 5		
Baseline (1981-2010)	Current climate	• Daily mean temperatures are close to 25°C throughout the year with daily maximums exceeding 30°C during the hottest months (October to November). • Zone 5 receives 300-450mm of precipitation between November and March with a distinct drier season between June to September with very low precipitation. • Zone 5 has experienced a warming trend during the wet season (November to March) and no observed change during the dry season (June to September). Zone 5 has experienced a notable drying trend through the year.
	Context	• Zone 5 includes the Java Sea and Banda Sea to the east and the Indian Ocean to the west. Other notable geographic features include Mount Ramelau in Timor-Leste and the Loes, Laklo and Seical rivers in Timor-Leste. • Key climate sensitivities include rising temperatures on water quality (health), compounded with changing rainfall patterns and heavy rainfall events and flooding on disease risk, hot extremes on health, rising sea levels on coastal flooding, and increasing sea surface temperatures on marine fisheries.
In the 2050s Zone 5 is projected to be warmer on average		
Future projections (2050s)	Climate trends	• There is high confidence for a warming trend between 1°C and 3°C in the future. • There is evidence for the zone to become wetter on average during the November to March wet season, but there is a lack of model consensus during the June to October dry season with both wetter and drier scenarios plausible. • Extreme rainfall is expected to increase while the number of consecutive dry days are also expected to increase. • It is virtually certain that sea levels will continue to rise. • Typhoons will continue to be a significant feature of the climate, although there may be a small reduction in their frequency but an increase in the intensity of the strongest typhoons.
	Relevant impacts	• Increased risk to water quality, exacerbated by flooding and rising temperatures, pose major risks to health. • Increased risk to diarrhoeal disease due to rising temperatures and changing rainfall patterns (e.g., heavy rainfall events and flooding) producing more optimal conditions for diseases to thrive. This also increases demand for clean water. • Increased risk to undernutrition levels, especially children under five years old. • More intense and frequent hot extremes and high overnight temperatures pose significant risks to health. • Increased risk particularly to informal (outdoor) labourers due to high heat exposure, especially during the hottest summer months. The elderly, infants, pregnant women are some of the most vulnerable to these risks. • Increased risk of coastal flooding due to rising sea levels (particularly Dili, capital city). • Increased risk to marine fisheries, through increased sea surface temperatures and marine heatwaves (key source of livelihoods in Timor-Leste).

F: Socio-economic data

Table F1: Demographic, economic, climate readiness and poverty data. Data sources and notes outlined below table. Instances of "pop" refer to population; "agric" to agriculture; and "insec" to insecurity.

	Demographics				Economics					Food security	
Country	**Total pop (M)**	**Pop growth/yr (%)**	**Rural pop (%)**	**Urban slum (%)**	**GDP/ capita (USD)**	**Annual GDP growth (%)**	**Agric GDP (%)**	**Below USD3.65 (%)**	**Below USD2.15 (%)**	**Food insec (%)**	**Food insec trend**
Myanmar	54.2	0.7	68	58	1096	3.0	20.3	19.7	2.0	29.3	Up
Lao PDR	7.5	1.4	62	22	2088	2.7	14.6	32.5	7.1	34.1	Up
Thailand	71.7	0.1	47	7	6909	2.6	8.8	0.6	0.1	7.1	Up
Viet Nam	98.2	0.7	61	6	4164	8.0	11.9	3.8	0.7	9.0	Up
Cambodia	16.8	1.1	75	40	1787	5.1	21.9	NA	NA	51.1	Up
Malaysia	33.9	1.1	22	NA	11972	8.7	8.9	0.2	0	16.0	Up
Singapore	5.6	3.3	0	NA	82808	3.6	0	NA	NA	6.6	Up
Brunei D	0.4	0.8	21	NA	37152	-1.6	1.1	NA	NA	NA	NA
Philippines	115.6	1.5	52	37	3499	7.6	9.5	17.8	3.0	44.7	Up
Indonesia	275.5	0.6	42	19	4788	5.3	12.3	20.2	2.5	4.9	Down
Timor-Leste	13.4	1.5	68	34	2358	-17.5	8.6	43.3	24.4	NA	NA
Total	*692.8*	-	-	-	-	-	-	-	-	-	-
Regional %	-	-	*49*	-	-	-	-	-	-	-	-

