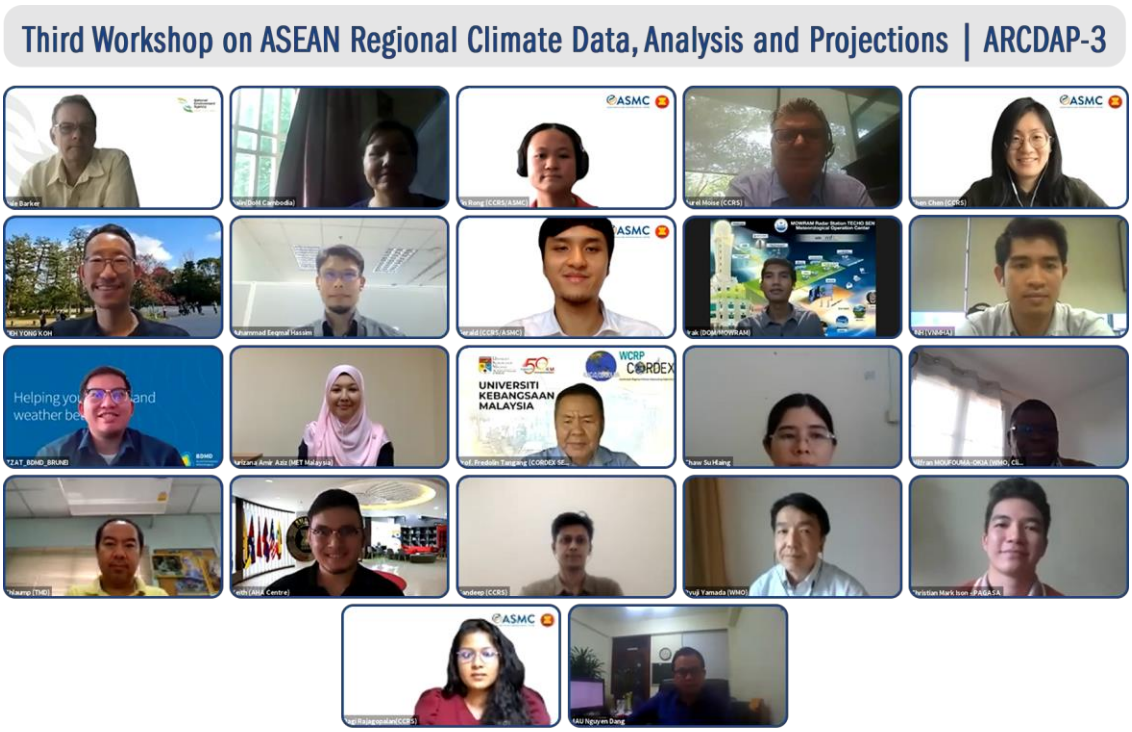
Third Workshop on ASEAN Regional Climate Data, Analysis and Projections (ARCDAP-3)

15 — 18 March 2021, Virtual

Meeting Report



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List of Abbreviations

AHA Centre	ASEAN Coordinating Centre for Humanitarian Assistance on disaster Management
APHRODITE	Asian Precipitation – Highly-Resolved Observational Data Integration Towards Evaluation
ARCDAP-3	Third Workshop on ASEAN Regional Climate Data, Analysis and Projections
ASEAN	Association of Southeast Asian Nations
ASMC	ASEAN Specialised Meteorological Centre
BDMD	Brunei Darussalam Meteorological Department
BOM	Bureau of Meteorology (Australia)
CCRS	Centre for Climate Research Singapore
CFSR	Climate Forecast System Reanalysis
CHIRPS	Climate Hazards Group InfraRed Precipitation with Station data
CMIP	Coupled Model Intercomparison Project
CORDEX	Coordinated Regional Climate Downscaling Experiment
CREWS	Climate Risk and Early Warning Systems initiative (Canada)
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DECK	Diagnostic, Evaluation and Characterization of Klima
DMH	Department of Meteorology and Hydrology, Myanmar
DOM	Department of Meteorology, Cambodia
ECMWF	European Centre for Medium-Range Weather Forecasts
ENSO	El Niño–Southern Oscillation
ERA	ECMWF Re-Analysis
ESGF	Earth System Grid Federation
ESMValTool	Earth System Model Evaluation Tool
GCM	Global Climate Model / General Circulation Model
IMHEN	Viet Nam Institute of Meteorology, Hydrology and Climate change
IPCC	Intergovernmental Panel on Climate Change
IOD	Indian Ocean Dipole
JRA-55	Japanese 55-year Reanalysis
KNMI	Royal Netherlands Meteorological Institute
MetMalaysia	Malaysia Meteorological Department
MERRA-2	Modern-Era Retrospective analysis for Research and Applications, Version 2
MIP	Model Intercomparison Project
MJO	Madden-Julian Oscillation
MRI	Meteorological Research Institute (Japan)
MSS	Meteorological Service Singapore
NetCDF	Network Common Data Form
NMHS	National Meteorological and Hydrological Services

OLR	Outgoing Longwave Radiation
PAGASA	Philippine Atmospheric, Geophysical, and Astronomical Services Administration
PCMDI	Program for Climate Model Diagnosis and Intercomparison
PMP	PCMDI Metrics Package
RCM	Regional Climate Model
RCP	Representative Concentration Pathway
SACA&D	Southeast Asian Climate Assessment & Dataset
ScenarioMIP	Scenario Model Intercomparison Project
SRES	Special Report on Emissions Scenarios
SSP	Shared Socioeconomic Pathway
SST	Sea-surface Temperature
SUSS	Singapore University of Social Sciences
TMD	Thai Meteorological Department
UKM	National University of Malaysia
UKMO	Meteorological Office (United Kingdom)
UNFCCC	United Nations Framework Convention on Climate Change
V2	Singapore's Second National Climate Change Study
V3	Singapore's Third National Climate Change Study
VNMHA	Viet Nam Meteorological and Hydrological Administration
WCRP	World Climate Research Programme
WMO	World Meteorological Organisation
WMO RAP	WMO Regional Office for Asia and the South-West Pacific

Introduction

The Third Workshop on ASEAN Regional Climate Data, Analysis and Projections (ARCDAP-3) was held virtually on the Zoom platform from 15th to 18th of March 2021. ARCDAP-3 was co-organised by the ASEAN Specialised Meteorological Centre (ASMC) and Meteorological Service Singapore (MSS) in consultation with the World Meteorological Organisation (WMO). The workshop had originally been scheduled to take place physically from 17th to 21st February 2020 in Singapore but was postponed due to the then emerging COVID-19 pandemic.

The ARCDAP workshop series was conceived in 2017 following a proposal from the WMO Regional Association (RA) V working group on climate services to consolidate the various national and regional-level climate projection studies that had been conducted in ASEAN and work towards formulating a set of best practices in generating climate change scenarios.

During the first workshop ARCDAP-1 (originally named Best Practice Workshop on Climate Change Projections and their Applications in ASEAN Countries) held in Singapore in March 2018, representatives from ASEAN National Meteorological and Hydrological Services (NMHSs) and end-user sectors, together with climate science experts, proposed a set of recommendations regarding the generation of climate change projections. A number of these called for enhancing the region's collective understanding behind the science and methodology behind climate change projections, e.g. compiling technical guidelines on existing methodologies such as downscaling, bias-correction and spatial resolution; advancing the understanding of key physical processes over the region and their reproduction in climate models; continuing the use of multiple scenarios to highlight not just the most impactful climate change signals but also the benefits of mitigation. It was also recommended that a follow-on workshop should develop strategies to incorporate the anticipated set of global climate model (GCM) simulations from Phase 6 of the Coupled Model Intercomparison Project (CMIP6) into existing and future work.

ARCDAP-2 which was held in March 2019 in Singapore, built on recommendations from ARCDAP-1 around observational data and the need for sector-relevant extreme indices by involving extensive hands-on sessions on the ClimPACT software led by international experts from the Expert Team on Sector-specific Climate Indices (ET-SCI). With much accomplished in the area of observational data at ARCDAP-2, it was recommended that ARCDAP-3 turn its focus to the newly available and growing CMIP6 database. Representatives and experts agreed that the need for ASEAN climate change practitioners to upgrade their knowledge of the latest global climate model database was important. With the most recent regional studies driven by output from preceding global databases, CMIP3 and CMIP5, studies would eventually need to move to the latest available database as well as future scenario standards (i.e. the use of RCPs in CMIP5 to SSPs in CMIP6).

Thus, ARCDAP-3 served as the ideal platform to support ASEAN NMHSs, related national agencies, and other academics into their next phase of national climate projection work. Encouraging the uptake and understanding of the latest ensemble of CMIP6 simulations would help provide a segue into discussions on evaluating regional climate processes, variability and change. The workshop would also provide opportunities to further develop on recommendations from ARCDAP-1 and work towards refining a set of best practices in terms of data, climate scenario use, key processes, etc. for regional climate science, climate change information and related services. In continuing the ARCDAP workshop series, ARCDAP-3 would maintain this effort to encourage regional collaboration and information sharing within the ASEAN as well as the international community.

In light of the above-mentioned needs highlighted by both the regional and international community, the objectives of ARCDAP-3 were as follows:

1) Assess the status of regional understanding of the CMIP databases (CMIP5 and 6).
2) Obtain a shared understanding of CMIP's current status and latest developments of CMIP6.
3) Be introduced to certain resources for CMIP model evaluation (ESMValTool, Climate Explorer).
4) Work towards developing a common framework for studying key regional climate processes across a range of climate models.
5) Develop a common understanding of suitable global climate models that can be relied upon for the ASEAN region.
6) Discuss and develop a regional consensus on most relevant emission scenarios to use for regional climate change projections.
7) Link the developed understanding about CMIP databases with existing and on-going projects that generate downscaled climate projections across the ASEAN region.

Workshop Recommendations

A. Documenting a set of regional best practices

It is recognised that the national climate change studies carried out by the ASEAN countries have a lot in common, especially in terms of the key climate variables and processes of interest to the region. While not every country has the resources to independently perform the full set of steps to produce climate change projections (e.g. evaluating and sub-selecting suitable GCMs for regional downscaling, running dynamical downscaling simulations), the participating ASEAN NMHSs are generally keen to develop climate science capabilities and become more informed users as well as future producers of such information. A regional best practices publication which provides guidelines on the many considerations behind generating climate change projections will go a long way towards synergising and enhancing the region's collective capabilities in this area. The following recommendations in sections B to E cover what will be key elements that will form this document.

Recommendation-1: *It is recommended that ASEAN NMHSs and relevant agencies work towards publishing a regional best practices document for producing and delivering national and regional climate change projections.*

B. Key variables, processes, datasets and methods for studying regional climate

Participants at ARCDAP-3 agreed that the CMIP has provided an invaluable resource of data for climate change study. Whilst not every country has immediate plans to analyse/interface directly with CMIP6, it is nonetheless important for the ASEAN NMHSs and relevant communities to understand and be able to identify key data sources and experiments (even outside of CMIP) that drive regional climate change projections. Besides the historical and scenario-based simulations from CMIP5/6, other experiments from CMIP6 that are highly relevant include the Decadal Climate Prediction Project (DCCP), the High-Resolution Model Intercomparison Project (HighResMIP) and the Global Monsoons Model Intercomparison Project (GMMIP). Insights from these more specialised experiments will deepen our understanding of regional climate mechanisms and help enhance the interpretability of regional projections. CMIP aside, existing and planned resources for downscaled projection data (e.g. CORDEX-SEA, NEX-GDDP) should be compiled to improve clarity and ease of access to potential users.

Recommendation-2: *It is recommended that ASEAN NMHSs work to identify a list of datasets and experiments for use in producing regional climate change projections.*

Climate variables such as temperature, precipitation and those related to key regional climate processes such as the ENSO (SSTs), MJO (OLR) and monsoons (winds) are important inputs for evaluating the performance of GCMS/RCMs and outputs from the subsequent climate projections in terms of the information that is ultimately disseminated and distributed. The seminars on Day 3 also exposed participants to ongoing research on the reproducibility and projected evolutions of these variables/processes (e.g. enhanced ENSO-rainfall teleconnections in the Maritime Continent) in the latest suite of GCMs which will drive the next set of regional climate projections. During the breakout sessions, participants also identified a common set of tools/software packages that they typically used for climate data analysis e.g. Python, MATLAB, CDO, Synda. It is thus crucial that ASEAN climate change practitioners are aware of their importance, the optimal set of tools and metrics for their analysis and keep abreast of regional research and developments in understanding of those areas. Participants agreed that having such a shared resource of said information will be extremely valuable.

Recommendation-3: *It is recommended that ASEAN NMHSs work to compile a list of important climate variables, processes and related literature, as well as common evaluation metrics and tools for climate data analysis.*

ARCDAP-2 made progress in the area of sector-specific indices by introducing participants to the ET-SCI indices and training them in the ClimPACT2 software with a focus on station-based observational data. Work should continue in this area by identifying a set of common variables that are key for assessing the projected changes in regional climate extremes. Variables and indices such as percentile-based rainfall and temperature thresholds along with the Standardised Precipitation-Evapotranspiration Index (SPEI) as information they have delivered and would envisage delivering to stakeholders in the future. Additionally, it would be useful to agree on common baseline periods (e.g. 1979 – 2014) for such indices wherever possible to improve the synergy across studies.

Recommendation-4: *It is recommended that ASEAN NMHSs work to identify key variables and ideal baseline periods for evaluating extreme thresholds and for climate impact studies.*

C. Benefits and limitations of different scales of climate modelling

Regional climate phenomena exist across a plethora of spatio-temporal scales, from large scale monsoon circulations, to mesoscale systems such as squall lines, to local extremes caused by thunderstorms and wind gusts. Regional climate projections and downscaling experiments are typically conducted on spatial resolutions in the order of 10 – 20km, sufficient for resolving important features such as tropical cyclones. There is however a demand for finer-scale (below 5km) projections typically from stakeholders and the end-user sector who wish to use these climatic inputs for specialised purposes (e.g. flood monitoring). On these accounts, the ASEAN

community will benefit from a concerted effort to identify the ideal resolutions for representing different processes and develop guidelines on how agencies can balance between technical expertise, computational expense and stakeholder requirements when planning for future climate change studies.

Recommendation-5: *It is recommended that a scientific consensus on the ideal model resolutions for representing different regional climate variables and processes is developed.*

It is established that high-resolution modelling is needed for any specific region both from the scientific perspective and the users' perspective. GCMs are generally useful for capturing large scale circulations such as the ENSO and MJO but are typically too coarse to model finer processes (e.g. convection, interactions with complex topography) and provide meaningful information at the regional and national scales. Previous studies using RCMs have shown that projected changes in temperature and rainfall trends and extremes will not be spatially coherent across Southeast Asia and even so within individual countries. However, these limitations should not discourage practitioners from using GCM information and understanding the value they bring. Instead, the complementary use of GCMs and RCMs should be encouraged. For instance, GCM and RCM projections should be broadly consistent (e.g overall pattern, trends). It could also be useful to examine if RCMs exceed the range of uncertainty predicted by GCMs and provide added value in variability. Ultimately, RCMs are driven by underlying GCM boundary conditions (which have their biases) and having an understanding of these original GCM biases can aid the interpretation of the RCM biases that manifest.

Recommendation-6: *It is recommended that a consensus is obtained on the added value of regional climate modelling and on how GCMs and RCMs should be evaluated and be used in a complementary manner.*

D. Future climate scenarios and uncertainty analysis

Participants agreed that climate change practitioners should continue with the use of multiple climate emission scenarios to sufficiently span the range between strong mitigation and strong climate change signals. It is also imperative that the ASEAN community keeps up to date with the advancements in the scenario standards used for CMIP6 and likewise for future phases of CMIP. Representative Concentration Pathways (RCPs) which were widely adopted by the CMIP5 experiments and featured in the IPCC Fifth Assessment Report are now accompanied in CMIP6 by Shared Socioeconomic Pathways (SSPs) which model how socioeconomic factors including population, economic growth, education, urbanisation and the rate of technological development, may change over the next century. Thus, this will allow future

regional projections using SSP-RCP scenarios to be related more closely to potential mitigation and policy-making pathways.

