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SECOND WORKSHOP ON ASEAN REGIONAL CLIMATE DATA, ANALYSIS AND PROJECTIONS (ARCDAP–2)

WORKSHOP REPORT

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List of Abbreviations

ACRE	Atmospheric Circulation Reconstructions over the Earth
APHRODITE	Asian Precipitation – Highly-Resolved Observational Data Integration Towards Evaluation
ARCDAP-2	Second Workshop on ASEAN Regional Climate Data, Analysis and Projections
ASCII	American Standard Code for Information Interchange
ASEAN	Association of Southeast Asian Nations
ASMC	ASEAN Specialised Meteorological Centre
ASOS	Automated Surface Observing Systems
AWS	Automatic Weather Station
BDMD	Brunei Darussalam Meteorological Department
C3S	Copernicus Climate Change Service, ECMWF
CariCOF	Caribbean Climate Outlook Forum
CCRS	Centre for Climate Research Singapore
CDMS	Climate Data Management System
CDPMN	Caribbean Drought and Precipitation Monitoring Network
CDS	Climate Data Store, ECMWF
CHIRPS	Climate Hazards Group InfraRed Precipitation with Station data
CIMH	Caribbean Institute for Meteorology and Hydrology
CIRES	Cooperative Institute for Research in Environmental Sciences
CMIP	Coupled Model Intercomparison Project
CMORPH	CPC Morphing Technique
CPC	Climate Prediction Centre, NOAA
CREWS	Climate Risk and Early Warning Systems initiative (Canada)
CSIS	Climate Services Information System
DMH	Department of Meteorology and Hydrology (Lao PDR/Myanmar)
DOM	Department of Meteorology, Cambodia
ECMWF	European Centre for Medium-Range Weather Forecasts
ENSO	El Niño–Southern Oscillation

ETCCDI	Expert Team on Climate Change Detection and Indices
ET-SCI	Expert Team on Sector-specific Climate Indices
ERA	ECMWF Re-Analysis
GCM	Global Climate Model / General Circulation Model
GFCS	Global Framework for Climate Services
GPCC	Global Precipitation Climatology Centre
GPCP	Global Precipitation Climatology Project
GSMaP	Global Satellite Mapping of Precipitation
HII	Hydro-Informatics Institute
IFD	Intensity-Frequency-Duration
IOD	Indian Ocean Dipole
IPCC	Intergovernmental Panel on Climate Change
ITCZ	Inter-Tropical Convergence Zone
JRA-55	Japanese 55-year Reanalysis
LMB	Lower Mekong Basin
MRC	Mekong River Commission
MMD	Malaysian Meteorological Department
MJO	Madden-Julian Oscillation
MSS	Meteorological Service Singapore
NCHMF	Vietnam National Centre for Hydro-Meteorological Forecasting
NetCDF	Network Common Data Form
NHC	National Hydro-informatics and Climate Data Centre (Thailand)
NMHSs	National Meteorological and Hydrological Services
NOAA	National Oceanic and Atmospheric Administration
NUS	National University of Singapore
OEH	Office of Environment and Heritage (New South Wales)
PAGASA	Philippine Atmospheric, Geophysical, and Astronomical Services Administration
PUMIS	PAGASA Unified Meteorological Information System
RCC	Regional Climate Centre
RCM	Regional Climate Model
SEACAM	Southeast Asia Climate Analysis and Modelling initiative
SEMDP	Space-based Weather and Climate Extremes Monitoring Demonstration Project
SMU	Singapore Management University
SYNOP	Surface synoptic observations
TMD	Thai Meteorological Department
TMPA	TRMM Multi-satellite Precipitation Analysis
TMSI	Tropical Marine Science Institute, NUS
TRMM	Tropical Rainfall Measuring Mission
UHI	Urban Heat Island
UN SDG	United Nations Sustainable Development Goals
UNSW	University of New South Wales (Sydney)
VIA	Vulnerability Impact Assessment
WCRP	World Climate Research Programme
WMO	World Meteorological Organisation

Introduction

The Second Workshop on ASEAN Regional Climate Data, Analysis and Projections (ARCDAP-2) was held in Singapore from 25th to 29th of March 2019. ARCDAP-2 was hosted by the ASEAN Specialised Meteorological Centre (ASMC) and organised by the Centre for Climate Research Singapore (CCRS) in collaboration with the World Meteorological Organisation (WMO) and the Expert Team on Sector-specific Climate Indices (ET-SCI). Co-sponsorship was provided by the Meteorological Service Singapore (MSS) and Environment and Climate Change Canada through the Climate Risk and Early Warning Systems Initiative (Canada-CREWS).

During the previous Best Practice Workshop on Climate Change Projections and their Applications in ASEAN Countries (ARCDAP-1), held in Singapore in March 2018, ASEAN National Meteorological and Hydrological Services (NMHSs) worked with experts and end-users to develop recommendations regarding the generation of climate change projections.

A range of recommendations was put forth, with several centred on climate data. These were driven in part by the concern that despite the transboundary nature of climatic events experienced by the ASEAN region, knowledge of available gridded products remained largely confined to the national level. The participants cited a pressing need to standardise regional understanding of the characteristics, strengths, and weaknesses of both gridded observational and reanalysis datasets. A robust regional understanding of the range of products available was agreed to be crucial in improving model validation and the development of bias-correction methods.

The Vulnerability Impact Assessment (VIA) community present during ARCDAP-1 also stressed the need for sector-relevant extreme indices, as opposed to current generic indices which often do not provide relevant information to the users in fields such as policy and agriculture. The importance of tailoring extreme indices to the needs of end-users is echoed by the ET-SCI, who in recent years have organised ClimPACT training workshops in the South Asian, Caribbean, Pacific, and South American regions. The ClimPACT software, created by the ET-SCI, builds upon the previous software RClimDex and utilises daily meteorological data to both conduct quality control and calculate extreme indices at monthly and annual time scales. Offering more than 60 climate indices, ClimPACT gives users the ability to customise the thresholds of selected indices, while standardised ones provide a robust dataset across which global trends can be assessed. With Myanmar being the only ASEAN country to have attended the 2016 ClimPACT South Asian workshop, there was a recognisable need to conduct a training workshop involving the ASEAN NMHSs.

ARCDAP-2 hence played a dual role – to build upon the recommendations from ARCDAP-1, and to take on the role of ClimPACT training workshop for the ASEAN region, joining a series of successful workshops conducted by the ET-SCI. The workshop is also a part of continued efforts to encourage regional collaboration and entrench sustainable links between the ASEAN countries. ARCDAP-2 aimed also to update the regional database built during the successful Southeast Asia Climate Analysis and Modelling (SEACAM) initiative, which ran from 2011 to 2012. Data gathered during this collaboration spanned 121 stations and 6 countries, and ran from 1970 to 2010. The recent workshop invited participants to utilise country-specific data for the ClimPACT training exercises, and encouraged them to contribute the calculated indices to the upcoming HadEX3 dataset, a global land-based dataset of climate extremes. In doing so, the workshop provided an opportunity to improve the quality and availability of data from the ASEAN region in a global database, a crucial move to facilitate further research on the regional climate.