Data sources and notes:

Demographics

- *Total population, rural population, population growth rate: UN World Population Prospects, 2022 data (World Bank, 2022).*
- *Slum population: UN-HABITAT 2020 data (World Bank, 2022). Note: represents proportion of urban population living in slum households, defined as households lacking >1 basic conditions (improved water and sanitation, sufficient living area, housing durability, secure tenure).*

Economics, poverty

- *GDP/capita, growth and agric as a % GDP: World Bank 2022 data (World Bank, 2022). Note: countries shaded red defined as low income (GDP/cap <USD1085), orange lower-middle income (GDP/cap USD1086 – USD4255) and yellow upper-middle income (USD4256 – USD13,205) (World Bank, 2022).*
- *Poverty: World Bank data for 2022 (Indonesia), 2021 (Thailand, Philippines), 2020 (Viet Nam), 2018 (Laos PDR, Malaysia), 2017 (Myanmar), 2014 (Timor-Leste) (Aquilar et al., 2023). Note: % population living below USD2.15 (extreme) and USD3.65 poverty line, measured in 2017 USD.*

Food security

- *Food insecure % population: FAO 2020-2022 3-year average data (FAO, 2023). Note: Prevalence of moderate or severe food insecurity in the population. Data used to monitor SDG Indicator 2.1.2 under Target 2.1: 'By 2030 end hunger and ensure access by all people…to safe, nutritious and sufficient food year-round'. NA not available – data not collected or not reported.*
- *Food insecurity trend: comparison between FAO 2017 – 2019 and 2020-2023 3-year average data (FAO, 2023).*

Total, regional %

- *Note: % calculations account for different country populations.*

Table F2: Water resources, water withdrawals, access to basic services and hydropower data. Data sources and notes outlined below table. Instances of "irrig" refer to irrigation; "agri" to agricultural; "ind" to industrial; "mun" to municipal; and "san" to sanitation.

	Water resources, water withdrawals						Access to basic services					
Country	**Water stress (%)**	**Depend ratio (%)**	**Irrig area (%)**	**Agric use (%)**	**Ind use (%)**	**Mun use (%)**	**Basic water all (%)**	**Safely manage water all (%)**	**Rural water basic (%)**	**Basic san all (%)**	**Safely manage san all (%)**	**Rural san basic (%)**
Myanmar	6	14	16.9	89	1	10	82	57	77	74	61	72
Lao PDR	5	43	32.6	96	2	2	85	18	78	80	61	69
Thailand	23	49	28.9	90	5	5	100	NA	100	99	26	98
Viet Nam	18	59	39.1	95	4	1	98	58	97	92	44	88
Cambodia	1	75	6.3	94	2	4	78	29	73	77	37	71
Malaysia	3	0	4.9	46	30	24	97	94	90	96	86	96
Singapore	83	0	NA	4	51	45	100	100	100	100	100	100
Brunei D	3	0	10.0	6	NA	NA	100	NA	100	100	NA	100
Philippines	26	0	16.9	79	12	9	95	48	92	85	63	86
Indonesia	30	0	13.1	85	4	11	94	30	88	88	NA	84
Timor-Leste	28	0	18.1	91	0	9	87	NA	82	58	NA	52
Regional %	-	-	-	-	-	-	*94*	-	*89*	*88*	-	*84*

Data sources and notes:

Water resources, withdrawals

- *Water stress %: SDG 6.4.2 water withdrawals as a percentage of renewable freshwater, FAO data for 2020 (FAO AQUASTAT, 2023). Note: countries where this % falls in the 0-25% bracket classified as 'no stress' (blue); >25-50% 'low stress' (yellow), >50-75% 'medium stress' (orange); >75-100% 'high stress' (light red); >100% 'critical stress' (dark red) in the SDG 6.4.2 monitoring framework.*
- *Dependency ratio %: percentage of renewable water originating outside country, FAO 2020 estimates (FAO AQUASTAT, 2023).*
- *Irrigated area %: percentage of cultivated land equipped for irrigation. FAO data for 2020 (FAO AQUASTAT, 2023).*
- *Agric, Ind and Mun use %: water withdrawals (use) by sector as a % of total withdrawals (agriculture, industrial, municipal), FAO data for 2020 (FAO AQUASTAT, 2023).*