Recommendation-7: *It is recommended that guidelines are developed on the appropriate use of future climate scenarios to highlight both the benefits of strong mitigation and risks of the stronger climate change signals.*

Regional climate change projections are associated with three main sources of uncertainty, 1) internal climate model variability, 2) inter-model spread, 3) spread in the RCP/SSP scenarios, which contribute varying amounts to the total variance of projections which are also dependent on the time frame considered. As several countries shared during the discussions that they had not previously performed any uncertainty assessments, it is thus important for practitioners to recognise these uncertainties going forward and use this information to assess the confidence of their own climate change projections. ARCDAP-1 had also recognised the importance of fostering a mutual understanding of projection uncertainties with stakeholders as part of climate services provision. This effort should be continued, and the best practices document should offer advice on how to engage stakeholders on this end.

Recommendation-8: *It is recommended that guidelines are developed on how uncertainties should be addressed (e.g. via multi-model ensembles) and meaningfully communicated to stakeholders.*

E. Data availability and needs

RCMs have their own limitations in terms of data accessibility, e.g. RCMs data will typically only be readily available several years after the data from their corresponding CMIP generation is. Additionally, not all ASEAN representatives indicated familiarity with existing data access portals such as ESGF, thus it would be useful to compile a GCM and RCM data access guide as part of this recommendation. This can also be further aided by striking a consensus on the common downscaling model outputs that can be shared amongst countries via an easily accessible portal e.g. CORDEX-ESGF.

Recommendation-9: *It is recommended to agree on suitable downscaling model characteristics for the region and to improve data accessibility by having a set of RCM projections available to be used by all ASEAN NMHSs.*

F. Continuation of the ARCDAP workshop series

The ARCDAP workshop series has served as a valuable platform for regional discussions and collaborations across the ASEAN NMHSs and relevant agencies. It is recommended to continue the workshop series with ARCDAP-4 tentatively scheduled for Q4 2022. Many ASEAN representatives had expressed interest in picking up various tools for analysing CMIP/RCM data and for hands-on sessions which unfortunately were not held at ARCDAP-3 due to the change to a virtual setting. Hence, it is proposed that the follow-up workshop, ARCDAP-4 should be held physically with a focus on the training of tools for analysing CMIP6 as well as RCM projections. ARCDAP-4 would support the development of shared capabilities and tools to produce regional climate projection information and deliverables. This will also enable the continuation of previous efforts which centred around climate extremes and impact assessments.

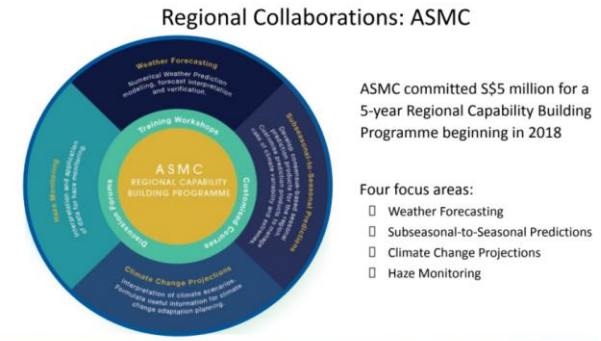
Recommendation-10: *It is recommended that funding opportunities are explored by CCRS, WMO, and ASMC in collaboration with the ASEAN NMHSs to continue the ARCDAP workshop series.*

1 Day 1: 15 March 2021

Welcome and Introduction

1.1 The Virtual Third Workshop on ASEAN Regional Climate Data, Analysis and Projections (ARCDAP-3) was held virtually on Zoom, from 15th to 18th March 2021.

1.2 **Dr Dale Barker, Director of CCRS, Singapore,** delivered the welcome address, thanking all ASEAN representatives, local and international experts and WMO for their continued support of the ARCDAP series. He emphasized the importance of seamless weather and climate modelling capabilities and how CCRS is working along this direction by using the SINGV model and its RCM version (SINGV-RCM) for weather prediction and climate change projections, respectively. He touched upon some of the challenges faced in NWP as well as the need for local data assimilation for high resolution modelling. On the climate modelling side, he talked about the V3 project which is to be completed by the end of 2022. The Climate Science Research Programme Office (CSRPO) is also a new department under CCRS, launched in November 2020 and tasked to coordinate climate impact research in Singapore where V3 datasets are expected to play a crucial role. Finally, he recognised the regional collaborations through the ASMC and its commitment towards a 5-year regional capability building programme beginning in 2018, spread across four focus areas, namely, (i) weather forecasting, (ii) sub-seasonal to seasonal predictions, (iii) climate change projections, and (iv) haze monitoring.



ASMC's 5-year Regional Capability Building Programme

1.3 **Mr Ben Churchill, Head of WMO RAP, Singapore** gave his opening address to the participants. He emphasized that SEA has unique sensitivities to climate change. He acknowledged that while member countries have been carrying out climate change projections, there is a wide range of capacity, capability, stakeholder needs and organizational structure across members. Hence, there was a need to facilitate and coordinate the national and regional climate change projections, which is ultimately the aim of the ARCDAP series. The WMO Executive Council in its 70th session, had discussed the Regional Climate Outlook Forum as a means to disseminate and discuss regional climate change projections to complement products such as the Climate Services Information System (CSIS). In this context, he emphasized the role of the SEA RCC network started in November 2017 to facilitate seasonal climate services, products and activities such as ASEANCOF to support the region's NMHSs, under the

coordination of MSS. He concluded by assuring that WMO will keep facilitating and promoting such workshops and sharing of best practices in this and other regions.

1.4 **Mr Gerald Lim, CCRS, Singapore,** gave a quick administrative brief and guidelines for presenters and participants to follow for the workshop. This was followed by the virtual first group photo that was taken.

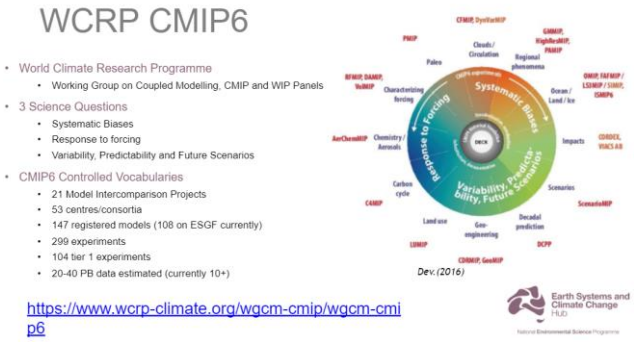
ARCDAP-3 participants group photo taken on Day 1

1.5 **Dr Aurel Moise, CCRS, Singapore,** shared with participants the context of ARCDAP-3 in the workshop series. He shared with the participants the objectives and recommendations drawn from ARCDAP–1 (20-23 March 2018) and ARCDAP-2 (25-29 March 2019). Next, he gave an overview of ARCDAP-3 and the main objectives of the workshop. He mentioned that the overarching objective of the workshop was around evaluation of climate model datasets in support of national and regional efforts to deliver improved climate change projections across the ASEAN region, and then delved into the specific objectives. He concluded by sharing the detailed program of the workshop with the participants, and this marked the conclusion of the welcome session.

Presentations on CMIP and CMIP6

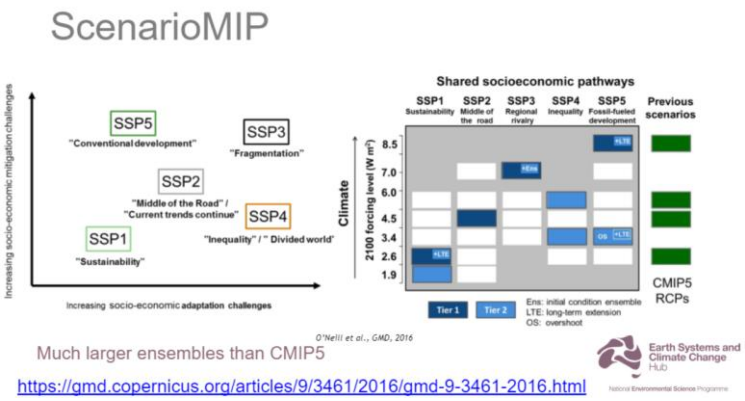
1.6 **Dr Simon Marsland, CSIRO, Australia,** began the session with a presentation about the WCRP, giving an overview of its 4 core projects (CLIVAR, CLIC, SPARC, GEWEX) and 2 major projects (CMIP and CORDEX) and sharing how it has been instrumental in facilitating global climate research. As a member of the Working Group on Coupled Modelling (WGCM), he contributes to the overseeing of CMIP6, which will attempt to answer 3 science questions, namely, (1) systematic biases in climate models, (2) response to forcing, and (3) variability, predictability and future scenarios. The design of CMIP6 also targets the WCRP grand

challenges, namely, (i) clouds, circulation and climate sensitivity, (ii) changes in cryosphere, (iii) climate extremes, (iv) regional sea-level rise, (v) water availability, (vi) near-term climate prediction, and (vii) biogeochemical cycles and climate change. The core of the CMIP6 experiments consists of DECK which comprises of 4 entry level experiments, i.e. AMIP, piControl, 1pctCO2, abrupt4xCO2, and the historical simulations (1850-2014).



Overview of the WCRP and CMIP6

Overall, 21 MIPs have so far been endorsed, with 147 GCMs and 53 modelling centres registered across them. He encouraged participants to seek further information on CMIP6 via the CMIP6 Special Issue in Geoscientific Model Development which includes an overview paper as well as papers on the 21 MIPs and individual forcings used. He briefly shared some CMIP6 analysis that has been done via the ESMValTool software which quantified the progress across different CMIP phases (CMIP3, CMIP5 and CMIP6) and about the new SSP scenarios that will build on the RCPs for CMIP6. He finally shared some key points from the IPCC's recent Special Report: Global Warming of 1.5°C (SR1.5), and Special Report on the Ocean and Cryosphere in a Changing Climate (SROCC).

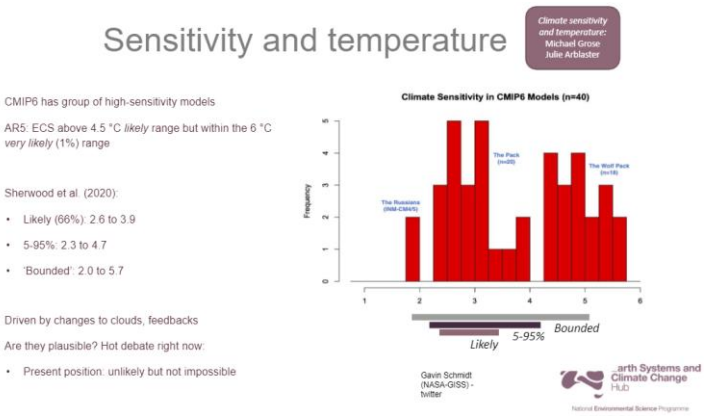


Schematic of the CMIP6 SSP scenarios

Dr Aurel Moise was curious to know Dr Marsland's opinions on whether CMIP6 was an overall improvement over CMIP5. Dr Marsland felt that although performance improvements have been generally small with some systematic biases remaining, CMIP6 has provided the community with a much larger number of GCMs, ensemble members, and higher resolutions.

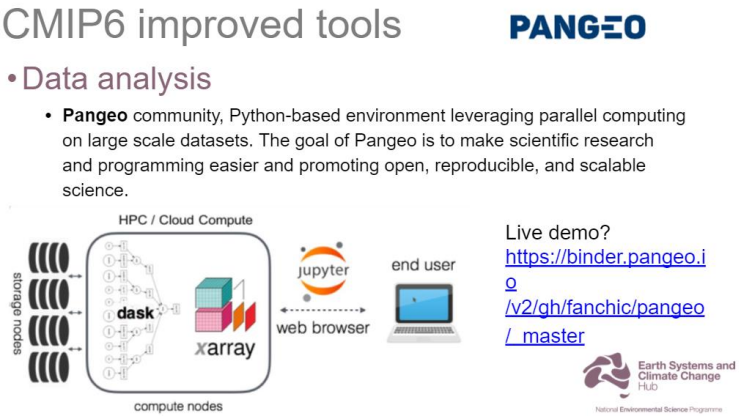
1.7 **Mr Francois Delage, BOM, Australia**, presented on the CMIP6 advancements in technology. He mentioned that some of the biggest science advancements in CMIP6 have been related to atmospheric chemistry. It has received the biggest update of any model component since CMIP5, with particular focus on aerosol indirect effect, impacting cloud feedbacks and cloud-aerosol interactions, and equilibrium climate sensitivity (ECS) in CMIP6 models. To date, the estimated range of ECS has laid within the range of 1.5 – 4.5°C. He showed a figure from Bock et al. (2020) comparing the ECS of climate models from CMIP3, CMIP5 and

CMIP6. While CMIP3 and CMIP5 GCMs' ECS values were within the well-known range of 1.5 – 4.5°C, CMIP6 has a group of high-sensitivity models, with around 10 models higher than 4.5°C which has raised some concern. He mentioned that most of the models with the higher range are from 2 – 3 institutes, e.g. NCAR and UKMO. Next, he showed an time series of the Australian mean surface temperature anomaly (1995 – 2014 baseline), compared to the global mean surface temperature, for 2 emission scenarios from CMIP5 (RCP2.6 and RCP8.5) and CMIP6 (SSP126 and SSP585). For both Australia and globally, CMIP6 end-of-century temperature change has some values higher than that in CMIP5. He concluded by saying that as compared to CMIP5, the biggest differences in CMIP6 surface temperatures seem to be coming from the Arctic.



The clusters of CMIP6 GCMs based on equilibrium climate sensitivity (ECS).

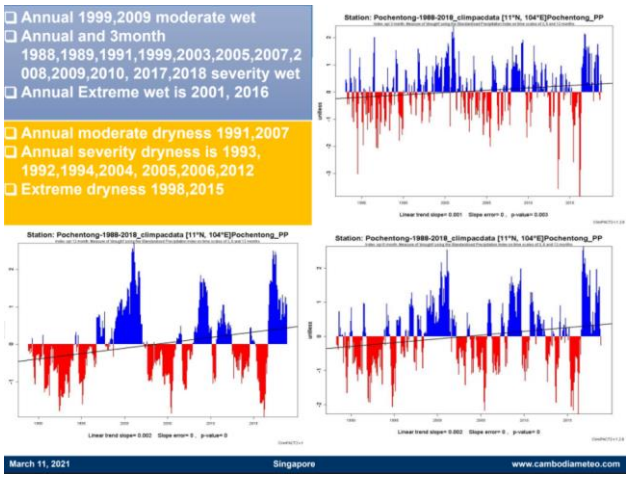
Ms Claire Trenham, CSIRO, Australia, presented the remaining part of the talk on technology. She started with the Synda tool that can be used to search and download files from the Earth System Grid Federation (ESGF) and "synchronise" the local data with that on ESGF. She then mentioned that there are also improved tools for CMIP6 model evaluation, such as the PCMDI metrics package and the ESMValTool which is a community diagnostic and performance metrics tool for routine evaluation of Earth system models in CMIP. For data analysis she mentioned about the Pangeo community, which provides a Python-based environment leveraging parallel computing on large scale datasets. Regarding improved CMIP6 tools for data access, she emphasized that for reliability, reproducibility, and collaboration, there needs to be connectivity of scientific computing (e.g., Github, Jupyter), automated replication of data from ESGF, and cloud technology to avoid the need and constraints of HPC access. She closed off her talk with a mention about the CMIP6 public cloud bucket, which is not yet mature, but a work in progress.