In view of the above mentioned needs highlighted by both the regional and international community, the aims of ARCDAP-2 were as follows:

a) Deliver sector-relevant extreme indices for the ASEAN region using the ClimPACT2 software package;
b) Evaluate and compare gridded products relevant to the ASEAN region;
c) Assess the representation of regionally-relevant large-scale processes in gridded products;
d) Develop the knowledge required to conduct model assessments of climate change mean, variability, and extremes;
e) Improve regional collaboration and cooperation, and encourage data- and knowledge-sharing across the region.

Workshop Recommendations

Robust station datasets are crucial not only for the calculation of sector-specific extreme indices, but also for the validation of satellite observations and the improvement of both observational and reanalysis products. Participants agreed that the ASEAN NMHSs should continue to expand and improve upon their observational networks while maintaining a comprehensive metadata record. Work on quality control and homogenisation should also be continued, to ensure that records are free from errors and influences from non-climatic effects.

It is recommended that the quality and quantity of station data continue to be improved upon, through data quality control and homogenisation.

The upcoming HadEX3 dataset will feature improved resolution and spatial and temporal coverage, compared to HadEX2. With the contribution deadline set for July 2019, each of the ASEAN NMHSs are highly encouraged to contribute the calculated ET-SCI indices for at least one station. Station data used should be quality controlled and homogenised, and span either the 1961-1990 period, the 1981-2010 period, or both.

It is recommended that all NMHSs in attendance at ARCDAP-2 aim to contribute at least one station for temperature and for rainfall to HadEX3.

Current literature on extreme indices lacks a sectoral and regional focus on Southeast Asia. ARCDAP-2 was centred on the ASEAN region and the improved ET-SCI indices, which have a greater sector focus. It is hence highly recommended that a peer-reviewed paper looking at the regional trends in the ET-SCI indices be published, building on the work done at ARCDAP-2. This will not only provide an update on regional climatic trends explored in previous publications, but also sharpen the focus on sector-specific indices and hence fill current gaps in the literature. Further, it will encourage and sustain transboundary collaborations and raise the international profile of the region.

It is recommended that all NMHSs in attendance at ARCDAP-2 contribute to a peer-reviewed publication on the variability and trends in the ET-SCI indices. The paper will be led by researchers from CCRS (Singapore).

Given the transboundary nature of the climatic events experienced by the region, it is important that countries continue to share knowledge pertaining to publicly available gridded products. Participants are encouraged to contribute to a questionnaire that will be circulated following the workshop. Results will be used to guide an upcoming peer-reviewed publication, which seeks to provide a comprehensive comparison and analysis of products available to the region.

It is recommended that a peer-reviewed publication evaluating and comparing the latest gridded products available for the region is completed, led by a researcher from the regional community. An important aspect of the paper should also be the evaluation and comparison of extreme indices computed from in-situ measurements and gridded products.

The ARCDAP workshop series has thus far provided valuable opportunities for regional discussions and collaborations across the ASEAN NMHSs. ARCDAP-2 in particular functioned as a ClimPACT2 training workshop as well as a platform through which data and knowledge on climate extremes, large-scale processes, and gridded products were shared. It is recommended that the workshop series be continued, with ARCDAP-3 tentatively scheduled for February 2020. The upcoming workshop will focus on the analysis of Phase 6 of the Coupled Model Intercomparison Project (CMIP6), the latest international database of Global Climate Models (GCM). This will provide a segue into discussions on climate processes relevant to the region and the evaluation of these processes in climate models. In the subsequent year, the agenda will likely broaden to include the sharing of Regional Climate Model (RCM) projections.

It is recommended that funding opportunities are explored by CCRS, WMO, and AMSC in collaboration with the ASEAN NMHSs to continue the ARCDAP workshop series.

1 Day 1: 25th March 2019, Monday

Summary

Following the opening and welcome addresses delivered by Dr Erland Källén and Dr Chung-Kyu Park respectively, Ms Anahit Hovsepyan introduced the audience to the WMO Climate Services Information System. Dr Bertrand Timbal then described the objectives of the workshop, before providing an overview of the week ahead.

Representatives from the National Meteorological and Hydrological Services (NMHSs) of nine ASEAN member states (Brunei, Cambodia, Lao PDR, Malaysia, Myanmar, Philippines, Singapore, Thailand, and Vietnam) presented on [1] the climate and extremes of their country, [2] the availability and quality of station data, [3] quality control procedures, and [4] the dataset brought for ARCDAP-2.

Participants noted that their respective countries were increasingly being affected by changes in the mean climate and that there was a pressing need to quantify the trends in extreme temperature and rainfall events. They highlighted clear trends in temperature over the last few decades, and noted the uncertainty in rainfall trends; while the NMHSs have observed an increased occurrence of floods, they have also been severely affected by droughts. Most NMHSs reported conducting quality control on their data, however the procedures and degrees to which this is done varies. Regardless of the level of quality control in place, participants felt that the workshop was nevertheless a good opportunity to better understand the intricacies and challenges of quality control procedures.

To maintain their database, only a few countries in the region used Climate Data Management Systems (CDMSs). There was also a considerable amount of historical datasets across all NMHSs yet to be digitised. Discussions raised the importance of metadata preservation and consistency in data collection. Data from 148 stations across nine countries was brought to ARCDAP-2 to be processed via ClimPACT2 and fed into a joint analysis, with most possessing data from 1981 to 2017.

The afternoon continued with the introduction and installation of ClimPACT2 software, led by Dr Nicholas Herold. Participants were guided through the process of downloading the required dependencies and running the software for the first time. Dr Cédric Van Meerbeeck then demonstrated the effectiveness of ClimPACT2 in conducting quality control, as opposed to basic processing commands using Microsoft Excel.

The rest of the day was spent on a hands-on session, which allowed participants to conduct quality control on their station data using ClimPACT2. The invited experts Dr Lisa Alexander, Dr Nicholas Herold, and Dr Cédric Van Meerbeeck were present to guide participants and resolve any technical issues that arose.

Participants spent the evening at a welcome dinner, held at The Landmark restaurant at Village Hotel Bugis and hosted by the Meteorological Service Singapore (MSS).

Welcome and Workshop Overview

1.1 The Second Workshop on ASEAN Regional Climate Data, Analysis and Projections (ARCDAP-2) was held at Village Hotel Albert Court, Singapore, from 25th to 29th March 2019.