Access to basic services: water, sanitation

- *Basic water all: % of total population with access to at least basic water services. (United Nations, 2023). Note: basic means from an improved source, collection time <30 mins.*
- *Safely managed water all: % of total population with access to safely managed water. (United Nations, 2023). Note: safely managed means accessible on premises, available when needed and free from contamination.*
- *Basic water rural: as above, rural only. (United Nations, 2023).*
- *Basic sanitation all: % of population with access to at least basic sanitation. (United Nations, 2023). Note: improved facilities i.e., not shared with other households.*
- *Safely managed sanitation all: % of total population with access to safely sanitation. (United Nations, 2023). Note: safely managed means improved facilities not shared with other households, with excreta safely disposed of in situ or treated off site.*
- *Basic san rural: as above, rural only. (United Nations, 2023).*

Regional (Reg) %

- *Excl UMI: excluding upper-middle income countries, i.e., low and lower-middle income countries only (see Economics above for definitions). Note: % calculations account for different country populations.*

Table F3: Potential direct impact of climate events on information and communication technology (ICT) infrastructure. Source: Sandhu and Raja (2019).

Infrastructure/climate event	**Inland/coastal floods**	**Sea-level rise**	**High temperature**	**Water scarcity**	**Storms/high winds**
Deep sea submarine cables	Low	Low	Low	Low	Low
Near Shore submarine cables	Low	Low	Low	Low	Medium
Underground terrestrial cables	Medium	Low	Low	Low	Low
Overland terrestrial cables	Low	Low	Low	Low	Medium
Landing stations	High	High	Low	Low	Low
Data centres	High	Low	Medium	Medium	Low
Antennas/towers	Low	Low	Low	Low	High

G: Glossary

A list of acronyms and definitions for technical terms used throughout the report are provided below.

Acronyms

AC	**Air conditioning**
ADB	Asian Development Bank
APHRODITE	Asian Precipitation – Highly-Resolved Observational Data Integration Towards Evaluation
ASEAN	Association of Southeast Asian Nations
BCR	Benefit-cost ratio
CDD	Cooling Degree Days
CMIP	Coupled Model Intercomparison Project
CO_2	Carbon dioxide
CORDEX	Coordinated Regional Climate Downscaling Experiment
COVID-19	Coronavirus Disease 2019
CRU TS	Climatic Research Unit gridded Time Series
CSA	Central and South Asia
DALY	Disability Adjusted Life Years
DRR	Disaster risk reduction
EAD	Expected annual damage
ENSO	El Niño Southern Oscillation
FAO	Food and Agriculture Organization
FCDO	Foreign, Commonwealth & Development Office
GBD	Global Burden of Disease
GCM	Global climate model
GDP	Gross Domestic Product
GHG	Greenhouse gas
GPCC	Global Precipitation Climatology Centre
HWFI	Heat Wave Frequency Index
ICT	Information and communications technology
IOD	Indian Ocean Dipole
IPCC	Intergovernmental Panel on Climate Change
ITCZ	Intertropical Convergence Zone
KSWS	Keo Seima Wildlife Sanctuary
Lao PDR	Lao People's Democratic Republic
LCOE	Levelised Cost of Energy

LULUCF	Land Use, Land-Use Change and Forestry
MHW	Marine heatwave
MRC	Mekong River Commission
NAO	North Atlantic Oscillation
NbS	Nature-based solutions
NDCs	Nationally Determined Contributions
OECD	Organisation for Economic Co-operation and Development
PDNA	Post-disaster needs assessment
PNG	Papua New Guinea
PV	Solar photovoltaic
RCM	Regional climate model
RCP	Representative Concentration Pathway
SDG	Sustainable Development Goal
SEA	Southeast Asia
SLR	Sea level rise
SRES	Special Report Emissions Scenarios
SSP	Shared Socioeconomic Pathways
SST	Sea surface temperature
TC	Tropical Cyclones (regionally termed Typhoons)
TRD	Technical Reference Document
USD	United States Dollar
WASH	Water, Sanitation, and Hygiene
WFP	World Food Programme
WHO	World Health Organization
W5E5	WATCH Forcing Data & ERA5 reanalysis data