Overview of the Python-based Pangeo environment

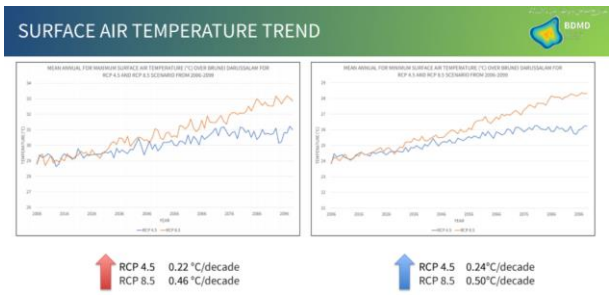
Introductory presentations by ASEAN representatives

1.8 **Mr Lonh Nrak, DOM, Cambodia,** kicked off the afternoon session of Day 1 themed around introductory sharing by the various ASEAN representatives on their experiences with using GCMs and regional climate studies. Mr Nrak presented his department's trend and variability analysis in Cambodia's monsoon-dominated climate with a focus on drought and wet-spell analysis using the Standardised Precipitation Index (SPI) and extreme temperature indices. Using daily time series data from four meteorological stations and the ClimPACT2 software, he showcased results of the trends, duration and intensity of the drought and wet spells. While temperature extreme indices exhibited a general increase across all stations, trends in the SPI had more variation across the stations (e.g. negligible SPI trend in southern Cambodia), a finding that Mr Nrak mentioned they are currently investigating. Mr Nrak concluded by expressing that while DOM lacks research experience with climate models, they are extremely keen to learn more in order to better support stakeholders.



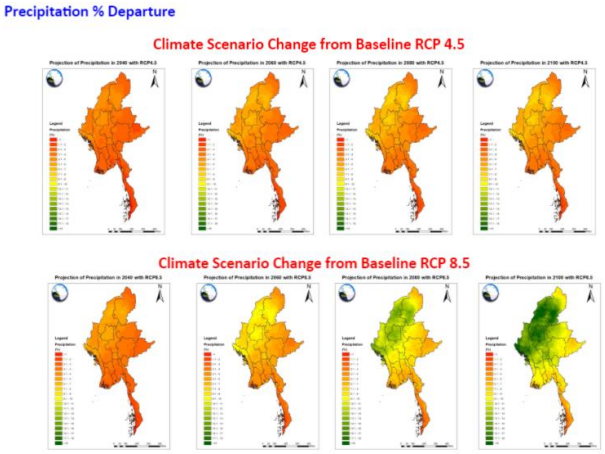
Analysis of Cambodia's station data with the Standardised Precipitation Index (SPI) produced using ClimPACT2.

1.9 **Mr Muhammad Khairul Izzat Haji Ibrahim, BDMD, Brunei Darussalam,** presented on his country's climate change study, which first looked at observational trends using data from one station at their airport which has records since the 1970s. He shared results that showed warming trends of daily maximum and minimum temperature at 0.15 and 0.31°C/decade respectively from 1970 to 2020. Yearly accumulated rainfall also increased at a rate of 100mm/decade from 1966-2020, while rainfall also increased for all but three seasons between the 1981-2010 to 1991-2020 periods. Future climate change was investigated using one GCM (HadGEM2-ES) and one RCM (HadRM3P, 25km) which projected continued warming of surface air temperature and enhanced precipitation over the 2006-2099 period under the RCP4.5 and RCP8.5 scenarios. In response to several audience questions, Mr Izzat added that as part of their follow-up work, they are investigating the drivers behind the observed rainfall trends and looking to supplement the observational analysis with several geographically close stations within the region.



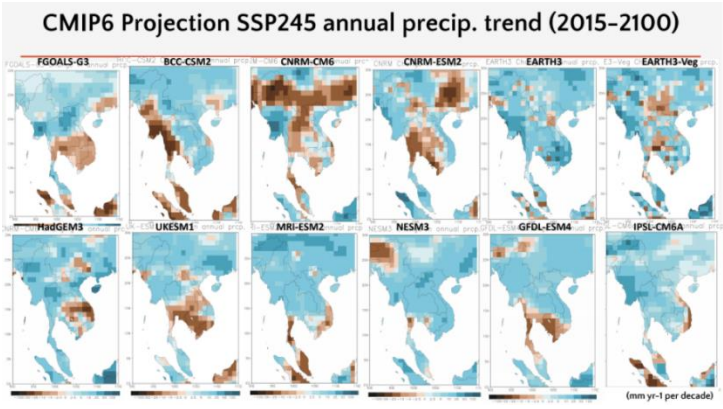
Trend analysis of observed surface temperature from Brunei's observational station.

1.10 **Dr Tin Mar Htay, DMH, Myanmar,** gave an overview of the climate change projection activities carried out by DMH for Myanmar and touched upon some of their contributions to national-level strategic action plans in 2012 and 2017. As part of their current work for Myanmar's Second National Communication (SNC) under the UNFCCC, they analysed CMIP5 projections packaged under the SimCLIM software tool. This dataset includes results from 40 CMIP5 GCMs and 13 RCMs from CORDEX under four scenarios: RCP2.6, RCP4.5, RCP6, RCP8.5 for 19 defined regions in Myanmar. One limitation of their study however was that they didn't manage to evaluate any of these CMIP5 models due to difficulties in obtaining sufficient station data for comparison. While SimCLIM does not include CMIP6 data at the moment, Dr Htay expressed that DMH plans to use CMIP6 data for their future studies.



Precipitation scenarios for Myanmar under the RCP4.5 and 8.5 scenarios.

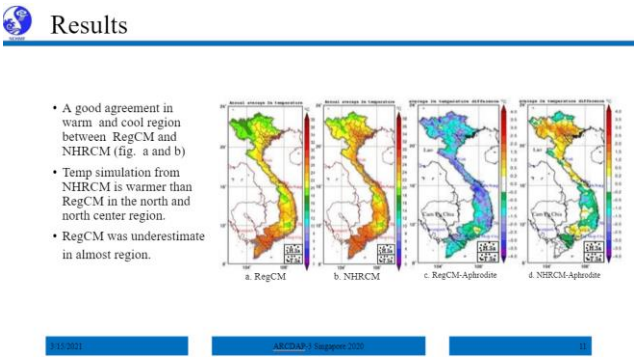
1.11 **Dr Chalump Oonariya, TMD, Thailand,** presented a study on mechanisms, impacts and future projections of interdecadal variations of rainfall extremes in Thailand. They evaluated historical simulations from 12 CMIP6 GCMs (BCC-CSM2-MR, BNU-ESM2, EC-EARTH3, FGOALS-f3-L, CNRM-CM6, CNRM-ESM2, HadGEM3-GC31-LL, UKESM1-0-LL, MRI-ESM2, NESM2, SAM0-UNICON, IPSL-CM6A-LR), obtained through their collaboration with the Chinese Academy of Sciences (CAS) together with the NCAR-GPCP and Climatic Research Unit gridded Time Series (CRU TS) observational datasets. They found that in general the GCMs were able to capture the annual rainfall intensity distribution up to 150 mm and through Canonical Correlation Analysis (CCA), that there is a strong correlation between SSTs in the Pacific and precipitation in Thailand. They then used gridded observation data to bias correct CMIP6 rainfall over the historical period of 1901-2014 via quantile mapping, which appeared not to work well for southern Thailand. For their climate projection work as part of their Joint China-Thai Research Project, they obtained CMIP6 multi-model projection via pattern scaling using the SSP126, SSP245 and SSP585 scenarios from 2015-2100. Beside mean state analyses, they also looked at extreme rainfall and Consecutive Dry Day changes under SSP245. For future



Trend of SSP245 projections for annual precipitation over Thailand and the surrounding region.

work, Dr Oonariya mentioned plans to perform statistical downscaling on the CMIP6 GCMs used.

1.12 **Mr Nguyen Manh Linh, VNMHA, Vietnam,** first introduced participants to the characteristics of the monsoon-dominated climate in Vietnam and the organization structure of Vietnam National Centre for Hydro-Meteorological Forecasting (NCHMF). Following this, he showcased studies that used two RCMs (NHRCM and RegCM4.2) to verify temperature simulations over the 1986-2007 period against the APHRODITE gridded observational dataset. Moving forward, Mr Linh shared that they are planning to evaluate CMIP6 GCMs and will most likely be using the RegCM for downscaling for their future climate change studies and research on climate processes such as the monsoons, tropical cyclones and heatwaves. In addition to gridded observation datasets that were used here, Mr Linh also shared that Vietnam has a network of meteorological stations with data since 1961.

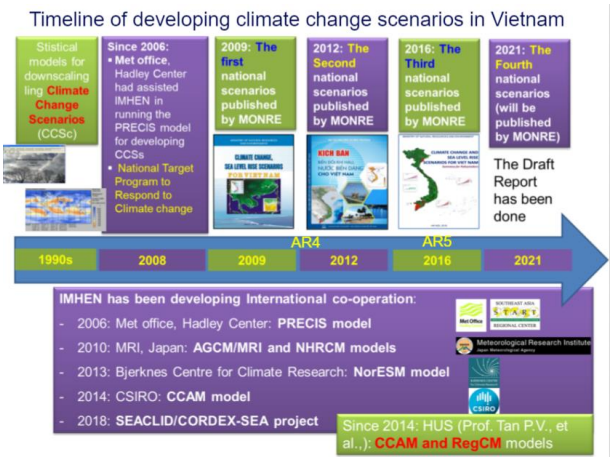


RCM temperature validation between RegCM and NHRCM over Vietnam in comparison with the APHRODITE gridded dataset.

2 Day 2: 16 March 2021

Introductory presentations by ASEAN representatives

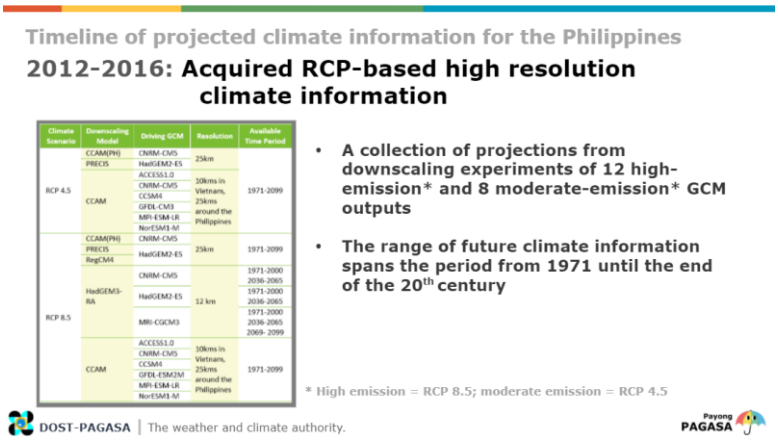
2.1 **Dr Mau Nguyen Dang, IMHEN, Vietnam,** introduced participants to IMHEN's methodology for developing national climate change scenarios for Vietnam and that their current work will be Vietnam's 4th national climate change scenario study. In 2009, IMHEN initiated Vietnam's first national report for climate change scenarios for 7 climatic regions using the SDSM statistical downscaling tool. Their second climate change scenario national report published in 2012 featured the use of 150 meteorological stations across Vietnam, both statistical and dynamical downscaling (PRECIS, AGCM/MRI), and expanded their analysis to include climate extremes. Their third climate change scenario was produced in 2016, which further expanded the use of dynamical models to five (WRF, PRECIS, CCAM, RegCM, AGCM/MRI) for downscaling 16 GCMs under RCP4.5 and RCP8.5 for future climate and 4 scenarios for sea level rise. Statistical bias correction methods were also applied on the downscaled climate projections. Projection uncertainties were accounted for and communicated to impact modellers/stakeholders through the provision of percentile ranges e.g. 10 to 90th percentile for temperature and 20 to 80th percentile for rainfall. Due to HPC and resource limitations in Vietnam, Dr Mau shared that at the moment IMHEN still runs their RCMs at partner institutes (e.g. UKMO, MRI, CSIRO, Bjerknes Centre for Climate Research-BCCR) and hence emphasised the importance of international collaborations for their future work. Dr Mau also stated that IMHEN expects to continue receiving support from their existing partners, as well as financial support from the United Nations Development Programme (UNDP) and World Bank for climate change projection studies in Vietmam. To end off, Dr Mau reiterated IMHEN's focus on developing cooperation within the ASEAN community in joint research, sharing experiences and data on climate change scenarios.



Timeline of the various climate change projections produced for Vietnam so far.

2.2 **Mr Wilmer Agustin, PAGASA, Philippines,** provided an overview of the climate change projections produced by PASAGA for the Philippines. Their first climate change projection report which was published in 2011, contained projections of mean precipitation and temperature from SRES scenarios for periods centred on 2020 and 2050 based on A2 (high emissions) and A1B ("best-case") scenarios using the PRECIS RCM downscaled from the ECHAM4 GCM. From 2012-2016, PAGASA worked on acquiring RCP-based high resolution

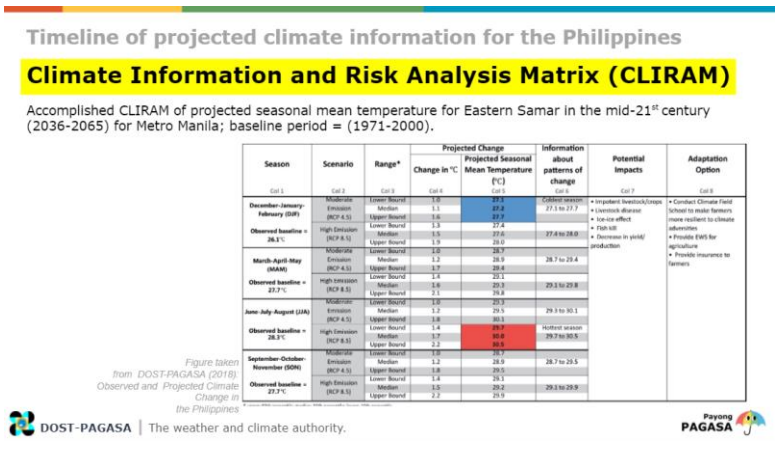
climate information, using 8 and 12 CMIP5 GCM outputs under the RCP4.5 and RCP8.5 scenarios respectively downscaled with a variety of RCMs (CCAM, PRECIS, RegCM4, HadGEM3-RA) at resolutions of 10, 12 and 25km. Results from this work contributed to their second national climate change report published in 2018 which provided a range of climate projections (5th, 10th and 90th percentiles) for the RCP4.5 and RCP8.5 scenarios.



Scenario-based and downscaled climate projections acquired by PAGASA from 2012-2016.

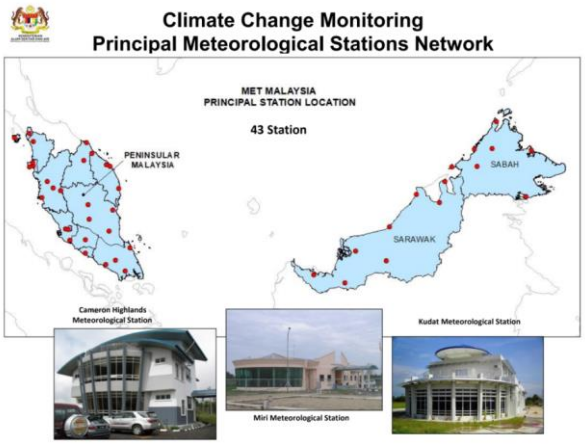
From 2015-2017, they worked towards improving the uptake of climate information for increasing climate change resilience via pilot projects and workshops in and around the Greater Metro Manila area while also receiving feedback from climate information users. Outputs from these efforts include a climate orientation pack, co-produced climate information, the Climate Information and Risk Analysis Matrix (CLIRAM) and guidance to support the integration of climate information for local planning.