1.2 **Dr Erland Källén, Director of the Centre for Climate Research Singapore (CCRS)** delivered a welcome address, thanking the participants from the ASEAN NMHSs for their attendance and the local, regional, and international experts for agreeing to share their expertise. He also acknowledged the support received from WMO, the Canada-CREWS initiative, and MSS. Finally, he highlighted the importance of such workshops and emphasised the importance both of regional collaboration and data sharing on a global scale.

1.3 **Dr Chung-Kyu Park, Director of the WMO Regional Office for Asia and the South-West Pacific (RAP)** similarly extended a warm welcome to the participants and thanked WMO, Environment and Climate Change Canada, and MSS for the support. He emphasised the importance of planning for climate change and highlighted the relevance of the workshop to WMO's contributions to the United Nations Sustainable Development Goals (UN SDGs). In particular, he referenced Goal 13 on Climate Action, for which WMO is co-custodian. He praised the objectives of the workshop as being helpful in providing decision-makers with the scientific facts necessary to build resilience in the ASEAN region. He also assured the participants that WMO will continue to support the ARCDAP initiative and promote the implementation of similar workshops in other regions.

1.4 **Ms Anahit Hovsepyan, Scientific Officer of the WMO Climate Prediction and Adaptation Branch** as part of the World Climate Applications and Services Division, delivered a presentation on the WMO Climate Services Information System (CSIS). She described the CSIS as the operational core of the Global Framework for Climate Services (GFCS), and explained that the system deals with climate data, monitoring, prediction, and projection. She also highlighted institutional mechanisms to exchange and disseminate quality climate information at global, regional, and national levels, citing the Regional Climate Centre (RCC) network as one such example. Looking forward, she spoke of plans to further develop and strengthen the effectiveness of Regional Climate Outlook Forums, and emphasised the importance of knowledge sharing between countries who experience similar climate concerns.

1.5 **Dr Bertrand Timbal, Senior Principal Research Scientist at CCRS**, described the background and objectives of the workshop, citing the success of ARCDAP-1, held in Singapore in March 2018. He noted that ARCDAP-2 was driven by the convergence of recommendations from ARCDAP-1, as well as the support from WMO to improve regional capability in the use of ClimPACT2 software. He thanked WMO and the ClimPACT2 experts in attendance for their help in developing a balanced agenda for the workshop, comprising hands-on sessions, informative seminars, and group discussions. He acknowledged the multiple expected outcomes of the workshop, but emphasised that one of the most crucial was to publish peer-reviewed scientific papers using the results of the workshop, so as to document the important work being conducted across the ASEAN region. Closing his address, he outlined the agenda for the five-day workshop, and wished the participants a successful and productive week ahead.

Introductory Presentations by ASEAN NMHSs

TABLE 1. Station data contributed by participants

Country	Number of Stations	Period of Record
Brunei	1	1980 – 2018
Cambodia	9	1985 – 2017
Lao PDR	6	1970 – 2017 *(1)* 1971 – 2015 *(2)* 1971 – 2017 *(2)* 1972 – 2017 *(1)*
Malaysia	15	1951 – 2018 *(12)* 1960 – 2018 *(1)* 1961 – 2018 *(1)* 1998 – 2018 *(1)*
Myanmar	17	1972 – 2018 *(9)* 1981 – 2010 *(8)*
Philippines	35	1951 – 2017 *(10)* 1972 – 2010 *(25)*
Singapore	4	1980 – 2018 *(3)* 1981 – 2018 *(1)*
Thailand	47	1981 – 2018
Vietnam	14	1979 – 2018

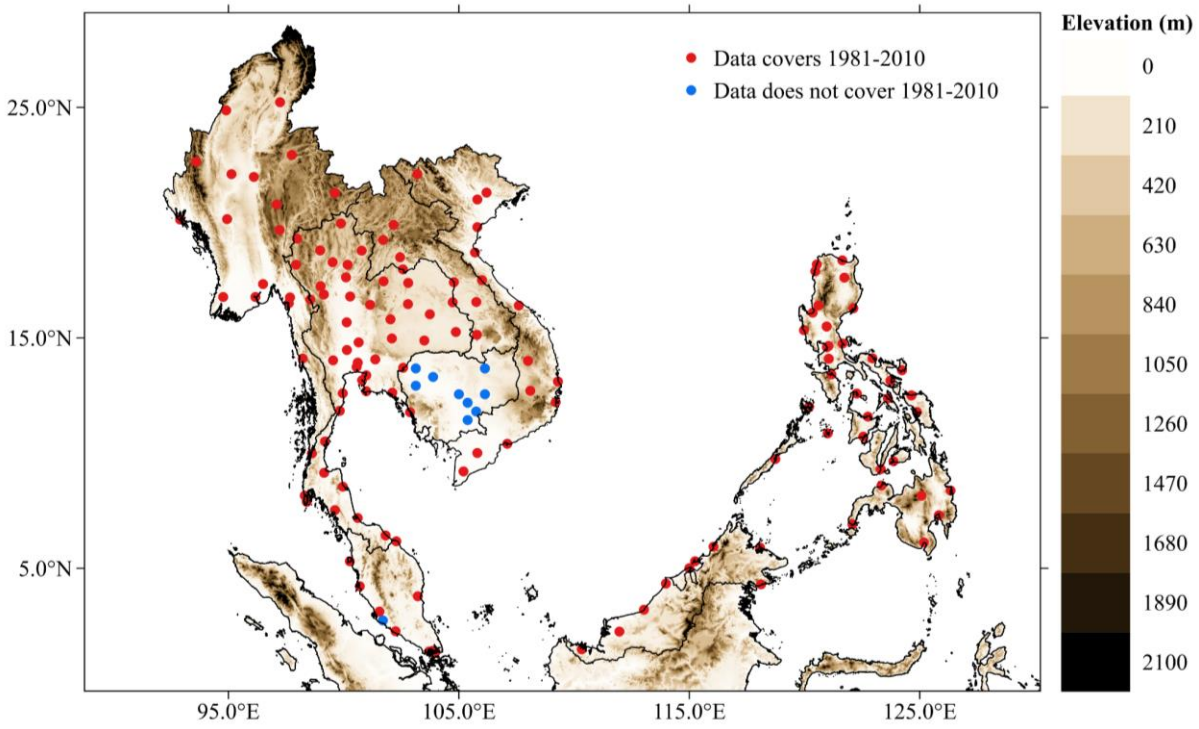
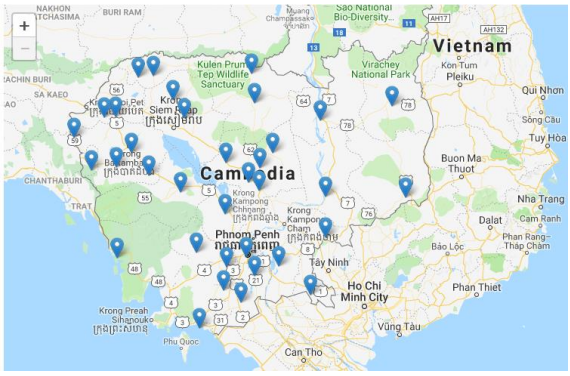