Technical Terms

Term	**Definition**
Adaptation	In human systems, the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities. In natural systems, the process of adjustment to actual climate and its effects; human intervention may facilitate adjustment to expected climate and its effects.
Aerosols	A suspension of airborne solid or liquid particles, with a typical size between a few nanometres and 10 μm that reside in the atmosphere for at least several hours. Aerosols may be of either natural or anthropogenic origin. Aerosols may influence climate in several ways: through both interactions that scatter and/or absorb radiation and through interactions with cloud microphysics and other

	cloud properties, or upon deposition on snow- or ice-covered surfaces thereby altering their albedo and contributing to climate feedback.
Agro-ecological	The process applied to agricultural production systems, bringing ecological principles to suggest new management approaches.
Agricultural Drought	Agricultural drought happens when there is lack of rainfall or dry soil affects farming and crop growth.
Anomaly	The deviation of a variable from its value averaged over a reference period.
Anthropogenic	Resulting from or produced by human activities.
Aquaculture	The breeding, rearing, and harvesting of fish, shellfish, algae, and other organisms in all types of water environments.
Archipelago	An extensive group of islands.
Atmosphere	The gaseous envelope surrounding the earth, divided into five layers – the troposphere which contains half of the Earth's atmosphere, the stratosphere, the mesosphere, the thermosphere, and the exosphere, which is the outer limit of the atmosphere.
Attribution	The action of regarding something as being caused by a person or thing. Climate attribution refers to the process of establishing the most likely causes for the detected climatic change with some level of confidence.
Baseline	The state against which change is measured. It might be a 'current baseline,' in which case it represents observable, present-day conditions. It might also be a 'future baseline,' which is a projected future set of conditions excluding the driving factor of interest. Alternative interpretations of the reference conditions can give rise to multiple baselines.
Biodiversity	The variability among living organisms from terrestrial, marine, and other ecosystems. Biodiversity includes variability at the genetic, species, and ecosystem levels.
Biodiversity	The variety of plant and animal life in the world or in a particular habitat, a high level of which is usually considered to be important and desirable.
Blue Economy	A term in economics relating to the exploitation, preservation, and regeneration of the marine environment.
Carbon Dioxide (CO_2)	A naturally occurring gas, CO_2 is also a by-product of burning fossil fuels (such as oil, gas, and coal), of burning biomass, of land-use changes (LUC) and of industrial processes (e.g., cement production). It is the principal anthropogenic greenhouse gas (GHG) that affects the Earth's radiative balance.
Catchment	An area that collects and drains precipitation.
Climate	In a narrow sense, climate is usually defined as the average weather, or more rigorously, as 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 classical period for averaging these variables is 30 years, as defined by the World Meteorological Organization.

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 Feedback	An interaction in which a perturbation in one climate quantity causes a change in a second and the change in the second quantity ultimately leads to an additional change in the first. A negative feedback is one in which the initial perturbation is weakened by the changes it causes; a positive feedback is one in which the initial perturbation is enhanced.
Climate Impacts	Impacts describe the consequences of realised risks on natural and human systems, where risks result from the interactions of climate-related hazards (including extreme weather and climate events), exposure, and vulnerability.
Climate Indicator	Measures of the climate system including large-scale variables and climate proxies.
Climate Information	Information about the past, current state, or future of the climate system that is relevant for mitigation, adaptation, and risk management. It may be tailored or “co-produced” for specific contexts, considering users' needs and values.
Climate Mitigation	A human intervention to reduce the sources or enhance the sinks of greenhouse gases.
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 some of its known properties.
Climate Projection	The simulated response of the climate system to a scenario of future emission or concentration of greenhouse gases (GHG) and aerosols, generally derived using climate models. Climate projections are distinguished from climate predictions by their dependence on the emission/concentration/radiative forcing scenario used, which is in turn based on assumptions concerning, for example, future socioeconomic and technological developments that may or may not be realized.
Climate Risk	The potential for adverse consequences where something of value is at stake and where the occurrence and degree of an outcome is uncertain. In the context of the assessment of climate impacts, the term risk is often used to refer to the potential for adverse consequences of a climate-related hazard, or of adaptation or mitigation responses to such a hazard, on lives, livelihoods, health and well-being, ecosystems and species, economic, social, and cultural assets, services (including ecosystem services), and infrastructure. Risk results from the interaction of vulnerability (of the affected system), its exposure over time (to the hazard), as well as the (climate-related) hazard and the likelihood of its occurrence.
Climate System	The highly complex system consisting of five major components: the atmosphere, the hydrosphere, the cryosphere, the lithosphere and the biosphere and the interactions between them.
Climate Variability	Variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate at all spatial and temporal scales beyond that of individual weather events.