Most recently, PAGASA produced the Philippine Climate Extremes Report 2020, which focused on observed and projected extremes computed using ClimPACT2 from a set of RCM data obtained through CSIRO (CCAM), PRECIS (DOST-PAGASA) and RegCM4.3 (CORDEX-SEA) as well as observational data from the SA-OBS daily high-resolution land observational gridded dataset, prepared at 25km spanning 1986-2000. For future work, PAGASA is looking into producing sector specific projections for water management and the health sector, although CMIP6 data is not being used yet. Additionally, they are developing an index for capturing tropical cyclones from climate projection data, though difficulties remain in identifying the intensity changes based on a scientific basis.



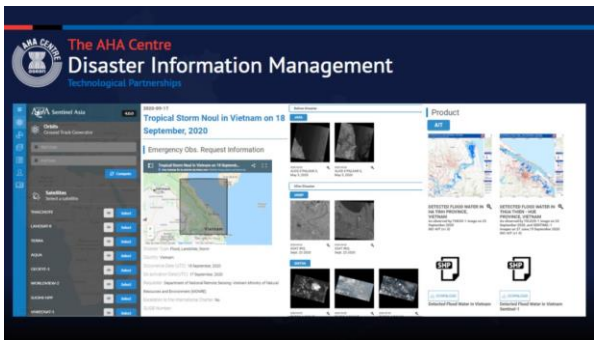
Climate Information and Risk Matrix (CLIRAM) produced by PAGASA as one of the climate services products for stakeholders.

2.3 **Ms Nurizana Amir Aziz, MetMalaysia, Malaysia,** talked about the operational medium range forecast services in Malaysia derived through the analysis of climate models from ECMWF, NCEP (CFSv2), JMA, IRI, APCC and NMME. In the area of climate change study, MetMalaysia is mainly involved in monitoring physical climate change trends, whereas high-resolution dynamical downscaling is mainly led by NAHRIM, contributing to vulnerability and adaptation (V&A) work that was reported in Malaysia's Third National Communication to the UNFCCC. Moving on, she elaborated on MetMalaysia's role in climate change monitoring, through their network of 43 principal meteorological stations, 400 auxiliary stations and 8 and 7 selected stations in Peninsular and East Malaysia respectively for coastal monitoring with temperature and precipitation data from 1966 and 1951 respectively. She shared time series graphs prepared using the observational data for max-min temperature and precipitation. Most stations showed increasing trends in both min-max temperature in west Malaysia, with min temperature trends generally larger. Rainfall exhibited similar non-trends for both Peninsular as well as East Malaysia. Looking forward, she shared that MetMalaysia is planning to downscale CMIP in the future at 5km resolutions, although a RCM hasn't been selected yet.



MetMalaysia's 43-station network for climate change monitoring.

2.4 **Mr Keith Paolo Landicho, AHA centre,** provided an overview of the AHA Centre's role key functions within ASEAN. As ASEAN's primary regional coordinating agency for disaster response, they deliver products such as disaster hazard updates, weekly updates, monthly review, seasonal outlooks, and the ASEAN Risk Monitor and Disaster Management review (ARMOR). Based on the ASEAN Disaster Information Network's (ADINet) records, 2302 disasters occurred in the ASEAN region from 2012-2020, with floods accounting for 58% of them. The highest annual number of disasters (530) was also seen in 2020 during this time period. He also shared about the importance of regional climate change impacts, adaptation initiatives and action plans towards mitigation discussed in publications such as the AADMER work programme for 2021-2025. Mr Landicho explained that at the moment, they make use of ASEAN climate projection data based only on agreements with individual countries for decision and planning purposes.



One of AHA Centre's disaster information products developed as part of their various technological partnerships.

2.5 **Dr Chua Xin Rong, CCRS, Singapore,** introduced the climate projection work carried out by CCRS and briefly discussed the previous V2 and the ongoing V3 climate change projections being developed for Singapore. She explained the motivations for the V3 project and its future downstream uses in sectors such as food security and water resources etc. through products catered towards climate resilience. She then compared the two projects, touching upon the RCMs used (SINGV-RCM for V3, HadGEM3-RA for V2), scenarios and resolutions (convection permitting), high temporal frequency (sub-daily for V3) data and uncertainty introduced by RCMs, before giving a brief overview of the V3 workflow and data dissemination. She shared about the GCM sub-selection methodology based on satisfactory performance of climatology, key processes over the region (ENSO, IOD, MJO, cold surge etc) as well as consideration of model independence. Lastly, she briefly covered the resolution and time-period details for the SINGV-RCM downscaling and mentioned CCRS's plans for the eventual downscaled data dissemination and communication via stakeholder reports and scientific papers.

Improvements in V3

	V3	V2
New Global Models	CMIP6	CMIP5
New Regional Model	SINGV-RCM	HadGEM3-RA
New Future Scenarios	SSP126, SSP245, SSP585	RCP4.5, RCP8.5
Higher Spatial Resolution	8km and 2km	12km
Higher Temporal Resolution of Rainfall	12min@8km, 10min@2km	Daily
Address Dynamical Downscaling Uncertainty	Yes – Additional simulations with WRF	No

Summary of the technical differences between the V2 and V3 projects.

2.6 **Dr Aurel Moise, CCRS, Singapore,** closed off Day 2's morning session with a general Q&A and discussion session on all the ASEAN introductory presentations. Dr Koh Tieh Yong was keen for further information on the differences between V2 and V3 with regards to downscaling, to which Dr Chua shared that in addition to the use of the new SINGV-RCM model with the Regional Atmosphere 1 – Tropical (RA1T) scheme, they are also aiming to address RCM uncertainty (which wasn't covered in V2) by downscaling the same GCMs separately with the WRF model and perform a comparison. Dr Moise posed a question to the audience about which projection scenarios from CMIP6 they would be interested in for their work. Mr Wilmer Agustin answered that PAGASA is interested in SSP245 and SSP585 due to their similarities with RCP4.5 and RCP8.5. In response to Dr Moise asking why they are not considering SSP126, Mr Agustin stated that those two SSPs would be easier to communicate to stakeholders due to their previous usage of the two RCPs, whereas SSP126 may be too "low" of an emission scenario to be of interest to stakeholders. Mr Francois Delage then suggested that it is very important to compare results across scenarios, although there may be data availability constraints for certain low priority scenarios.

Dr Chua Xin Rong then directed the last question of the session towards Mr Keith Landicho, on how AHA Centre defined flood events and whether tropical cyclones affect multiple categories (e.g. winds/storms/floods) in their definitions. Mr Landicho shared that floods and other disasters tend to be reported in terms of factors such as, affected families, persons, damaged infrastructure and costs of damages and sometimes, the specifics per hazard (flood-flood height, earthquake-intensity and magnitude, tsunami-inundated area, storms-

precipitation level/inundated area. etc. etc.) as outlined by international disaster reporting standards. A tropical cyclone will be composed of different hazards. Reports from the national disaster management organization of a member state serve as primary information sources, which are then coordinated by AHA Centre to the ASEAN member states for possible offers of assistance and need for international coordinated response.

CMIP for evaluating regional climate processes/applications

2.7 **Dr Aurel Moise, CCRS, Singapore,** started the first roundtable discussion of the workshop by sharing several key goals for ASEAN climate change study, e.g. key messages, recommendations, regional aspirations for CMIP6 analysis, rules and guidelines. He emphasized the need to develop a common framework for studying key regional climate processes and have a regional consensus on most relevant emission scenarios. He reviewed the recommendations from ARCDAP-1. One of the recommendations he emphasized was the development of a common dataset to standardise model evaluation. Next, he invited the participants from each country to share their experience, thoughts and understanding on CMIP6, downscaling methods used, scenarios and resolutions, key processes in the region and future aspirations in the context of national and regional climate change studies. The inputs from the participants were captured in Table 2.1. While Cambodia, Brunei Darussalam, Myanmar and Thailand participants shared their inputs during the session, due to lack of time, the remaining participants were requested to share their inputs via an online Google form.

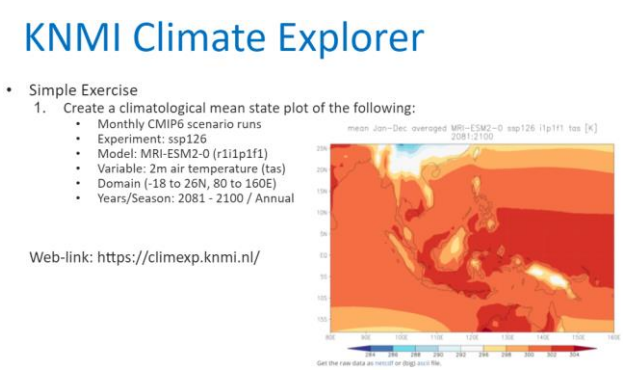
Institute	**CMIP6 comments**	**Downscaling methods**	**Scenarios & resolution**	**Key processes in the region**	**Aspirations for climate change studies**
BDMD	No experience	PRECIS only; keen to learn how to access/analyse and display information	RCP4.5 and RCP8.5	Temperature; Rainfall; MJO and IOD, ENSO	
CCRS	Conducted evaluation of CMIP6 models	Dynamical	SSP126, 245, 585 at 8km/2km resolution	Monsoons, ENSO, MJO, IOD	Provide value to stakeholders and advance our scientific understanding
DMH	No experience	External use of NEX-GDDP as well as SIMCLIM data (currently based on CMIP5)	RCP2.6, 4.5, 6.0, 8.5. We chose RCP4.5 and RCP8.5 as the most important for information	Tmax, Tmin, precipitation. IOD, ENSO and MJO analysis for current climate.	We have plans to use CMIP-6.

			dissemination. All using 1km SIMCLIM data.		
DOM	No experience	No experience in downscaling. New to regional climate change projections	Want to learn more on scenario choices	Monsoons and dry season; ENSO; would like to know more about ENSO impacts on Cambodia	
MetMalaysia	No experience	MetMalaysia, NAHRIM and UKM have experience using PRECIS and published climate change scenarios (for 100 years) in their NC-3 to the UNFCCC. MetMalaysia used GCMs: ECHM5, MRI-CGCM2.3.2, CCSM3, RCMs: RegHCM-PM, RegHCM-SS. MetMalaysia has just started a new development project for climate models and plans to use CMIP6	In the NC-3, the SRES A1F1, A2, A1B and B1 scenarios were used. In the new MetMalaysia climate models development project, we plan to use < 5km spatial and hourly temporal resolution	ENSO, MJO, IOD, Tropical Cyclones. Monsoon related processes such as cold surge, monsoon trough, Borneo Vortex. Extreme rainfall and temperature	Climate extremes
PAGASA	No experience but interested to acquire CMIP6 outputs for the SSP245 and SSP585	We use RCMs in downscaling, particularly the PRECIS and RegCM4. Also, we are currently doing sensitivity tests with WRF	For CMIP6 we are interested in the SSP245 and SSP585 scenarios, with pre-downscaling resolution of 50 – 100km. For downscaled projections we are interested in resolutions of 5 – 25km	Large scale processes, e.g. the monsoons, MJO, ENSO. We're also interested in the simulation of atmospheric convection	Application of the simulation outputs on impact modelling for sectors

			(and 2km, if possible)		
TMD	We are analysing CMIP6, but GCMs can't capture extreme rainfall well. Also, long term droughts	Collaboration with CAS (using FGOALS), using RegCM4 as well as statistical downscaling (Thailand developed)	SSP126, 245, 585 used. Stakeholder-required information needs 1km resolution over Thailand	Extreme rainfall is key interest. Monsoon, PDO, ENSO, long-term droughts (had a 12-month drought recently), sea level rise; MJO and extratropical cyclones as well in future	Use GPCP and CRU as evaluation data sets and station data
VNMHA	No experience on CMIP6 but want to use and verify in the future	Statistical method first; using the tools from the community to analyse and display the data. Secondly, using RCMs to downscale GCMs	RCP4.5, 8.5; < 10km resolution	Tropical Cyclone, extreme temperature and rainfall, monsoon, MJO, ENSO, sea level rise	

Table 2.1: Participant responses to roundtable discussion 1

2.8 **Mr Gerald Lim, CCRS**, **Singapore,** introduced participants to complimentary tools for CMIP exploration. He started with a discussion on the schematic diagram of the workflow for CMIP evaluation tools running alongside ESGF and highlighted that the focus of his talk would be around community tools for routine ESM evaluation. The first tool introduced was the KNMI Climate Explorer, a web-based tool with no data download required. Elaborating, he said that although it is fast and simple, some downsides were that the CMIP selection could be somewhat limited (e.g., only monthly scenario runs) and that users cannot define their own indices. Next, he gave a live demonstration on how to do simple data analysis using the KNMI Climate Explorer by plotting the ERA5 global mean precipitation time series. He further shared that one can not only

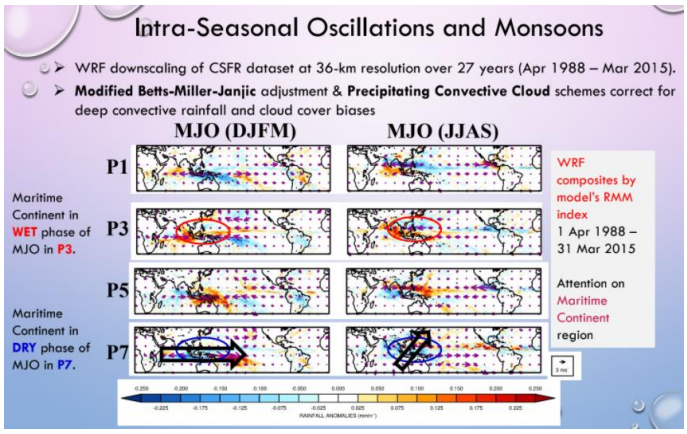


Exercise with the KNMI Climate Explorer to produce a temperature plot with the MRI-ESM2-0 GCM.

produce plots, but also download the data shown in the plot. He then asked the participants to perform a simple hands-on exercise using the KNMI Climate Explorer.

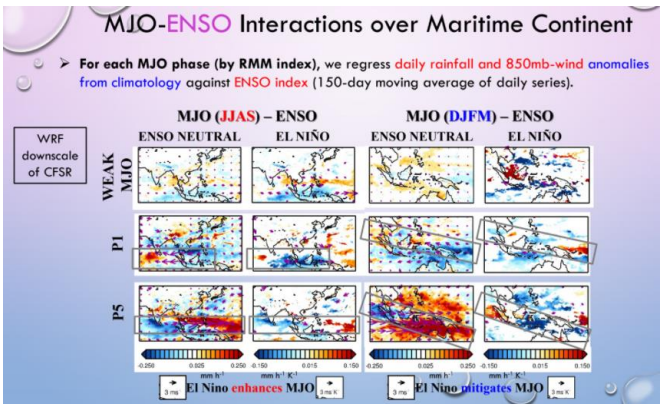
Subsequently, he moved onto more complex unix-based standalone applications such as ESMValTool and PMP that typically require local installation and data download. He continued with brief walk-throughs of the PMP and ESMValTool results webpages to demonstrate the types of metrics and figures that the tools could produce. He then concluded by sharing a Jupyter notebook worksheet designed for an ESMValTool based hands-on exercise that was originally planned for the physical ARCDAP-3 workshop.

2.9 **Dr. Koh Tieh-Yong, SUSS, Singapore,** presented his talk on intra-seasonal oscillations (ISOs) in SEA. He discussed the MJO, boreal summer intraseasonal oscillations (BSISO), MJO-ENSO interactions over the Maritime Continent, MJO-IOD interactions over MC, and finally gave an example of the impact of MJO on Malay peninsula rainfall. In the context of MJO, he introduced the Realtime Multivariate MJO (RMM) index that is used to track MJO. He presented results from his work on WRF downscaling of the CFSR dataset at 36km resolution over 27 years (Apr 1988 – Mar 2015). He then talked about the BSISO and discussed how it breaks the symmetry of the MJO across the equator and complicates the understanding of MJO. He highlighted the importance of recognising that ISOs propagate north-eastward during the boreal summer over the continental SEA and the Philippines and then talked about the bimodal index for the global tropical ISO.