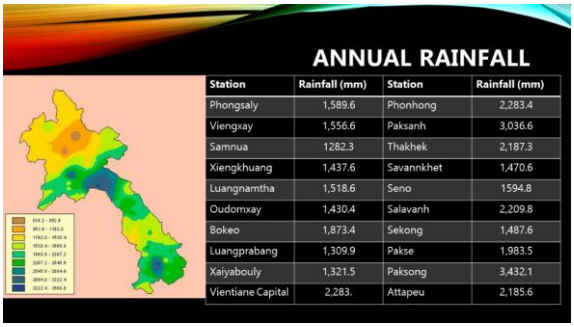
FIGURE 1. Locations of the 148 stations contributed across 9 countries

1.6 **Mr Monichoth So Im, Department of Meteorology (DOM), Cambodia**, shared that there are currently more than 42 Automatic Weather Stations (AWS) available, providing data on air temperature, relative humidity, wind speed, wind direction, solar radiation, precipitation, and pressure. Manual station records are taken by observers twice a day, with written observations sent to DOM both daily and annually. There are currently no quality control procedures in place. For the purposes of the workshop, the department brought data for nine stations. Mr So Im highlighted floods and droughts as extreme events that were of most concern for Cambodia.



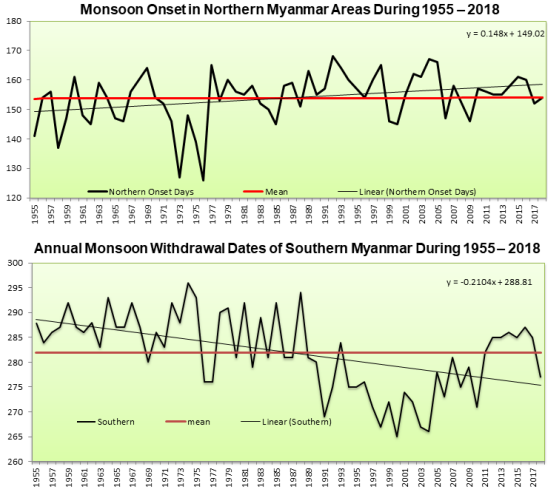
Map of automatic weather stations in Cambodia

1.7 **Mr Bounteum Sysouphanthavong, Department of Meteorology and Hydrology (DMH), Lao PDR**, shared that the meteorological network comprises 19 synoptic stations, five manual stations and 14 AWS. This is in addition to 119 rain gauges and 43 climatological stations. Quality control procedures include referring to SYNOP messages and observation log books and counter-checking collected data, before digitisation is carried out using Microsoft Excel. For the purposes of the workshop, the department brought data for six stations. Mr Sysouphanthavong also explained to the audience the geography and climate of Lao PDR, pointing out the influence of monsoons in driving the onset and retreat of the wet and dry seasons. Floods and droughts were once again at the forefront of extremes observed, with the influence of tropical cyclones and depressions on extreme rainfall also highlighted.



Annual rainfall in Lao PDR

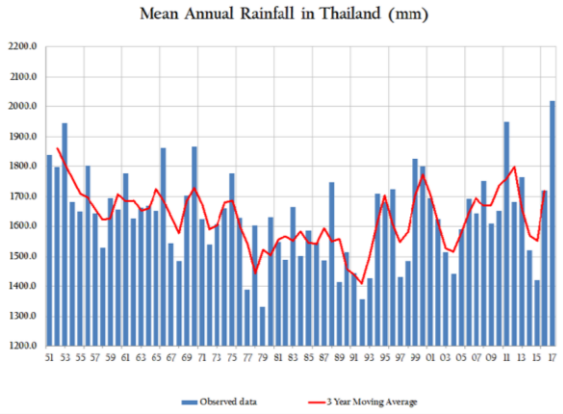
1.8 **Dr Tin Mar Htay, Department of Meteorology and Hydrology (DMH), Myanmar**, presented on the department's current observation network, consisting of 121 manual stations, and 168 AWS and Automated Surface Observing Systems (ASOS). All station data is digitised and quality control is conducted using RClimDex and ClimPACT2 software. For the purposes of the workshop, the department brought data for 17 stations. Dr Tin Mar Htay noted that annual rainfall in Myanmar has shown an increasing trend since the 1980s. In addition, the monsoon season has shortened in length since the 1990s, largely due to earlier



Monsoon onset and withdrawal dates in Myanmar

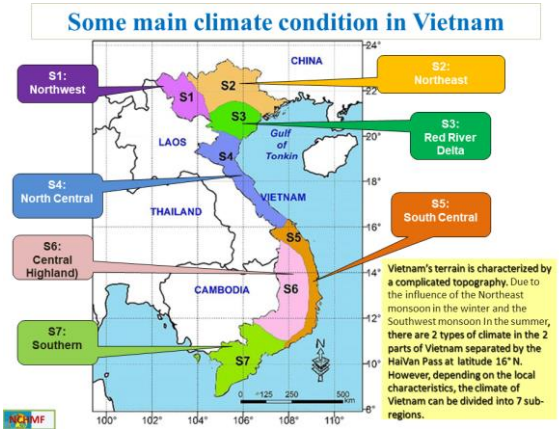
withdrawals. She voiced concerns over the possible increase in intensity of monsoon seasons, and cited the severe floods of 2015, where unusually heavy rainfall combined with the effects of Cyclone Komen resulted in widespread flooding and landslides, resulting in agricultural losses and property damage.

1.9 **Dr Chalump Oonariya, Thai Meteorological Department (TMD), Thailand**, shared a map of TMD's 146 stations. These comprised 95 synoptic stations, 35 agro-meteorological stations, and 16 hydro-meteorological stations. For the purposes of ARCDAP-2, TMD contributed 47 stations. During quality control, meteorological variables are assumed to be normally distributed and values beyond four standard deviations from the mean are classified as abnormal. The climatology of Thailand can be broadly divided into three seasons, driven both by monsoons and the oscillations of the Inter-Tropical Convergence Zone (ITCZ). Recent years however have seen Thailand experiencing significant climate anomalies. Dr Oonariya cited the storms and heavy monsoonal rains in 2011, which resulted in the worst flooding in Thailand since 1942. The summer seasons of 2007, 2009, and 2010 also saw daily maximum temperature records being broken in various parts of the country.