Communicable Disease	Refers to an illness caused by an infectious agent or its toxins that occurs through the direct or indirect transmission of the infectious agent or its products from an infected individual or via an animal, vector or the inanimate environment to a susceptible animal or human host (CDC, 2012).
Confidence	The robustness of a finding based on the type, amount, quality, and consistency of evidence (e.g., mechanistic understanding, theory, data, 51 models, expert judgment) and on the degree of agreement across multiple lines of evidence.
Coral Bleaching	The process when corals become white due to various stressors, such as changes in temperature, light or nutrients. Ocean acidification reduces the availability of calcium minerals for coral skeleton building and repair. Rising temperatures and ocean acidification work together to increase coral bleaching.
Crop Water Deficit	A water deficit occurs whenever water loss exceeds absorption. The use of total water potential as the best single indicator of plant water status has its limitations while attempting to understand the effect of water deficits on the various physiological processes involved in plant growth. Water deficits reduce photosynthesis by closing stomata, decreasing the efficiency of the carbon fixation process, suppressing leaf formation and expansion, and inducing shedding of leaves.
Dam	A barrier constructed to hold back water and raise its level, forming a reservoir of water used to generate electricity or as a water supply.
Deltaic	Of or pertaining to a river delta.
Disaster	A 'serious disruption of the functioning of a community or a society at any scale due to hazardous events interacting with conditions of exposure, vulnerability, and capacity, leading to one or more of the following: human, material, economic and environmental losses and impacts' (UNDRR, 'Disaster').
Downscaling	A method that derives local- to regional-scale (up to 100 km) information from larger-scale models or data analyses.
Drought	A prolonged period of abnormally low rainfall, leading to a shortage of water.
El Niño Southern Oscillation (ENSO)	The term El Niño was initially used to describe a warm-water current that periodically flows along the coast of Ecuador and Peru, disrupting the local fishery. It has since become identified with warming of the tropical Pacific Ocean east of the dateline. This oceanic event is associated with a fluctuation of a global-scale tropical and subtropical surface pressure pattern called the Southern Oscillation. This coupled atmosphere–ocean phenomenon, with preferred time scales of two to about seven years, is known as the El Niño-Southern Oscillation (ENSO). The cold phase of ENSO is called La Niña.
Emissions Scenario	A plausible representation of the future development of emissions of substances that are radiatively active (e.g., greenhouse gases (GHGs), aerosols) based on a coherent and internally consistent set of assumptions about driving forces (such as demographic and socio-economic development, technological change, energy, and land use) and their key relationships.