Modelled MJO composites for four phases using the WRF RCM on the CSFR dataset.

Next, he talked about the MJO-ENSO interactions and mentioned that during the boreal summer (JJAS) El-Nino enhances the MJO, whereas, during the boreal winter (DJFM), El-Nino mitigates MJO. Subsequently, he talked about the MJO-IOD interactions, and mentioned that during boreal summer the IOD enhances MJO, whereas, during boreal winter (DJFM), IOD has a less coherent effect on MJO. Following this, he shared about the impact of MJO on extreme



Modelled MJO-ENSO interactions over the Maritime Continent with the WRF RCM.

rainfall over Malay Peninsula, and showed that heavy rain events are more likely when MJO is active up to 30 days in advance, and as MJO approaches its active phase over Malay Peninsula, the chance of heavy rainfall increases to around 70%. To round things up, he emphasized that a good MJO simulation in climate projections is important for good heavy rainfall statistics, and the CMIP6 GCMs that are used for downscaling should ideally have a good MJO representation.

Dr Dale Barker questioned what value add the WRF downscaling brought to the CFSR data and about the sensitivity of the results to other reanalysis products (e.g., ERA-5, MERRA-2 vs CFSR). Dr. Koh replied that they nudged the mid-tropospheric moisture field of the WRF model to the global dataset to achieve a good MJO simulation. Using the WRF downscaled products, the MJO's impact on the MC can then be analysed at higher spatial resolution. Regarding the second question Dr. Koh answered that his group has not looked at other reanalyses. He mentioned that although the large-scale features of MJO may not be too different between various reanalyses, the finer scale features would be different due to different spatial resolutions, which is especially important for the MC. Dr Aurel Moise provided a comment that for the GCM sub-selection component of V3, CCRS did look at the MJO using MJO Task Force-prescribed statistics such as the east-west power ratio, etc. He remarked that along with the MJO, there are other climate modes that drive extreme rain events over Singapore and the wider SEA. He also mentioned that CCRS has just finished downscaling ERA5 over the SEA domain, and it would be interesting to compare the MJO simulations with Dr Koh's results. Regarding the monsoons, he mentioned that once the monsoons propagate through this region, the IOD is pretty much dissipated and has a negligible impact.

2.10 **Dr Wilfran Moufoumia-Okia, WMO, Switzerland,** gave a seminar on enhancing climate services for resilient development. He presented some key results from the IPCC SR1.5 report released in 2018 and emphasized the importance of resiliency planning and development for risk mitigation. He talked about the integration of climate science into decision-making processes through the National Adaptation Plans (NAPs) and praised the growing involvement of NMHSs worldwide in NAPs. He touched upon the funding opportunities available at the Green Climate Fund (GCF) and expressed that while the benefits of investments in climate services greatly outweigh the costs, the capacity to deliver and access these services remains uneven and inadequate. He cited a statistic that

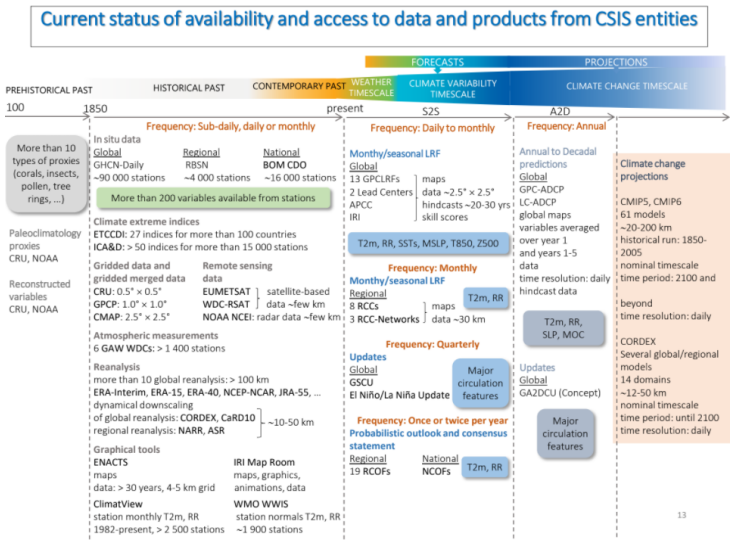
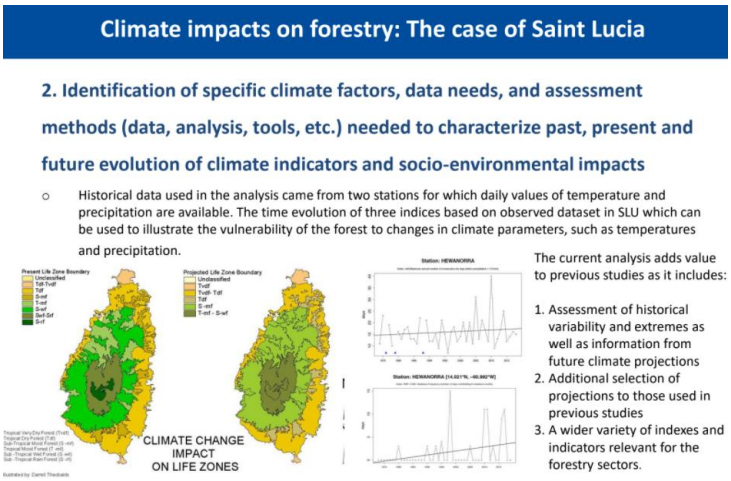


Table summarising how availability and access of climate data from CSIS entities varies with the timeframe of interest.

despite 44% of countries being capable of providing “essential” climate services, only 14% are capable of providing “full” climate services.

He then talked about the Global Framework for Climate Services (GFCS), specifically, 4 out of its 5 pillars, namely, the user interface platform, observations and monitoring, research, modelling and prediction, and capacity building. Next, he talked about the Climate Services Information System (CSIS), specifically, about functional descriptions and product development, operational infrastructure, climate services toolkit and capacity development. Following this, he introduced the scientific framework of the climate rationale produced by WMO and GCF, and mentioned the global climate indicators, context-specific indicators and high impact events. An example on the climate impact on forestry in Saint Lucia was then shared. To end his talk and the day, he informed participants about the Climate Information website, a data analysis platform developed by WMO and SMHI, that is targeted towards climate impacts and climate action using data from datasets such as those from CORDEX and CMIP.

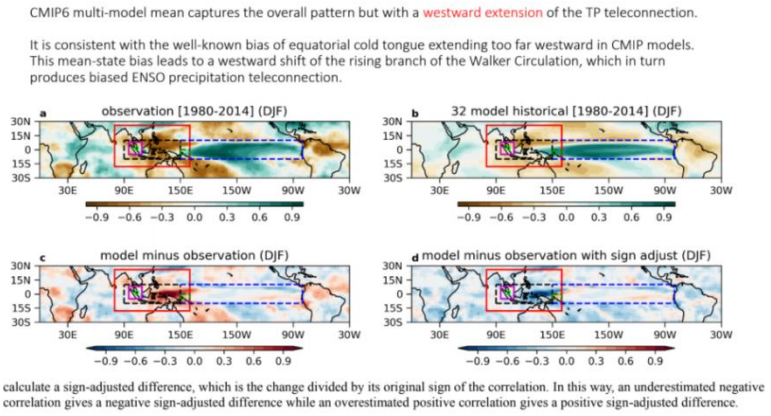


A case study of a climate impacts study on forestry over Saint Lucia.

3 Day 3: 17 March 2021

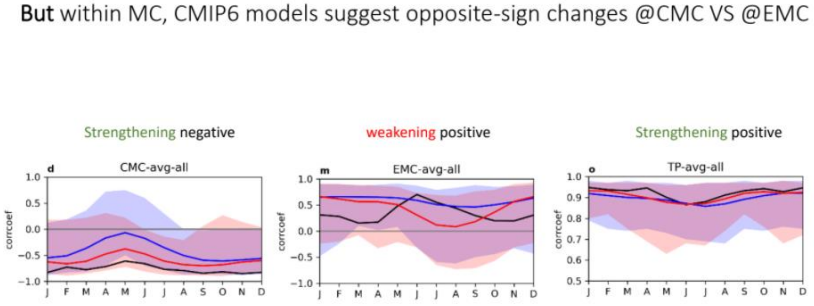
CMIP for evaluating regional climate processes/applications

3.1 **Dr Chen Chen, CCRS, Singapore,** gave a talk on her research study on ENSO-rainfall correlations over the Maritime Continent (MC), their representation in CMIP6 GCMs, and GCM projections of ENSO over the MC. Observations indicate that rainfall is negatively correlated with ENSO over the MC as a whole, which comprises a negative correlation over the Western and Central MC and a positive correlation over the Eastern MC. These correlations provide a major source of predictability for rainfall changes over the MC. The CMIP6 multi-model-ensemble mean captures the teleconnection well, except for a westward extension of the positive teleconnection response over the tropical Pacific. Models underestimate the magnitude of the negative correlation over the MC, which arises from an underestimation of the negative correlation over the central MC and tropical Pacific and an overestimation of the positive correlation over the eastern MC. These results suggest that CMIP6 model simulations of ENSO are realistic enough to make their projections of future change useful.



CMIP6 GCMs' overall ability to capture the ENSO pattern and teleconnections.

In a future business as usual scenario (SSP585), Dr Chen showed that 23/32 CMIP6 GCMs predict enhanced (more negative) correlations over the MC. These changes would be linked to stronger precipitation variability in the Pacific, as proposed in Power and Delage (2018). Within the MC itself, GCMs suggest that the magnitude of the correlation increases (more negative) in the central MC and decreases (less positive) in the eastern MC. She hypothesised that the change in the eastern MC could be due to changes in the mean circulation shift, as opposed to purely being related to ENSO variability. Her results also implied that the central MC can expect a higher predictability in seasonal rainfall when ENSO conditions are present, with the opposite

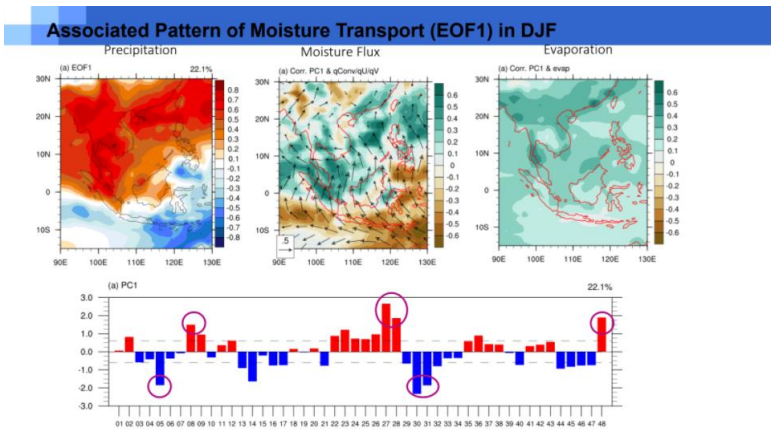


Projected ENSO-rainfall correlations over different domains. Blue: CMIP6 historical mean, Red: CMIP6 SSP585 mean, Black: Observation.

(lower predictability) being true for the eastern MC, which could have implications on future agricultural yield.

Dr Fredolin Tangang suggested that only models that perform well in capturing ENSO occurrences should be considered for the projections, to which Dr Chen clarified that ENSO performance was accounted for in the GCM sub-selection for V3, while also agreeing that it would be useful to compare results from her work (with all available CMIP6 GCMs) to the subset of GCMs with better ENSO performance. Dr Tangang made a further comment that teleconnections over the MC have complex seasonal and spatial characteristics, which would smooth out if averaged over a large domain. Dr Chen concurred about the importance of domain selection, citing an example of a strong seasonal variation that occurs in a domain around Singapore but not in a wider domain.

3.2 **Dr Senfeng Liu, TMSI, Singapore,** presented on behalf of **Dr Srivastan Raghavan**, work done by TMSI on evaluation of CMIP6 models in terms of their representation of precipitation and moisture budget variables over Southeast Asia. They characterised the monsoonal representation in boreal winter (DJF) and summer (JJA) in CMIP6 GCMs relative to observations in terms of the different elements of the moisture budget: precipitation, evaporation, and moisture convergence. The bulk of the model bias in precipitation was attributed to the moisture convergence component, as opposed to evaporation. In DJF, precipitation biases were mainly positive over the ocean; in JJA, moisture flux convergence biases were positive over the ocean and negative over the Indochina Peninsula. Increasing model resolution had a positive, but non-significant, correlation with model performance. In addition, they performed empirical orthogonal function (EOF) analysis on the inter-model spread to obtain the principal components of precipitation bias. Dr Liu showed that the first mode in DJF is associated with southerly moisture flux, while the first mode of JJA shows a positive precipitation bias in the south. Based on their evaluation of precipitation-related metrics, they recommended the NorESM2-MM GCM for downscaling.

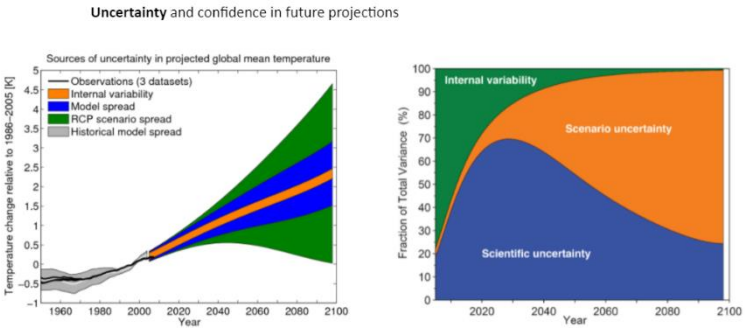


The leading EOF derived from CMIP6 precipitation bias in DJF and the corresponding moisture flux pattern.

Dr Muhammad Eeqmal Hassim suggested that Dr Liu could look into the individual components (circulation and specific humidity) of moisture convergence to explore which of them dominates most of the GCM biases. Dr Hassim was also keen to know the physical mechanisms that would explain the precipitation bias EOFs, to which Dr Liu suggested that the bias might be related to common dynamical core or physical parameterizations used in the GCMs. Dr Hassim added that the representation of monsoons might also play a role. Dr

Prasanna Venkatraman asked for details about the calculation of moisture convergence, to which Dr Liu indicated that they used monthly specific humidity and wind at all pressure levels in the raw GCM data, integrated from surface pressure to the top of atmosphere.

3.3 **Dr Aurel Moise, CCRS, Singapore,** opened the second roundtable discussion with an overview of the regional climate processes over the Maritime continent: deep convection, monsoons, MJO, ENSO, IOD, and Walker circulation, tropical cyclones, tropical -extratropical interactions, South China Sea cold surges and the Borneo Vortex. He then noted that process understanding is one of key factors in uncertainty assessment and discussion of future climate changes. He further emphasized the importance of having multiple lines of evidence to support any discussion of future changes. Uncertainty in predictions arise from three components: internal variability, scenario uncertainty, and scientific uncertainty, which have differing contributions to the overall uncertainty as time passes. Internal variability dominates on short timescales (e.g. within the next decade) while scenario and scientific uncertainty plays larger roles on longer timescales (e.g. near the end of the century).



The different sources of climate projection uncertainties and how they vary in different timeframes.

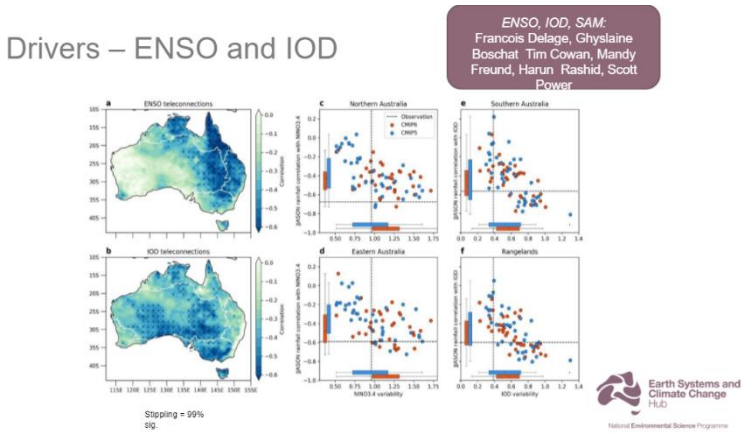
Dr Moise then solicited feedback from the participants regarding the evaluation and uncertainty assessment regarding key climate processes. The participant inputs for this discussion are summarised in Table 3.1 on the next page.