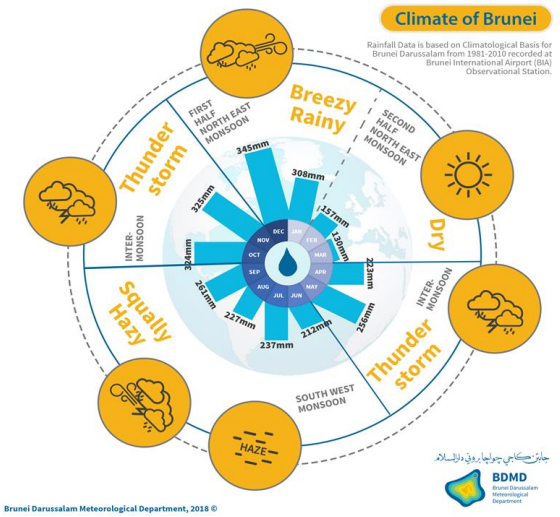
Observed (blue bars) and 3-year moving average (red line) for mean annual rainfall in Thailand

1.10 **Mr Nguyen Duc Hoa, Vietnam National Centre for Hydro-Meteorological Forecasting (NCHMF), Vietnam**, shared with the audience that there were currently 186 synoptic stations and 232 hydrological stations in Vietnam. The centre also receives data from approximately 500 automatic rain gauges and seven weather radars. For ARCDAP-2, NCHMF brought data for 14 stations. The climate in Vietnam is strongly influenced by the onset and withdrawals of the monsoons, as well as tropical cyclones in the South China Sea. In recent years, climate extremes have been occurring more frequently – record-breaking daily minimum and maximum temperatures were observed in 2016 and 2017 respectively. Severe drought events driven by El Niño, such as that in 2015 and 2016 also result in water shortages and lead to the loss of crops and cattle. Anomalies such as floods in the typically dry Quang Ninh region in 2015 also result in extensive damage of property and loss of lives.



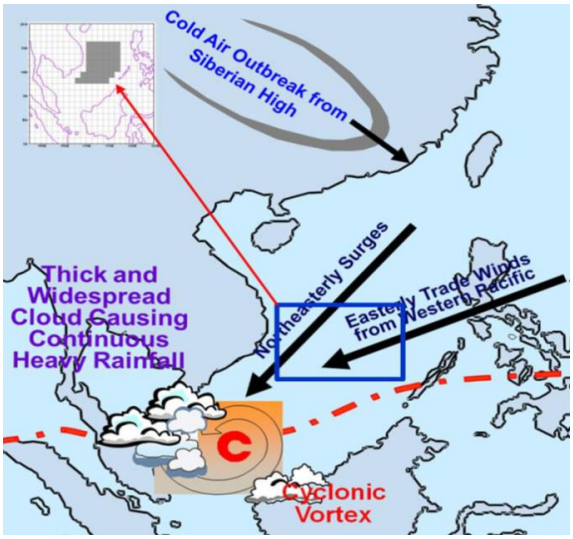
Climate of Vietnam can be divided into 7 sub-regions

1.11 **Mr Izzat Ibrahim, Brunei Darussalam Meteorological Department (BDMD), Brunei**, shared that BDMD has one weather station, with records from 1969 to 2018. Data is collected by quality instruments calibrated to WMO guidelines and by highly trained observers, and the climate services department ensures that data is accurately archived with no missing data. For the purposes of ARCDAP-2, BDMD contributed data from 1980 to 2018. Mr Ibrahim concluded his presentation by sharing an infographic on the weather and climate of Brunei, citing maximum and minimum recorded values for temperature and rainfall. He also noted the strong influence of monsoons and mentioned the occurrence of haze episodes, with the worst occurring in 1998 and resulting in a visibility of 100 metres.



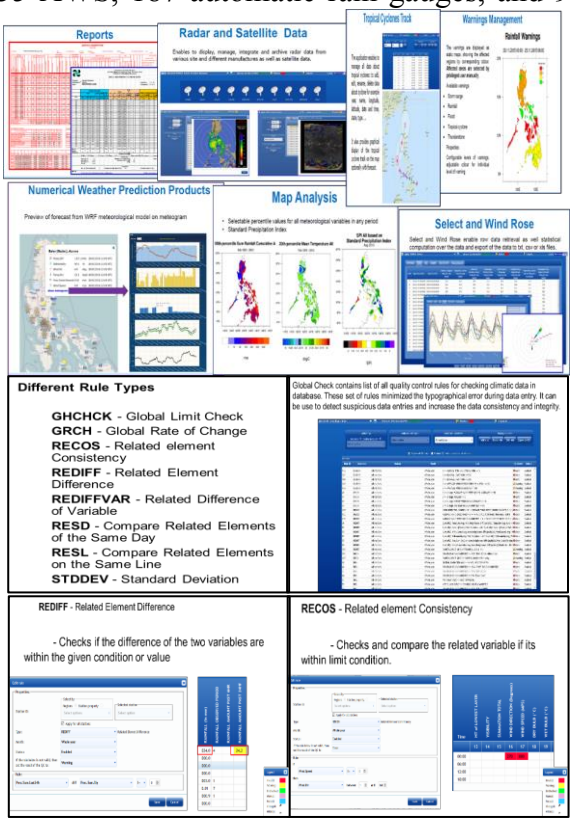
Characteristics of the climate of Brunei

1.12 **Ms Wan Maisarah Wan Ibadullah, Malaysian Meteorological Department (MMD), Malaysia**, shared that in general, Malaysia experiences uniform temperature, high amounts of rainfall, and light wind. Seasons are driven by the monsoons, with the northeast monsoon bringing heavy rain and the southwest monsoon resulting in drier weather. The MMD's observation network includes 45 principal meteorological stations, 490 auxiliary weather stations, 8 upper air stations, 12 weather radar stations, and 1 satellite ground receiving station. For ARCDAP-2, the department prepared and contributed data from 15 stations. Severe weather conditions typically take the form of monsoon floods, flash floods, strong winds, and haze, such as the monsoon flood in Kota Bharu in 2014 which flooded the Sultan Muhammad IV Stadium and strong winds in Petaling Jaya in 2015 which felled trees.



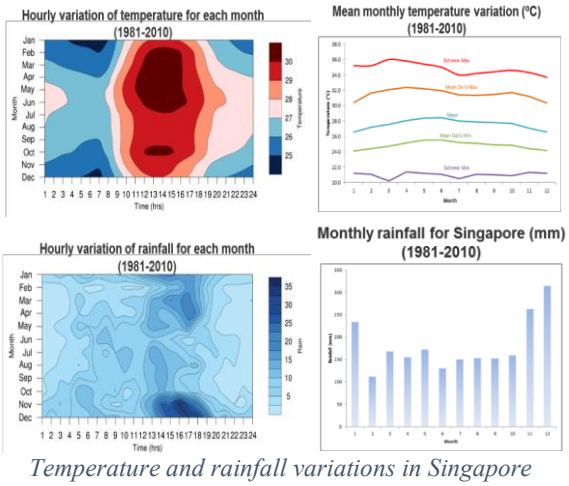
Effects of the northeast monsoon on rainfall

1.13 **Ms Rosalina De Guzman, Philippine Atmospheric, Geophysical, and Astronomical Services Administration (PAGASA), Philippines**, showcased the observation network, which includes 58 synoptic stations, 155 AWS, 187 automatic rain gauges, and 9 upper air stations. The organisation utilises the PAGASA Unified Meteorological Information System (PUMIS) to compile both data and metadata from all observing facilities into a centralised database. The system conducts periodic quality checks and monitors the spatial and internal consistency of climate data according to WMO guidelines, flagging erroneous data. Efforts are also being made to complete the digital imaging of 1.7 million observation forms that are at risk of being lost. For this workshop, PAGASA supplied 35 stations. Ms Guzman noted that over the past 65 years (1951 to 2015), annual mean temperature has increased by 0.68°C. Further, there has been an increasing number of hot days and decreasing number of cold nights. While extreme rainfall events have been increasing in frequency, there has however been a slight decrease in the number of tropical cyclones that make landfall.