Enhanced Greenhouse Effect	The process in which human activities have added additional greenhouse gases into the atmosphere, this has resulted in a ‘stronger’ greenhouse gas effect as there are more gases available to trap outgoing radiation.
ERA5	Fifth generation ECMWF atmospheric reanalysis of the global climate covering January 1940-present. ERA5 is produced by the Copernicus Climate Change Service (C3S) at ECMWF.
Evaporation	The physical process by which a liquid (e.g., water) becomes a gas (e.g., water vapour).
Evapotranspiration	The process in which water moves from the earth to the air from evaporation (= water changing to a gas) and from transpiration (= water lost from plants).
Exposure	Exposure describes the presence of people; livelihoods; species or ecosystems; environmental functions, services, and resources; infrastructure; or economic, social, or cultural assets in places and settings that could be adversely affected.
Extreme/Heavy Precipitation Event	An extreme/heavy precipitation event is an event that is of very high magnitude with a very rare occurrence at a particular place. Types of extreme precipitation may vary depending on its duration, hourly, daily, or multi-days (e.g., 5 days), though all of them qualitatively represent high magnitude. The intensity of such events may be defined with block maxima approach such as annual maxima or with peak over threshold approach, such as rainfall above 95th or 99th percentile at a particular space.
Fifth Assessment Report (AR5)	A series of IPCC reports published in 2013-2014, reports are divided into publications by three working groups.
Food security	The state of having reliable access to a sufficient quantity of affordable, nutritious food.
Fossil Fuels	Carbon-based fuels from fossil hydrocarbon deposits, including coal, oil, and natural gas.
Global Breadbasket	The term "breadbasket" is used to refer to an area with highly arable land. The breadbaskets of the world are the regions in the world that produce food, particularly grains to feed their people as well as for export to other places.
Global Warming	The estimated increase in global mean surface temperature (GMST) averaged over a 30-year period, or the 30-year period centred on a particular year or decade, expressed relative to pre-industrial levels unless otherwise specified. For 30-year periods that span past and future years, the current multi-decadal warming trend is assumed to continue.
Green Revolution	A period of technology transfer initiatives that saw greatly increased crop yields. These changes in agriculture began in developed countries in the early 20th century and spread globally until the late 1980s.
Greenhouse Effect	Greenhouse gases are those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of terrestrial radiation emitted by the Earth’s surface, the atmosphere itself and by clouds. This property causes the greenhouse effect.

Greenhouse Gas (GHG) Concentrations	Lead to an increased infrared opacity of the atmosphere and therefore to an effective radiation into space from a higher altitude at a lower temperature. This causes a radiative forcing that leads to an enhancement of the greenhouse effect, the so-called enhanced greenhouse effect.
Greenhouse Gases (GHGs)	The gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of terrestrial radiation emitted by the Earth's surface, the atmosphere itself and by clouds. This property causes the greenhouse effect. Water vapour (H2O), carbon dioxide (CO2), nitrous oxide (N2O), methane (CH4) and ozone (O3) are the primary GHGs in the Earth's atmosphere. Moreover, there are a number of entirely human-made GHGs in the atmosphere, such as the halocarbons and other chlorine- and bromine-containing substances, dealt with under the Montreal Protocol. Beside CO2, N2O and CH4, the Kyoto Protocol deals with the GHGs sulphur hexafluoride (SF6), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs). (IPCC, 2018).
Hazard	The potential occurrence of a natural or human-induced physical event or trend that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems, and environmental resources.
Heat Stress	A range of conditions in, e.g., terrestrial, or aquatic organisms when the body absorbs heat during overexposure to high air or water temperatures or thermal radiation. In aquatic water breathing animals, hypoxia and acidification can exacerbate vulnerability to heat. Heat stress in mammals (including humans) and birds, both in air, is exacerbated by a detrimental combination of ambient heat, high humidity, and low wind-speeds, causing regulation of body temperature to fail.
Heatwave	A period of abnormally hot weather often defined with reference to a relative temperature threshold, lasting from two days to months. Heatwaves and warm spells have various and, in some cases, overlapping definitions.
Hydrological Drought	Hydrological drought occurs when low water supply becomes evident, especially in streams, reservoirs, and groundwater levels, usually after many months of meteorological drought.
Ice Sheet	An ice body originating on land that covers an area of continental size, generally defined as covering >50,000km2 , and that has formed over thousands of years through accumulation and compaction of snow. (IPCC, 2019).
Impacts	Impacts generally refer to effects on lives, livelihoods, health, ecosystems, economies, societies, cultures, services, and infrastructure due to the interaction of climate changes or hazardous climate events occurring within a specific time period and the vulnerability of an exposed society or system.
Indian Ocean Dipole (IOD)	The Indian Ocean Dipole (IOD) is an irregular oscillation of sea surface temperatures in which the western Indian Ocean becomes alternately warmer (positive phase) and then colder (negative phase) than the eastern part of the ocean. The Subtropical Indian Ocean Dipole (SIOD) is featured by the oscillation of sea surface temperatures.