Institute	What are some key climate processes for your country/region ?	What is your current confidence in your climate change projections?	Have you assessed uncertainty in your climate change projections? if not, do you plan to in your future studies?	What data did you use to evaluate climate processes? what data do you plan to use for future studies?	Any additional comments
BDMD	ENSO, IOD, MJO.	No experience in projections other than the PRECIS we have done previously. Need more climate model projections.	No.	Any available data.	We do not have a dedicated climate modelling team.
CCRS	Deep convection, monsoons, MJO, ENSO, IOD, and Walker circulation, tropical-extratropical interactions, South China Sea cold surges, Borneo Vortex.	V2: temperature increases are relatively robust, less so for precipitation	Scientific and scenario uncertainty were addressed by downscaling different GCMs and scenarios. In V3, we further quantify regional model uncertainty with additional simulations with WRF. We will provide a percentile range of changes in climate variables.	V3: Multiple reanalysis (ERA5, JRA55, MERRA2) and observational datasets (e.g. FROGs)	
DMH	ENSO, IOD, MJO.	Models underestimate monsoon precipitation at coastal zones, overestimate at dry zones.	Ensemble mean, percentage departure for precipitation and anomaly for max-min temperature.	WorldCLIM 2, CHIPS, GPCP APHRODITE, CHIRPS.	Want to develop climate change projection s with CMIP6.
DOM	Drought, wet spells, floods	Daily temperature and precipitation for river basins for water resource management	No, but we wish to use for our master plan	Daily and monthly temperature and precipitation for water resource management for agriculture, industry (hydropower)	

PAGASA	IOD; TC; ENSO; MJO Also, cold surges; ITCZ	No study done on how CC impacts monsoon; just trends in TAS/PR. Dependency on HPC capability.	Model biases; ensemble biases; Mainly used the ensemble mean. Percentile range communicated; No weighting scheme.	Gridded data; Aphrodite; SACA&D/SA-OBS data (daily high-res data) for extremes; Downloaded to own systems.
TMSI	ENSO, IOD, Monsoon, ITCZ.	Projections still have great uncertainty. Trying to reduce uncertainty by using the emergent constraints. More historical observed data and multi-model ensembles are combined to improve the projections.	Yes. We have assessed precipitation for 37 CMIP6 GCMs over SEA.	ERA5 and JRA55, CMIP6 experiments including historical, SSP126, SSP245, SSP370, SSP585. For future, HighResMIP, GMMIP. WRF downscaling output.
VNMHA	TC, MJO, Monsoon, cold surges.	Our organization has not performed climate change projections yet. It will depend on the HPC capability, but it has been promised for this to be carried out.	No	Synoptic stations, Aphrodite, rainfall from GPCP

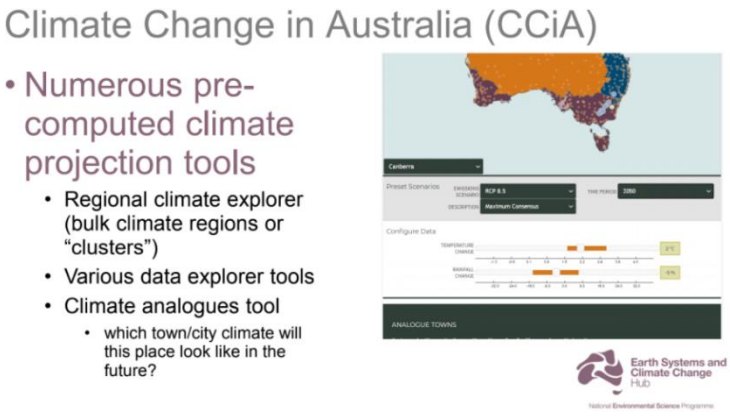
Table 3.1: Participant responses to roundtable discussion 2

3.4 **Mr Francois Delage, BOM, Australia**, delivered a presentation on the climate change research and next-gen projections in Australia. He shared results from the model evaluation of Australia and the surrounding region's climate, which involved 27 CMIP6 and 47 CMIP5 GCMs and explored the mean state evaluation of SST biases, the cold tongue bias, ENSO and IOD teleconnections. In particular, cold tongue bias was still present in CMIP6 GCMs but incrementally improved compared to CMIP5. He then talked about the differences in projected rainfall changes between an ensemble of GCMs that get wetter with global warming ("wet") against an ensemble of "dry" GCMs separately for CMIP5 and CMIP6. They found that there was a similar pattern of responses for the change in precipitation for the dry ensemble minus the wet one, though this difference was weaker in CMIP6. He suggested that the dry-wet differences are partly linked to the biases in CMIP5 but less so in CMIP6, while the Southern hemisphere land response is similar between the CMIP generations.



ENSO and IOD-rainfall teleconnections assessed for the CMIP6 ensemble over Australia.

Ms Claire Trenham, CSIRO, Australia, continued with the next section of the talk, discussing the value of RCMs and the new concept of "realised added value", where a range of different RCMs not only provide a better simulation of current climate, but also potential provide a different signal from its driving GCM. She shared a brief example of this added value with the modelled rainfall over the Australian alps. Dr Mau was keen to know how projections were modelled for Australia's small islands, to which Ms Trenham clarified that the same SSP pathways were applied and that good bathymetry is key for accurately representing the islands. Ms Trenham then shared a number of climate projection applications and tools packaged within the Climate Change in Australia (CCiA) website. She highlighted the climate analogues tool which draws parallels between future climates in Australian cities with that of the current climates in other cities around the world. She then shared about their latest

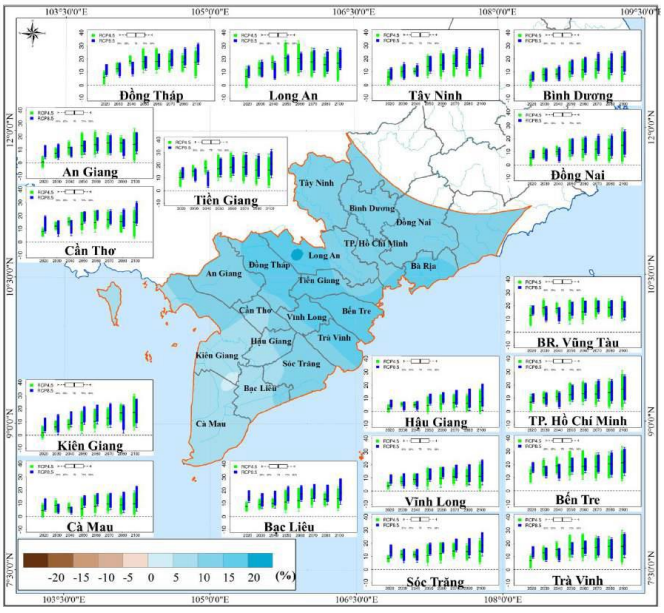


Features of the Climate Change in Australia (CCiA) website.

work on warming level projections for temperature and rainfall in line with the Paris agreement (+1.5, 2, 3 and 4 °C since pre-industrial 1850-1900).

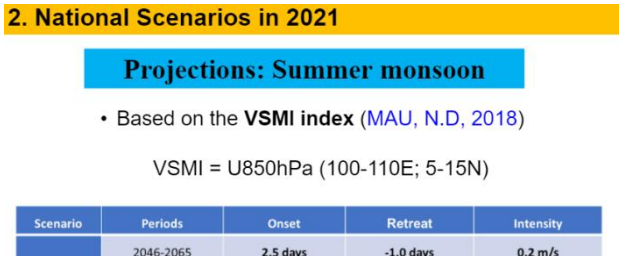
Dr Simon Marsland, CSIRO, Australia, then ended their presentation with an overview of several upcoming projection projects such as downscaling with the potentially the BARPA, CCAM, WRF RCMs and work with Climate and Resilience Service Australia (CARSA) and the National Environmental Science Program (NESP) 2.

3.5 **Dr Mau Nguyen Dang, IMHEN, Vietnam,** gave a detailed presentation on the development of National Climate Change Scenarios (VNCC) for Vietnam in 2016 and discussed the plans for an updated version to be published in 2021. As mentioned in his talk on Day 2, the 2016 VNCC involved the use of 16 CMIP5 GCM-RCM downscaling combinations from 5 RCMs (PRECIS, CCAM, RegCM, clWRF, AGCM/MRI) at resolutions between 10 to 30km. Bias corrections were applied, via quantile mapping (QM) method for daily rainfall and the mapping of probability density functions (as explained in Amengual et. al, (2012)) for daily temperature. Uncertainty was handled by using the 10 – 90th percentile for temperature and 20 – 80th percentile for rainfall, as defined by the in total, 16 members of projections produced from the RCMs. Projections at detailed provincial level were provided in the report, with surface temperatures projected to rise by 1.9 – 2.4 °C on average in the North and 1.7 – 1.9 °C in the South under RCP4.5, and by 3.3 – 4.0 °C in the North and 3.0 – 3.5 °C in the South under RCP8.5 by the end of the 21st century. Similar information was provided for rainfall and also sea level rise which covered 28 coastal provinces and islands of Vietnam.



Provincial level projected change in annual rainfall (%) over Southern Vietnam for RCP4.5 and 8.5.

Dr Mau then moved on the updated national scenarios set to be published in 2021, which will include additional projections from 10 CMIP5 GCM-RCM pairs with 4 RCMs (RegCM4, PRECIS, WRF, RCA3) from the CORDEX-SEA database. Projections under RCP2.6 and RCP6.0 will also be included. The Cumulative Distribution Function transformation (CDFt) algorithm was used for bias correcting daily rainfall projections in this study. Additionally, projections for

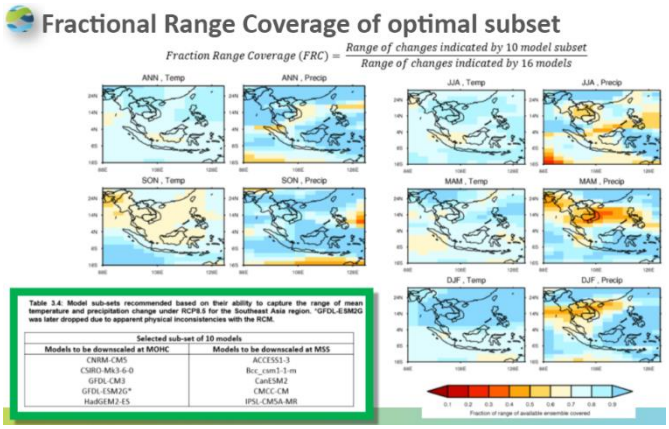


Summer monsoon projections using the VSMI index for Vietnam's 2021 updated national climate change scenarios.

extremes (using ETCCDI/ET-SCI indices such as Rx5day) and the summer monsoon based on their VSMI index (Mau, 2018) will be included. Dr Mau concluded his sharing with IMHEN's expectations for the next VNCC in 2025-2026, where they hope to update projections with CMIP6, add more RCMs and GCMs to reduce uncertainties, analyse more extreme events and strengthen their international collaborations.

Dr Koh was keen to known if IMHEN had tested the reliability of the stationarity assumption behind the QM bias correction method, to which Dr Mau shared that while they had not scrutinised this aspect of the algorithm, they updated the algorithm to CDFt for their 2021 report due to empirical problems they observed with the corrected rainfall in some regions. Ms Aziz asked if IMHEN had done specific projections for dry spells. Dr Mau replied that while they don't explicitly have dry spell projections, they do use drought indices such as the Keetch-Byram Drought Index (KBDI) instead. He noted the projections suggest increases in drought intensity but not significantly so for duration.

3.6 **Dr Muhammad Eeqmal Hassim, CCRS, Singapore,** gave the final talk of the day on the strategic sub-selecting of GCMs for downscaling in the V2 project. From the initial set of 43 CMIP5 GCMs, 10 passed the various criteria to be selected for downscaling which included, being able to span the range of projections, model independence, ability to accurately simulate historical climate, regional climate processes (e.g. ENSO, monsoons) and large-scale features (ITCZ migration, cold tongue bias). He stressed that the main objective was to discard GCMs that were deemed "implausible", rather than to select the "best" models. While 16 GCMs were initially not eliminated from 47, this was further narrowed down to a selected 10 by evaluating the Fractional Range Coverage (FRC) of different combinations to obtain an optimal subset. These steps thus allowed the final subset of chosen GCMs to maximise the range of projections from the GCMs while also avoiding models in which they had the least confidence.



CMIP5 GCM sub-selection via the fraction range coverage (FRC) method in the V2 project.

Ms Trenham was curious if the decision to downscale the CSIRO-Mk-3-6-0 GCM even though its performance was not "satisfactory" was a deliberate choice to keep some of the 'weaker' model representation in. Dr Hassim confirmed that this was indeed the case in order to capture a range of GCM projections. Mr Agustin asked if observations were used as a reference when looking at the range of GCM projections, to which Dr Hassim replied that they only looked at the range of future projections in the full GCM ensemble. They also computed individual model correlations to the full-ensemble mean to see how much of an outlier a model is (or not) relative to the ensemble-mean.

Some questions and discussions followed on the topic of bias correction. Dr Koh suggested that CCRS should perform QM on historical simulations and on warmer and cooler years to check for any significant differences in these or if they have dependencies on any variables eg: average surface temperature. He also asked what variables from the SINGV-RCM will be bias corrected, stating that he feels bias correcting every variable would be throwing out a lot of the utilities of the RCMs and should only be used in cases with obvious mismatches in data. Dr Sandeep Sahany shared that for V2, bias correction was applied for temperature, rainfall, relative humidity and winds as requested by stakeholders (e.g. aviation industry). Dr Fredolin Tangang also commented that it is best to exercise caution with bias corrections and not to over-apply them. Ending off, Dr Aurel Moise noted that the final bias correction method for V3 hasn't been selected yet and highlighted that it will be done on the 2km data for stakeholder usage and impact studies. Acknowledging that bias correction is a highly complex field on its own, he said CCRS will be sure to also look at the unbiased representation of the fields for a complete comparison.

4 Day 4: 18 March 2021

Breakout room discussions

4.1 **Dr Aurel Moise, CCRS, Singapore,** began the day with a recap of the past three days, thanking everybody for their presentations and contributions, as well as sharing the inputs that were submitted for the roundtable discussions so far.

4.2 **Dr Aurel Moise** proceeded to brief participants on the subsequent breakout room discussions. Participants were split into three virtual breakout rooms to facilitate specific discussions on three topics, each led by a scientist:

Room 1: Rules and guidelines for CMIP/ RCM/ Climate Data use
Room 2: Limitations of CMIP6/ GCMs/ RCMs output for regional evaluation
Room 3: What would you want in a regional best practices document for CMIP6 /RCMs and future climate projection studies?

Breakout room 1 was led by **Dr Sandeep Sahany**, who began the session by sharing some of his ideas on the topic to kickstart the discussion, before opening the floor to the participants to contribute to the ideas he raised. Together, the group identified certain key datasets that are useful for regional climate analysis. This included CMIP, CORDEX-SEA, NEX-GDPP and also several CMIP experiments that while none of the countries are using so far, will be exploring things of relevance to regional climate e.g. DCPP and GMMIP. Dr Sahany also gathered a consensus on key variables for climate impact studies (e.g. daily + hourly rainfall and its extreme percentiles, 10m humidity, wind gusts, derived indices like the heat index and SPI), processes, their associated metrics (e.g. RMM phase for MJO, 850hPa winds for monsoons, NINO3.4 SST and its correlations with rainfall) and common tools for climate data analysis (Python, MATLAB, CDO, Pangeo).