PUMIS quality control and outputs

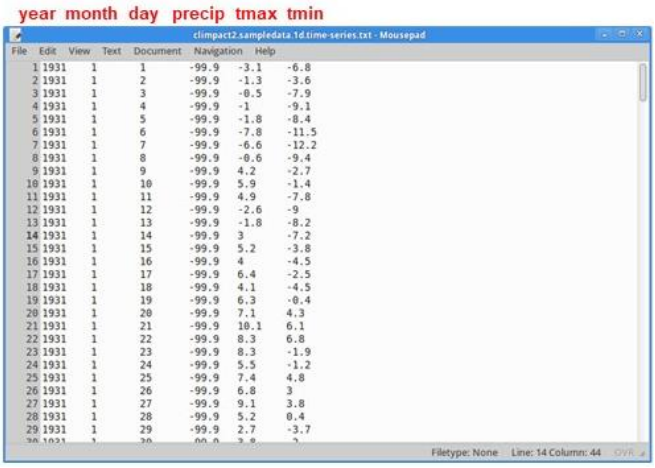
1.14 **Mr Wee Leng Tan, Meteorological Service Singapore (MSS), Singapore**, presented a map of Singapore's observation network, comprising one upper air station, five manned meteorological stations, and close to 100 AWS, with more stations to be added in the coming years. He shared with the audience the range of products that can be accessed via the MSS website, including historical daily records for each station as well as maps of climatological rainfall normals. Speaking on the climate of Singapore, Mr Tan showcased plots of the hourly and monthly temperature variations, as well as choropleth maps of monthly rainfall normals during the four main seasons – the northeast and southwest monsoon seasons, and the two inter-monsoon periods. He highlighted the impact of ENSO on rainfall and noted the negative correlation between monthly rainfall and the de-trended Niño 3.4 index from June to October. For the workshop, MSS provided data for four manned stations.



Temperature and rainfall variations in Singapore

Introduction and Installation of ClimPACT2

1.15 **Dr Nicholas Herold, New South Wales Office of Environment and Heritage (OEH), Australia**, kicked off the ClimPACT2 training by introducing the participants to the software. ClimPACT2 was developed using the R programming language and is capable of calculating over 60 climate indices and producing over 200 files. Details of all the indices can be found in Appendix A of the ClimPACT2 user guide, accessible through https://github.com/ARCCSS-extremes/climpact2/blob/master/user_guide/ClimPACT2_user_guide.htm. The software can be used either via a graphical user interface or the Linux command line. Although the workshop focuses on the former, the latter is required to compute the indices using gridded data. Dr Herold displayed examples of the input data required by the software, emphasising the importance of utilising the correct format and including daily values of precipitation, maximum temperature, and minimum temperature. Participants raised the possibility of changing default data criteria, as they felt it was too harsh to exclude an entire month should more than three days of data be missing. Dr Herold clarified that while changes to default thresholds were possible, it is not recommended if the consistent comparison of results globally is desired.



Input data format required by ClimPACT2

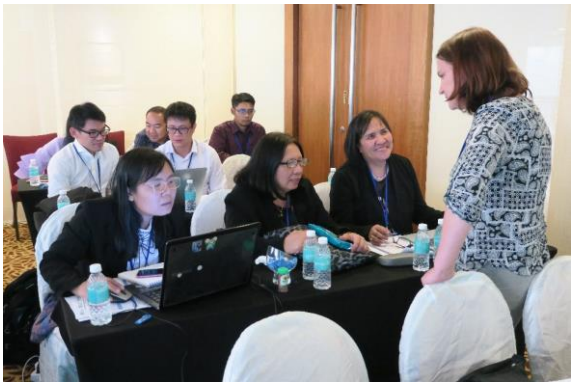
1.16 Dr Nicholas Herold then guided the participants through the initial installation and execution of ClimPACT2, with the support of Dr Lisa Alexander and Dr Cédric Van Meerbeeck. Experts and end-users were invited to team up with the ASEAN NMHSs for all ClimPACT2 training sessions. As instructions to download R, Panoply, and ClimPACT2 were distributed before the workshop, some participants already had the required software installed. These participants were encouraged to produce exploratory plots and familiarise themselves with the interface and capabilities of the software. The session concluded with all participants able to successfully run ClimPACT2 on their laptops.

Quality Control using ClimPACT2

1.17 **Dr Cédric Van Meerbeeck, Caribbean Institute for Meteorology and Hydrology (CIMH), Barbados**, demonstrated the process of quality control using Microsoft Excel. It quickly became evident to the participants that Excel was cumbersome and inefficient where large datasets were involved. Dr Van Meerbeeck then proceeded to demonstrate the quality control features of ClimPACT2, flagging erroneous data in large datasets efficiently. He noted that while ClimPACT2 is capable of identifying possibly erroneous data, the knowledge possessed by the NMHSs is still required to discern between truly extreme values and erroneous data. Dr Van Meerbeeck also emphasised the importance of metadata, and recommended that the participants document all changes made to the data.

Dr Van Meerbeeck demonstrating the quality control capabilities of ClimPACT2

1.18 To conclude the day's activities and apply the knowledge gained from the lectures, participants were encouraged to conduct quality control on their station data during a hands-on session. Prior to the workshop, most participants had already completed the necessary first step of ensuring their data conformed to the format required by ClimPACT2. For others who had not yet done so or who were facing difficulties, assistance was provided at the workshop. Each country was also provided with a metadata template prepared by Dr Nicholas Herold, through which they could record any changes made to the data during quality control. Participants then split into country-specific groups to work on their respective datasets, with support from the ClimPACT2 experts.



Dr Lisa Alexander with Dr Tin Mar Htay, Ms Rosalina De Guzman, and Ms Thelma Cinco

Dr Cédric Van Meerbeeck guiding Mr Izzat Ibrahim and Mr Arifin Yussof

Dr Nicholas Herold assisting Ms Rosalina De Guzman and Ms Thelma Cinco

2 Day 2: 26th March 2019, Tuesday

Summary

Dr Lisa Alexander provided an overview of the concept of homogenisation and emphasised its importance in accounting for scenarios such as station shifts and the urban heat island effect. Through examples, she showed how inhomogeneities could manifest as both sudden and gradual changes, and cautioned the participants against making changes to the data without first consulting metadata.