Influx	An arrival or entry of large numbers of people or things.
Intergovernmental Panel on Climate Change (IPCC)	The leading international body for the assessment of climate change. Scientists come together approximately every six years, to assess peer reviewed research in working groups to generate three reports including the Physical Science Basis, impact adaptation and vulnerability, and Mitigation of Climate Change.
Intertropical Convergence Zone (ITCZ)	The Intertropical Convergence Zone (ITCZ) is a band of low pressure around the Earth which generally lies near to the equator. The trade winds of the northern and southern hemispheres come together here, which leads to the development of frequent thunderstorms and heavy rain.
Macro-economic (Factors)	A phenomenon, pattern, or condition that emanates from, or relates to, a large aspects of an economy rather than to a particular population. Inflation, GDP, and national income are examples of macroeconomic factors.
Marine Heatwave	A period during which water temperature is abnormally warm for the time of the year relative to historical temperatures with that extreme warmth persisting for days to months. The phenomenon can manifest in any place in the ocean and at scales of up to thousands of kilometres.
Maritime	Connected/associated with the sea.
Meteorological drought	When rainfall in an area is below average for the region.
Mitigation	A human intervention to reduce the sources or enhance the sinks of greenhouse gases.
Monsoon	A seasonal prevailing wind in the region of south and southeast Asia, blowing from the south-west between May and September and bringing rain (the wet monsoon), or from the north-east between October and April (the dry monsoon).
NbS	Nature-based solutions (NbS) refers to the sustainable management and use of nature for tackling socio-environmental challenges. The challenges include issues such as climate change, water security, water pollution, food security, human health, biodiversity loss and disaster risk management.
Ocean Acidification	A reduction in the pH of the ocean, accompanied by other chemical changes (primarily in the levels of carbonate and bicarbonate ions), over an extended period, typically decades or longer, which is caused primarily by uptake of carbon dioxide (CO_2) from the atmosphere, but can also be caused by other chemical additions or subtractions from the ocean. Anthropogenic ocean acidification refers to the component of pH reduction that is caused by human activity.
Overharvested	Refers to harvesting a renewable resource to the point of diminishing returns.
Paris Agreement	The Paris Agreement under the United Nations Framework Convention on Climate Change (UNFCCC) was adopted on December 2015 in Paris, France, at the 21st session of the Conference of the Parties (COP) to the UNFCCC. The agreement, adopted by 196 Parties to the UNFCCC, entered into force on 4 November 2016 and as of May 2018 had 195 Signatories and was ratified by 177 Parties. One of the goals of the Paris Agreement is 'Holding the

	increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels', recognising that this would significantly reduce the risks and impacts of climate change. Additionally, the Agreement aims to strengthen the ability of countries to deal with the impacts of climate change.
pH	pH is a measure of how acidic/basic water is. The range goes from 0 to 14, with 7 being neutral. pHs of less than 7 indicate acidity, whereas a pH of greater than 7 indicates a base.
Projection/Projected	A projection is a potential future evolution of a quantity or set of quantities, often computed with the aid of a model. Unlike predictions, projections are conditional on assumptions concerning, for example, future socio-economic and technological developments that may or may not be realised.
Radiative Forcing	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 a driver of climate change, such as a change in the concentration of carbon dioxide (CO_2) or the output of the sun.
Reanalysis	Atmospheric and oceanic analyses of temperature, wind, current and other meteorological and oceanographic quantities, created by processing past meteorological and oceanographic data using fixed state-of-the-art weather forecasting models and data assimilation techniques.
Representative Concentration Pathways (RCPs)	Scenarios that include time series of emissions and concentrations of the full suite of greenhouse gases (GHGs) and aerosols and chemically active gases, as well as land use/land cover.
Research Gap	A question or problem that has not been answered by any of the existing studies or research.
Resilience	The capacity of social, economic, and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganising in ways that maintain their essential function, identity and structure, while also maintaining the capacity for adaptation, learning and transformation.
Resolution	In climate models, this term refers to the physical distance (metres 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.
Risk	The potential for consequences where something of value is at stake and where the outcome is uncertain, recognising the diversity of values. Risk is often represented as probability of occurrence of hazardous events or trends multiplied by the impacts if these events or trends occur. Risk results from the interaction of vulnerability, exposure, and hazard.
Runoff	The flow of water over the surface or through the subsurface, which typically originates from the part of liquid precipitation and/or snow/ice melt that does not evaporate or refreeze and is not transpired.
Saline Intrusion	The movement of saline water into freshwater aquifers, which can lead to groundwater quality degradation, including drinking water.