Dr Muhammad Eeqmal Hassim spearheaded the discussion in breakout room 2 and sought to gather participants' opinions on the limitations of the various scales of climate modelling and how they should be used in a complementary manner. Participants were in agreement that the primary deficiencies of GCMs included the low spatio-temporal resolution, inability to resolve small scale processes and its related implications such as model biases and use for extremes representation. Data accessibility was also raised, with most participants unfamiliar with access portals such as ESGF. They then identified ideal resolutions for representing different processes, e.g. < 5km for small scale processes and acknowledged that there is often a balance that needs to be struck between computational expense and stakeholder requirements. Ways to use GCMs and RCMs in a complementary manner include understanding their pros and cons, the features that benefit most from downscaling and ensuring that scales of representations remain broadly consistent.

Dr Aurel Moise headed the breakout room 3 which aimed to seek participants' inputs on what they envision in a regional best practices document for CMIP6/RCM future climate projection studies in SEA. Dr Moise felt that such a document will offer the region an invaluable resource in the domain of delivering robust climate change information for all levels of competency and experience. He broke the discussion up into five key areas, what participants would like to see in a best practices document in terms of (1) key topics that would benefit from a regional consensus, (2) dataset recommendations and access, (3) how to address uncertainty, (4) any further recommendations, (5) what linkages there are to the national impact research in ASEAN countries. Participants agreed that a consensus should be reached on the recommended GCM sub-selection methodology, projection scenarios and on metrics to analyse extremes such as rainfall/ floods. Recommendations for handling uncertainties included the use of ensemble approach, sensitivity studies as well as process-based analyses. Key impact sectors identified were agriculture, water resources, energy, urban planning, health, disaster management.

4.3 The participants reconvened for a plenary sharing of the ideas discussed across the three breakout groups, with feedback led by **Dr Aurel Moise** and **Dr Simon Marsland**. All participants were welcome to provide additional inputs to any of the other breakout discussions which weren't involved in. Ms Nurizana Amir Aziz elaborated on the heatwave warning system currently employed by MetMalaysia, sharing that it has 3 temperature-based levels, (1) Watch: 35 – 37°C, (2) Heatwave: 37 – 40°C, (3) Emergency: 40°C and above. She also shared that at least for the current year, they have experienced every day at least one district of Malaysia that will have temperatures that enter "Watch". Stronger incidences also tend to occur during the Southwest monsoon and ENSO events. While relative humidity is not a factor in this warning system due to its typically high value throughout the year, it does decrease during the Southwest monsoon and haze period. Dr Moise was interested to know if any of the ASEAN countries are currently using humidity for their heatwave or heat stress indices and have deployed any form of heat stress monitoring networks that use e.g. wet bulb globe temperature (WBGT) sensors. Mr Wilmer Agustin commented that PAGASA uses their own heat index which is based on an identified range of values for humidity and daily maximum temperature. He explained that their concern with several currently accepted heat index formulas is that they are typically designed for mid-latitude weather, rather than the tropics. Mr Agustin expressed that PAGASA would be interested to learn about indices that can be calibrated for the tropics, if any.

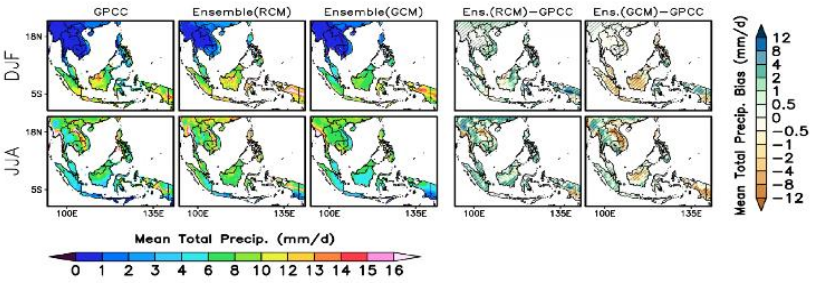
Regarding regional downscaling, Dr Moise commended a point brought up by breakout room 2 on high-resolution ocean modelling, remarking that all regional downscaling efforts so far have only been on the atmosphere components of the GCMs. As sea level rise is a pertinent issue for most ASEAN countries, it will be extremely useful to also stock-take the region's efforts in accessing sea level rise projections so far and think about what high resolution regional simulations are and will be available soon. Dr Simon Marsland added that the use of wave models to capture storm surges and the impacts of future sea level rise will be helpful.

The final discussion point of the session brought up by Dr Moise was on the HighResMIP experiments of CMIP6, which he noted had not been discussed much throughout the workshop.

Dr Marsland mentioned that 36 GCMs have so far uploaded data to the HighResMIP database on ESGF and felt that it should be likely that some centres will extend the end of the high-resolution future simulations to 2100. Dr Aurel Moise ended the session with a comment that a comparison between high-resolution coupled GCMs with the atmosphere-only RCMs to probe the impact of ocean-atmosphere coupling would be an interesting science question to contribute to.

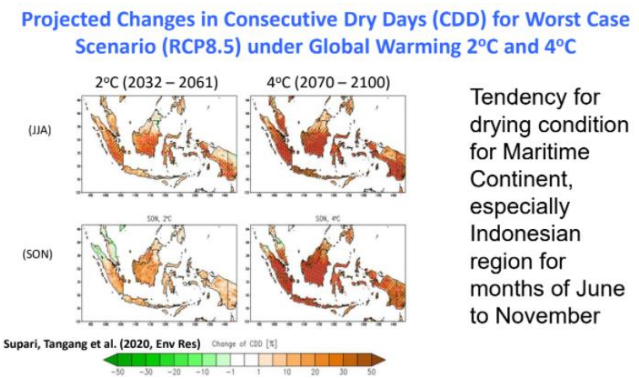
Downscaling GCMs: current work by CCRS and CORDEX-SEA

4.4 **Dr Fredolin Tangang, UKM/CORDEX-SEA, Malaysia,** delivered his presentation on the history and progress of the Coordinated Regional Climate Downscaling Experiment for Southeast Asia (CORDEX-SEA). Phase 1 has been completed, where 11 GCMs and 7 RCMs were downscaled at 25km by 25km resolution. Phase 2, where smaller subdomains will be downscaled at 5km resolution, is still ongoing. The ESGF data node for the data is hosted in Bangkok, while the index node is in SMHI. He was pleased to share that CORDEX-SEA data is being used widely by many including the vulnerable impact assessment community and the IPCC regional atlas, as well as national agencies in Vietnam and Indonesia. Future plans for CORDEX are under way, including ultra-high resolution <5km runs, downscaling CMIP6 GCMs, as well as regional atmosphere-ocean coupled runs. Dr Tangang then showcased some precipitation results from phase 1 of CORDEX-SEA. He showed that the downscaled RCM simulations were broadly consistent with the driving GCMs, with some areas of added value (e.g. over Borneo in DJF) that allow the simulations to better match GPCC observations.



Mean total precipitation comparisons between GPCC (observation), CMIP5 ensemble and the CORDEX RCM ensemble.

He also displayed the projected changes in mean seasonal rainfall, 850hPa divergence, annual extreme indices such as the number of consecutive dry days (CDD) under the RCP8.5 scenario, which implied heightened drought risk. He remarked that dry conditions could also be exacerbated by El Nino conditions. Dr Muhammad Eeqmal Hassim noticed the RCMs reversed the sign of the JJA projections from GCMs (from positive to

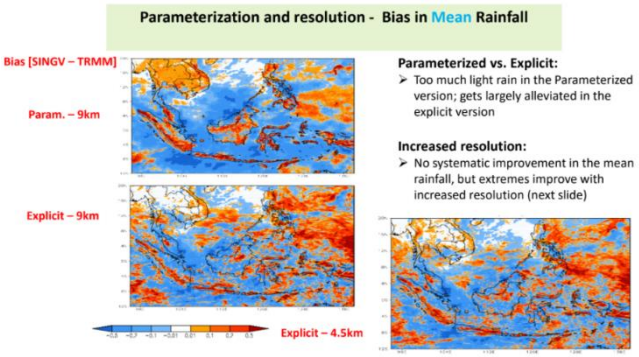


Projected changes in Consecutive Dry Days (CDD) for RCP8.5 over the CORDEX-SEA domain.

negative) over continental SEA and asked if Dr Tangang has investigated why that is the case? Dr Tangang noted that this result was not uncommon. Given that the plot is of the ensemble mean, the individual model simulations will need investigating. He emphasized that the data is available for further analysis and publications and noted that publications are not just important in terms of scientific impact, but also for contributing to the IPCC assessment. Dr Aurel Moise remarked that even though the IPCC 6th assessment (AR6) has closed, regional papers will continue to play a role in AR7. Dr Koh then asked how the RCMs performance was for temperature, Dr Tangang mentioned that a group had been assigned to look into temperature, but they are yet to complete their analysis.

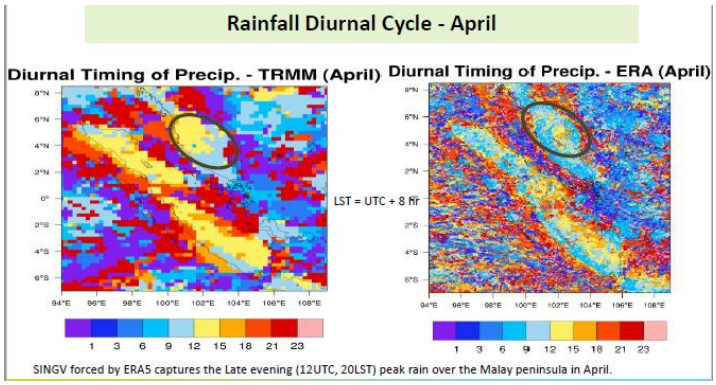
On the point of ensemble averaging, Dr Moise noted that there was a discussion in the CMIP6 community on whether to use the ensemble mean or to pick subsets based on their ability to represent processes, and asked if there was a similar discussion in the regional modelling community. Dr Tangang said that there were two schools of thought. Some believe that having more models is better from a statistical point of view in the sense that more models are sampled. Another method is to evaluate the models based on their skill in simulating present day climate, but projections from those models could still diverge. Dr Moise noted that model skill is one metric and that process-based metrics could also be used. Dr Tangang agreed and added that going the statistical route tends to be the easier choice and noted that tuning the model does not imply a removal of bias. He remarked that CORDEX is a good avenue for training practitioners to embark on deeper scientific analysis (e.g. to interpret the physical mechanisms underlying model bias).

4.5 **Dr Prasanna Venkatraman, CCRS, Singapore,** gave an update on progress on Singapore's 3rd National Climate Change study (V3). V3 will use the SINGV-RCM, which benefits from the science developments in SINGV as part of a seamless weather-climate strategy. SINGV-RCM will be run with a larger domain relative to Singapore's 2nd National Climate Change Study (V2) that will support CORDEX submission. He provided an overview of the experiments that had been performed in transit SINGV from a NWP model to a RCM. He showed that moving from a parameterized to explicit convection scheme led to improvements in the representation of extreme rainfall over land, as well as the timing of peak convection and diurnal cycle. He also showed some preliminary results from 2km high resolution downscaling simulations in V3. Relative to the 30km ERA reanalysis, there were improvements in the simulation of regional features of the diurnal cycle.



Comparison of the mean rainfall biases in SINGV when using parameterised vs explicit convection schemes.

Dr Koh Tieh Yong noted that the diurnal cycle over Singapore differs across seasons and asked Dr Prasanna if he would investigate in greater detail. Dr Venkatraman indicated that more detailed analysis has been planned. Dr Fredolin Tangang remarked that the dry bias in the rainfall simulation over the east coast of the Malay Peninsula over DJF is similar to that in many of the models in CORDEX-SEA. He commented that these models may not be simulating the right mechanism (e.g. cold surge, Borneo vortex). Dr Venkatraman noted that resolution did not seem to play a major role in this bias, and that further process-based analysis on the cold surge has been planned. Dr Aurel Moise noted that the bias over the Malay peninsula could also be related to the cold tongue bias and that cold surges were considered in the CMIP6 evaluation.



Comparison of the diurnal timings of precipitation between ERA5-driven SINGV-RCM and TRMM reference observation in April.

Dr Tangang also felt that 8km seemed to be a little coarse for using explicit convection. Dr Venkatraman and Dr Moise clarified that explicit convection showed improvements over parameterized convection. Separately, increasing the resolution from 8km to 4.5km did not lead to significant improvements, thus the 8km resolution was selected for reduced computation cost. Dr Moise noted that the improvements from using explicit (vs parameterized) convection could be domain dependent, remarking that Dr Elizabeth Kendon's group at the UKMO did not find significant improvements over the UK/Europe domain.

Dr Koh additionally commented on the rainfall histogram between resolutions at 8km and 2km versus station/TRMM data. He was curious to know if the improvements from increasing resolution from 8km to 2km justified the increased computational cost. Dr Prasanna noted that evaluating these results against station data was worth investigating.

4.6 **Dr Aurel Moise, CCRS, Singapore,** led the final roundtable discussion on the ASEAN countries' current plans and recommendations for ARCDAP-4. He began by asking participants to think about what will be done over the coming 12 – 15 months in your country with respect to climate change projections and listed several possibilities such as downscaling, investigating decadal variability and working on climate data applications. Some of the suggestions he had with regards to ARCDAP-4 were to conduct face-to-face practicals on CMIP/RCM data access, analysis, visualisation, and climate change communication. The detailed inputs that he collected from the various participants are summarised in Table 4.1.

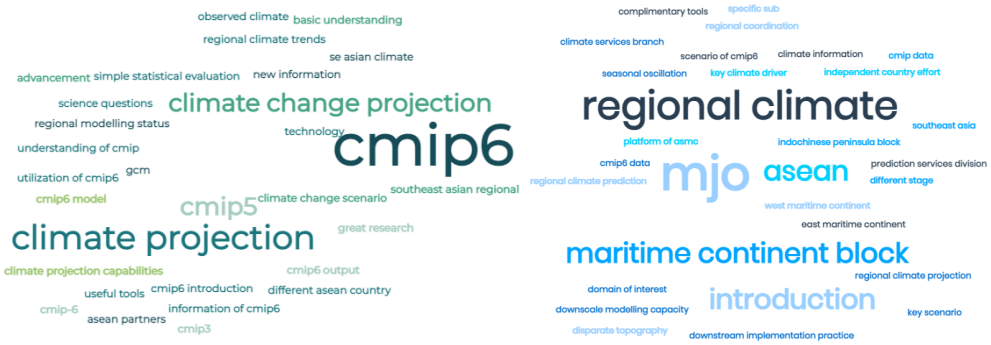
Institute	What will be done over the coming 12 – 15 months in your country w.r.t climate change projections?	What would you like to see being covered in arcdap-4?
AHA Centre	Finalising agreement on disaster response (ASEAN). Adaptation Focus.	Would like to join future workshops to better understand and communicate outputs from these networks to other areas.
BDMD	Would like to join any workshop planned in the next few months. Collaboration with others. Guidelines on use of CMIP data.	High priority: hands-on practicals (face-to-face maybe) on data analysis of CMIP/RCMs
BOM/ CSIRO	Could run smaller workshops in 2-months' time (a 2-hour meeting regular; every 2 months). AR6 will come out September; good opportunity to come together then to update everyone on results.	
CCRS	Dynamical downscaling simulations at 8km and 2km resolutions for domains surrounding Singapore, dissemination of outputs and communication of the key results to stakeholders.	Discussion on decadal variability in the context of detection and attribution/ separating the climate change signal from background variability.
CORDEX-SEA	CORDEX will continue as planned. CMIP6 downscaling will commence soon once the guidelines are official. Impact of 1.5 degree warming in region; collaboration with Met Malaysia and NARHIM; using CORDEX simulations plus higher resolution.	Varying capabilities on analysing CMIP/RCM data; what is needed to equip them to communicate/translate science outcome to national stakeholders. How to raise capacity?
DMH	Seek help from others to provide CMIP data for analysis.	High priority: hands-on practicals (face-to-face maybe) on data analysis of CMIP/RCMs; for drought and rainfall assessment.
DOM	Provide guidelines on access/use of CMIP6 data and on the processing; Want to become more Dricient on using CMIP data. What IT/HPC facilities are there? Move towards web-based analysis (e.g. local data is not needed) Thailand is providing training on server access.	High priority: hands-on practicals (face-to-face maybe) on data analysis of CMIP/RCMs. Move towards web-based analysis (e.g. data is not needed locally).