Participants were then introduced to the RHtestV4 software, which detects inhomogeneities or change points in datasets. They were guided in the installation and use of the software through a hands-on session, which allowed them to identify and correct inhomogeneities detected in the station data brought to the workshop.

To acquaint participants with the sectoral links of the ET-SCI indices, experts from the heat health, food and water security, and climate change adaptation communities presented on their respective fields.

Dr Jason Kai Wei Lee introduced participants to the concept of thermal stress, focusing on its impacts on human health and productivity. He emphasised the subjectivity of thermal comfort and stressed the need for personalised heat guidelines.

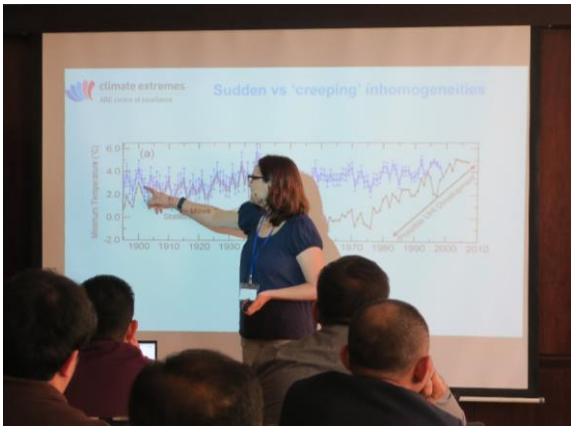
Dr Kanoksri Sarinnapakorn provided an overview of the Hydro-Informatics Institute and its observation network in Thailand. She highlighted the varying levels of climate change vulnerability and water risk in the region, and emphasised the importance of working with local communities to analyse and solve problems using local data.

Dr Nguyen Dinh Cong shared on the indices used by the Mekong River Commission in flood and drought forecasting and climate monitoring. He noted the importance of transboundary cooperation, citing an ongoing project between Cambodia and Thailand.

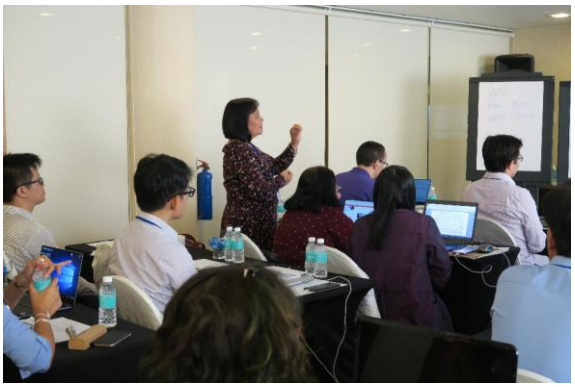
Returning to ClimPACT2, Dr Nicholas Herold introduced participants to the ET-SCI indices, noting how they allowed for comparison on a global scale across various climates. Indices can be broadly divided into the four categories of minimum and maximum indices, threshold indices, duration indices, and complex indices, with the importance and relevance of each index varying by country. Participants were given the opportunity to raise indices they were interested to explore in greater detail. Following the discussion, they then calculated the ET-SCI indices using their station data through a hands-on session.

Homogenisation using RHtestV4

2.1 **Dr Lisa Alexander, University of New South Wales (UNSW) Sydney, Australia**, introduced participants to the concept of homogenisation and highlighted the importance of adjusting records to account for non-climatic effects such as growing urbanisation and the Urban Heat Island (UHI) effect. She listed examples of situations that could result in inhomogeneities, such as multi-day rainfall accumulation, where manual observations of gauges were only taken on weekdays. Dr Alexander outlined the two-step process of homogenisation, involving first detecting inhomogeneities and subsequently manually intervening to make the appropriate adjustments. She cautioned that while inhomogeneities can appear as obvious jumps in the record, they can also exist as gradual climbs or dips that are inconspicuous and challenging to detect without metadata. Ms Thelma Cinco (PAGASA, Philippines) questioned if it would be necessary to remove the UHI effect. Dr Alexander responded that it was important to consider the purpose of the study; a climate change study would require the removal of the UHI effect, while a study on the effects of urbanisation would not. Ms Cinco also shared that a recent change in instruments to alcohol thermometers has resulted in a reversal of the previously rising temperature trend and sought advice on how this could be accounted for. Dr Alexander suggested that comparison to sites at which no instrument change has occurred could provide the best guess for the climate signal. Should this not be possible, it would be advisable to continue collecting data for a few years and observing the record before attempting homogenisation. Mr Bounteum Sysouphanthavong (DMH, Lao PDR) questioned how homogenisation should be carried out if a station was replaced and the old station closed soon after. Dr Alexander suggested that the surrounding stations could be used as a benchmark, and recommended that both new and old stations are maintained for at least two years according to WMO guidelines, so as to ascertain that any jump in the record is associated with relocation.



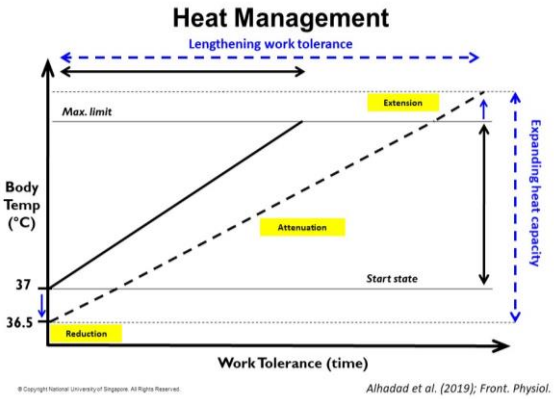
Dr Lisa Alexander emphasising that inhomogeneities can sometimes exist as gradual changes



Ms Thelma Cinco relaying concerns regarding instrument changes

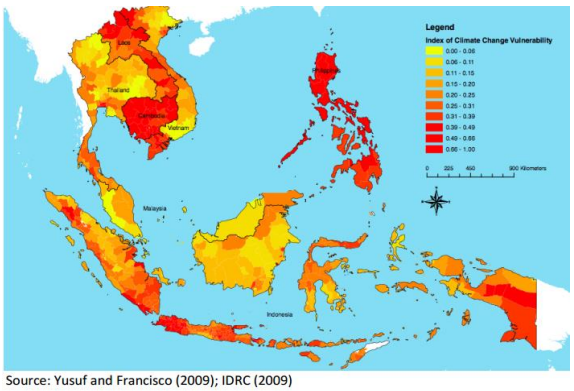
2.2 Following the lecture on homogenisation, Dr Lisa Alexander began the hands-on session by demonstrating how inhomogeneities could be detected using the RHtestV4 software package. Participants then either made the necessary adjustments to remove the inhomogeneity, or recognised the detected anomaly as a valid extreme value. Once again, the ClimPACT2 experts moved around the room, assisting participants where necessary and sharing tips and experiences pertaining to the software.