Scenario	A plausible description of how the future may develop based on a coherent and internally consistent set of assumptions about key driving forces (e.g., rate of technological change, prices) and relationships. Note that scenarios are neither predictions nor forecasts but are used to provide a view of the implications of developments and actions.
Signal	Climate signals are long-term trends and projections that carry the fingerprint of climate change.
Sixth Assessment Report (AR6)	The latest series of IPCC reports published in 2021-2022, reports are divided into publications by three working groups. At the time of writing this report only the Working Group I contribution to the Sixth Assessment Report published in 2021 was available to use.
Soil Moisture	Water stored in the soil in liquid or frozen form. Root-zone soil moisture is of most relevance for plant activity.
Special Report on Emissions Scenarios (SRES)	A report by the Intergovernmental Panel on Climate Change (IPCC) that was published in 2000. The SRES scenarios, as they are often called, were used in the IPCC Third Assessment Report (TAR), published in 2001, and in the IPCC Fourth Assessment Report (AR4), published in 2007.
Storm Surge	The temporary increase, at a particular locality, in the height of the sea due to extreme meteorological conditions (low atmospheric pressure and/or strong winds). The storm surge is defined as being the excess above the level expected from the tidal variation alone at that time and place. (IPCC, 2019).
Stream Flow	Water flow within a river channel, for example, expressed in m3s1 . A synonym for river discharge.
Teleconnection	Association between climate variables at widely separated, geographically fixed locations related to each other through physical processes and oceanic and/or atmospheric dynamical pathways. Teleconnections can be 58 caused by several climate phenomena, such as Rossby wave-trains, midlatitude jet and storm track displacements, fluctuations of the Atlantic Meridional Overturning Circulation, fluctuations of the Walker circulation, etc. They can be initiated by modes of climate variability thus providing the development of remote climate anomalies at various temporal lags.
Temperate	Relating to or denoting a region or climate characterised by mild temperatures.
Tourism	The commercial organisation and operation of holidays and visits to places of interest. A social, cultural, and economic phenomenon which entails the movement of people to countries or places outside their usual environment for personal or business/professional purposes.
Tropical	A climatic zone typically found in the equatorial zone and characterised by high temperatures throughout the year, generally high humidity, and high precipitation, although the latter may occur in a distinct rainy season.
Typhoon	A rapidly rotating storm system characterised by a low-pressure centre, a closed low-level atmospheric circulation, strong winds, and a spiral arrangement of thunderstorms that produce heavy rains and strong winds.

Uncertainty	A state of incomplete knowledge that can result from a lack of information or from disagreement about what is known or even knowable. In climate change analysis, it may have many types of sources, from imprecision in the data to ambiguously defined concepts or terminology, incomplete understanding of critical processes, or uncertain projections of human behaviour.
United Nations Framework Convention on Climate Change (UNFCCC)	The United Nations Framework Convention on Climate Change (UNFCCC) was adopted in May 1992 and opened for signature at the 1992 Earth Summit in Rio de Janeiro. It entered into force in March 1994 and as of May 2018 had 197 Parties (196 States and the European Union). The Convention's ultimate objective is the 'stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system.' The provisions of the Convention are pursued and implemented by two treaties: the Kyoto Protocol and the Paris Agreement. (IPCC, 2018).
Urban Heat Island	The relative warmth of a city compared with surrounding rural areas, associated with changes in runoff, effects on heat retention, and changes in surface albedo.
Urbanisation	The process of making an area more urban.
Vulnerability	The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm, and lack of capacity to cope and adapt.
Weather	The conditions in the air above the earth such as wind, rain, or temperature, especially at a particular time over a particular area.

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