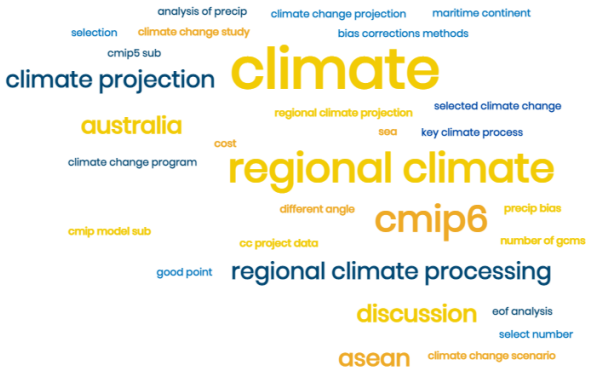
IMHEN	The fourth national climate change and sea level rise scenarios for Vietnam report will be published in Sep-Oct, 2021. Evaluating CMIP6 for Vietnam region to define the suitable GCM simulations. Try to downscalling GCM simulations to high-resolutions based on statistical-dynamical models. Urban climate change projections under coupled impacts of global warming and local urbanization	Statistical and dynamical downscalling model for CMIP6: Receive supports from UKMO, CSIRO, BCCR and MRI etc. Develop climate Analogue Tool for next scenarios: Hope to receive support from CSIRO. Partipating in and contributing to CORDEX-SEA project. More detailed climate change projections: Extreme climate events (heat waves, extreme rainfall, drought, tropical cyclones, etc.), monsoon, ENSO, novel climate, urban climate change projections under under coupled impacts of global warming and local urbanization etc. Participating in the ARCDAP-4
MetMalaysia	New R&D project using new HPC: run downscaling from CMIP6 (3 GCMs); <5km/hourly; not finalised which RCM will be used. Strong link to Dr Fredolin's team, collaborating on Malaysian climate change scenarios, with NAHRIM as well. Gridded observational data set is hourly frequency.	Sharing/discussing analysis of climate projections/data across ASEAN.
PAGASA	Continued analysis of observations (e.g. produce gridded data set) to support analysis of CMIP6 models. Partner with local experts (for extreme indices in historical and future). Access to in-country HPC: more robust analysis possible e.g. using WRF.	Focus more on the utilisation of extreme indices (follow-on from ACRDAP-2); e.g. when to use which index? Sharing across ASEAN on use cases.

SUSS		Exchange knowledge and results Collaborate on some work that requires more resources and would benefit from cross-country collaborations (e.g. on monsoons) Maybe identify some core projects/foci for cross-ASEAN collaboration.
TMD	Talk to stakeholders on CC impacts (e.g. Urban area; health sector; transportation). Urban: air pollution (e.g. Bangkok); analysis of historical observations first, then climate projections;	Enhance collaboration across ASEAN; have access to tools and calculations to analysis projections.
TMSI	Working closely with CCRS; will continue to downscale CMIP6 aligned with CCRS to support V3 using WRF.	Regional model downscaling with CMIP6 projection data.
VNMHA	Want to use CMIP6; high priority is the use of statistical methods (downscaling).	Want to know how to use CMIP6; access data; how to apply projections. Would like to include projections for tropical cyclones.

Table 4.1: Participant/institute inputs to the roundtable discussion 3

4.7 **Dr Aurel Moise, CCRS, Singapore,** wrapped up the ARCDAP-3 workshop, thanking everyone for their participation and enthusiasm over the past four days. He shared a consolidation of key messages from the workshop, illustrated through the word clouds made from participants' feedback.





World clouds generated from participants' feedback on the key learning points from Days 1 to 3 (clockwise, from top left).

He then shared several slides of draft recommendations drawn out from the past four days, before bringing the workshop to a formal close and optimistically expressing that he hoped to see everyone again at ARCDAP-4, in a physical setting.

Annex B: Workshop Programme

Day 1: Monday, 15th of March 2021 (All timings given in local time GMT +8)			
Welcome and Introduction **Chair: Mr Gerald Lim** **Notetaker: Dr Sandeep Sahany**			
10:15 - 10:30	1.1	Registration	
10:30 - 10:40	1.2	Welcome address - Director, CCRS	Dr Dale Barker (Centre for Climate Research Singapore - CCRS)
10:40 - 10:50	1.3	Opening address - WMO-Regional Office for Asia and the South-West Pacific (RAP)	Mr Ben Churchill (World Meteorological Organisation - WMO)
10:50 - 10:55	1.4	Admin brief + Group photo 1	Mr Gerald Lim (Centre for Climate Research Singapore - CCRS)
10:55 - 11:10	1.5	Workshop overview and objectives	Dr Aurel Moise (Centre for Climate Research Singapore - CCRS)
Presentations on CMIP and CMIP6 **Chair: Mr Gerald Lim** **Notetaker: Dr Sandeep Sahany**			
11:10 - 11:30	1.6	World Climate Research Programme (WCRP) and Coupled Model Intercomparison Project (CMIP) *History and structure of CMIP; focus on the relevant science in the MIPs within CMIP6*	Dr Simon Marsland *(Commonwealth Scientific and Industrial Research Organisation - CSIRO)*
11:30 - 12:00	1.7	CMIP6 advancements in technology *Advances in modelling, experiments, scenarios, and observations.*	Mr Francois Delage, Ms Claire Trenham and Dr Simon Marsland *(Bureau of Meteorology - BoM, CSIRO, CSIRO)*
12:00 - 13:00	Lunch		
Introductory Presentations by ASEAN NMHS/Agency representatives on experiences with GCMs and regional climate studies **Chair: Dr Muhammad Eeqmal Hassim** **Notetaker: Dr Chen Chen**			
13:00 - 13:15	1.8	Climate trend and variability analysis in Cambodia	Mr Lonh Nrak *(Department of Meteorology Cambodia)*
13:15 - 13:30	1.9	Climate change studies in Brunei Darussalam	Mr Muhammad Khairul Izzat Haji Ibrahim *(Brunei Darussalam Meteorological Department - BDMD)*
13:30 - 13:45	1.10	Climate change projection activities in Department of Meteorology and Hydrology Myanmar	Dr Tin Mar Htay *(Department of Meteorology and Hydrology Myanmar - DMH)*

13:45 - 14:00	Break		
14:00 - 14:15	1.11	Mechanisms, impacts and future projections of the interdecadal variations of rainfall extremes in Thailand	Dr Chalump Oonariya *(Thai Meteorological Department - TMD)*
14:15 - 14:30	1.12	Verification of temperature simulations over Vietnam using high resolution regional climate models NHRCM and REGCM	Mr Nguyen Manh Linh *(Viet Nam Meteorological and Hydrological Administration - VNMHA)*
14:30	End of Day 1		

Day 2: Tuesday, 16th of March 2021			
Introductory Presentations by ASEAN NMHS/Agency representatives on experiences with GCMs and regional climate studies **Chair: Dr Chen Chen** **Notetaker: Dr Prasanna Venkatraman**			
10:30 - 10:45	2.1	Experience in developing climate change scenarios in Vietnam	Dr Mau Nguyen Dang *(Viet Nam Institute of Meteorology, Hydrology and Climate Change - IMHEN)*
10:45 - 11:00	2.2	Timeline of development of local climate projection information for the Philippines	Mr Wilmer Agustin *(Philippine Atmospheric, Geophysical and Astronomical Services Administration - PAGASA)*
11:00 - 11:15	2.3	Operational Medium Range Forecast in Malaysia	Ms Nurizana Binti Amir Aziz *(Malaysian Meteorological Department - MET Malaysia)*
11:15 - 11:30	2.4	Operations Division: Disaster Monitoring and Analysis Unit	Mr Keith Paolo Landicho *(ASEAN Coordinating Centre for Humanitarian Assistance on disaster management - AHA Centre)*
11:30 - 11:45	2.5	MSS/CCRS involvement in climate projections for Singapore	Dr Xin Rong Chua *(Centre for Climate Research Singapore - CCRS)*
11:45 - 12:00	2.6	General Q&A and discussion on ASEAN representatives' presentations	Dr Aurel Moise *(Centre for Climate Research Singapore - CCRS)*
12:00 - 13:00	Lunch		

CMIP for evaluating regional climate processes/applications **Chair: Mr Gerald Lim** **Notetaker: Dr Sandeep Sahany**			
13:00 - 13:30	2.7	Presentation and roundtable discussion on goals for ASEAN climate change study *Key messages, recommendations and progress from ARCDAP-1, regional aspirations for using CMIP6*	Dr Aurel Moise *(Centre for Climate Research Singapore - CCRS)*
13:30 - 14:00	2.8	Introduction to complimentary tools for CMIP exploration *Tour of ESMValTool, Climate Explorer, PCMDI Metrics Package (PMP) results page*	Mr Gerald Lim *(Centre for Climate Research Singapore - CCRS)*
14:00 - 14:15	Break		
14:15 - 14:45	2.9	Intra-seasonal oscillations in Southeast Asia	Dr Koh Tieh Yong *(Singapore University of Social Sciences - SUSS)*
14:45 - 15:15	2.10	Enhancing climate services for resilient development and planning	Dr Wilfran Moufouma-Okia *(World Meteorological Organisation - WMO)*
15:15 - 15:20	2.11	Group Photo 2 (on Zoom)	
15:20	End of Day 2		

Day 3: Wednesday, 17th of March 2021			
CMIP for evaluating regional climate processes/applications **Chair: Dr Prasanna Venkatraman** **Notetaker: Dr Chua Xin Rong**			
10:30 - 11:00	3.1	Evaluating ENSO-rainfall teleconnections over the Maritime Continent in CMIP6 models	Dr Chen Chen *(Centre for Climate Research Singapore - CCRS)*
11:00 - 11:30	3.2	Evaluations of the precipitation regime over Southeast Asia: Moisture Cycle in CMIP6 models	Dr Srivatsan Raghavan and Dr Liu Senfeng *(Tropical Marine Science Institute - TMSI)*
11:30 - 12:00	3.3	Roundtable discussion on CMIP6 for studying regional climate processes in ASEAN *Approaches to take and practices to adopt for the region*	Dr Aurel Moise *(Centre for Climate Research Singapore - CCRS)*
12:00 - 13:00	Lunch		

Experiences in using CMIP for national climate change projections **Chair: Dr Sandeep Sahany** **Notetaker: Dr Ragi Rajagopalan**			
13:00 - 13:30	3.4	Climate Change in Australia and plans for NextGen Projections	Mr Francois Delage, Ms Claire Trenham and Dr Simon Marsland *(BoM, CSIRO, CSIRO)*
13:30 - 14:00	3.5	National Climate Change Scenarios in 2016 (VNCC16) and the updated version in 2021 (VNCC21)	Dr Mau Nguyen Dang *(Viet Nam Institute of Meteorology, Hydrology and Climate Change - IMHEN)*
14:00 - 14:30	3.6	Sub-selecting CMIP5 models for Singapore's 2nd National Climate Change Study (V2)	Dr Muhammad Eeqmal Hassim *(Centre for Climate Research Singapore - CCRS)*
14:30	End of Day 3		

Day 4: Thursday, 18th of March 2021			
Breakout room discussions **Chair: Mr Gerald Lim** **Notetaker: Dr Ragi Rajagopalan**			
10:30 - 10:40	4.1	Recap of previous days	Dr Aurel Moise *(Centre for Climate Research Singapore - CCRS)*
10:40 - 11:15	4.2	Breakout room discussions (towards regional best practices): *1) Rules and guidelines for CMIP/RCM/Climate Data use* *2) Limitations of CMIP6/GCMs/RCMs output for regional evaluation* *3) What would you want in a regional best practices document for CMIP6/RCM future climate projection studies*	Led by CCRS scientists + 1-2 experts assigned to each breakout room
11:15 - 12:00	4.3	Plenary discussion: *1) Report from break-out groups 2) What are the most important aspects of best practices for the region?* *3) What are the key takeaways about CMIP6? 4) Feedback on CMIP6*	Expert Panel (Dr Simon Marsland, Dr Aurel Moise, MC = Mr Gerald Lim) + Breakout representatives
12:00 - 13:00	Lunch		

Regional downscaling and future work **Chair: Dr Aurel Moise** **Notetaker: Dr Chua Xin Rong**			
13:00 - 13:30	4.4	CORDEX-SEA: Providing regional climate information in Southeast Asia	Dr Fredolin Tangang *(National University of Malaysia - UKM/CORDEX-SEA)*
13:30 - 14:00	4.5	Progress on downscaling experiments for Singapore's 3rd National Climate Change Study (V3)	Dr Prasanna Venkatraman *(Centre for Climate Research Singapore - CCRS)*
14:00 - 14:15	Break		
14:15 - 15:00	4.6	Roundtable discussion on current plans and recommendations for ARCDAP-4 *Directions of existing projects, scope for future collaborations, more regular exchanges between groups*	Dr Aurel Moise *(Centre for Climate Research Singapore - CCRS)*
15:00 - 15:15	4.7	Workshop wrap-up *Consolidation of key messages, results, and recommendations.*	Dr Aurel Moise *(Centre for Climate Research Singapore - CCRS)*
15:15	End of Day 4		

Annex C: Workshop Feedback

Linear scale-based questions

Question	**Average score (out of 5, unless stated otherwise)**
How would you rate the workshop overall?	4.69
How was the duration of the workshop?	All answered “Just Right”
How would you rate the overall organisation of the workshop?	4.62
The knowledge and information gained from this workshop met my expectations	4.46
The knowledge and information gained from this workshop will be relevant to my work	4.31
How likely are you to recommend your colleagues to attend similar workshops in the future?	4.85

Selected responses to short answer questions:

1. What were the key points that you took away from this workshop?
    - *Using GCM and RCM to analyse and project climate*
    - *To get experience and knowledge from expertise and other ASEAN members about CMIP6/RCMs.*
    - *I got up to date on the climate change capabilities of the different countries in our region, and learned a bit more about CMIP6 and climate modelling in general.*

2. How do you think the workshop could have been more effective?
    - *ASEAN countries could work together on one research project. We can share data, projections, knowledge, experiences, etc.*
    - *Face-to-face workshops and practicals are important due to issues such as time, internet and interruptions that limit an online workshop.*
    - *Obviously if we'd met face to face it could have been more hands-on, however holding the workshop online is *definitely* better than not holding it at all, and allows us to continue to progress this work in a much less environmentally damaging way than air travel would have meant.*
    - *I think the workshop was about as effective as it could have been. Maybe what the next ARCDAP workshop could do is include a few speakers who have done such support work (from e.g. CAS, UKMO) to share about their work in building up climate change capabilities, and also invite someone from an agency like the*

World Bank which might be able to provide funding to those countries who don't have the resources to build up their capabilities.

3. Are there any topics that should have been covered in MORE detail?
    - *Applied use of tools to countries' use cases would have been good but difficult in this setting, maybe this could be well suited to monthly webinars instead?*
    - *I think more explanation of how and why CMIP was started in the first place could have been helpful.*
    - *How to access CMIP6 data, producing the extreme indices, statistical techniques for model evaluation*

4. What are some topics that you would like to see covered at future workshops?
    - *Statistical Downscaling methods and modern bias correction methods*
    - *More on the application of the climate extremes indices for impact assessment.*
    - *GMIP/RCMs data processing and analysis*