2.3 **Dr Jason Kai Wei Lee, National University of Singapore (NUS), Singapore**, introduced the concept of thermal stress and focused on the impact of heat on human productivity and health. Dr Lee explained that the problem was not limited to classic ones such as heat stroke, but that heat stress can also exacerbate underlying health conditions and adversely impact fertility, productivity, and decision-making abilities. He noted that China alone lost 21 billion hours of work in 2017 due to extreme heat and that a small rise in temperature is sufficient to result in negative impacts. He highlighted the importance of behavioural traits and heat management; expanding a person's heat capacity and lengthening one's work tolerance. Given the subjectivity of thermal comfort, he recommended the development and implementation of personalised heat guidelines, tailored according to an individual's health, environment, occupation, and heat capacity. He raised the example of the common recommendation to increase one's fluid intake, which in some cases has led to potentially fatal water intoxication. In addition, he cited research showing that a young diabetic has the heat capacity of a 65-year-old healthy individual. Hence, a diabetic may find it challenging to exercise in the heat. Concluding his presentation, Dr Lee pointed out the need for closer collaboration with stakeholders to provide better guidelines to cope with thermal stress. He also introduced the audience to the Global Heat Health Information Network and the Scientific Committee on Thermal Factors, which he chairs at the International Commission on Occupational Health. Thanking Dr Lee for his presentation, Dr Cédric Van Meerbeeck wondered if a sauna would help to increase one's heat capacity. Dr Lee responded that while a sauna may confer some benefits, greater adaptations to heat stress can be gained by exercising in the heat. Dr Muhammad Eeqmal Hassim (CCRS, Singapore) wondered about the impacts of a 35°C wet bulb temperature, generally regarded as lethal to the human body. Dr Lee speculated that while death might not be certain, there would likely be a severe loss in productivity and well-being.

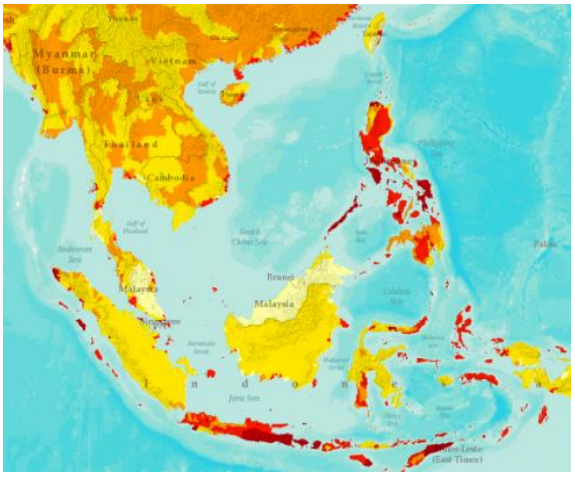


Heat management graph shared by Dr Jason Lee

2.4 **Dr Kanoksri Sarinnapakorn, Hydro-Informatics Institute (HII), Thailand**, focused on weather extremes and water and food security in Thailand. She introduced the audience to HII and the National Hydro-informatics and Climate Data Centre (NHC), which collectively house 400 data items from 37 agencies, providing a unified water management system. She emphasised the linkages between food, water, and energy security and noted that climate change and extremes will further threaten these securities when most of the region already has a moderate or serious rating on the Global Hunger Index. She displayed maps showing climate change vulnerability and water risk across Southeast Asia, noting that the two were largely similar with the exception of countries such as Cambodia and Lao PDR, which were highly vulnerable but had differing water risk levels across the country. Dr Sarinnapakorn discussed the ways in which HII applies science and technology to improve water and food security, focusing on the development of a community water resource management system. She emphasised the importance of working with local communities to understand, analyse, and solve the problem using local data. She also discussed the Thai-developed Sufficiency Economy Philosophy, which combines reasonableness, moderation, and prudence, with knowledge and morality to help guide efforts to work towards the UNSDGs. While HII currently had an extensive network of 2000 gauges, with 1500 active and relaying data every 10 to 15 minutes, the main challenge remains the lack of a long-term record on which research can be based and extreme thresholds set.



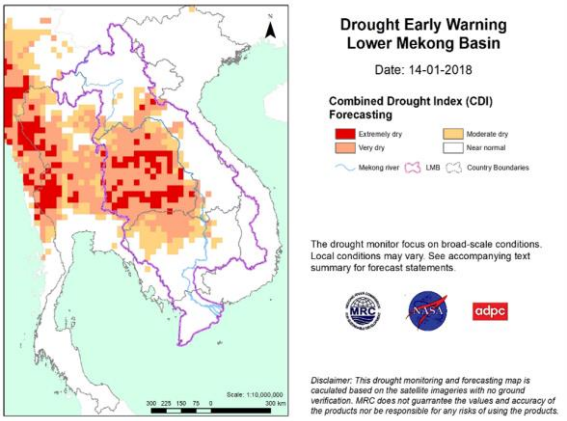
Source: Yusuf and Francisco (2009); IDRC (2009)



Maps displaying climate change vulnerability (top) and water risk (bottom) in the ASEAN region

2.5 **Dr Nguyen Dinh Cong, Mekong River Commission (MRC), Lao PDR**, presented on climate extremes and adaptation in the MRC, an inter-governmental organisation comprising Cambodia, Lao PDR, Thailand, and Vietnam, focusing on the sustainable development of the Mekong River. Dr Cong explained that activities such as water management, hydropower generation, agriculture, and navigation performed by the four countries in the Lower Mekong Basin (LMB) are highly vulnerable to climate variability and change. He shared how MRC led the development of the Mekong Climate Change Adaptation Strategy and Action Plan, a challenge given the countries' economic dependence on the river and the low adaptive capacity. Dr Cong also discussed the various indices used for flood and drought forecasting and climate monitoring, despite challenges in obtaining suitable data for each index from member countries. One of the highest priorities for the MRC currently is to mainstream climate change into regional and national policies, programmes, and plans. Dr Cong noted that it was important that policy-makers recognised that small changes can have large consequences; for example, a 2°C increase in temperature can reduce rice production, sea level rise combined with subsidence can lead to salt water intrusion, and floods and droughts are expected to increase in the region, especially in Vietnam. Transboundary projects are also high on the agenda for the MRC, and Dr Cong cited an ongoing joint project on flood and drought between Cambodia (upstream) and Thailand (downstream). Transboundary projects are however costly, and Dr Cong noted the need for a climate fund. The MRC is also working towards enhancing early warnings for extreme events such as flash floods. Questions raised concerned the forecasting system and the challenges of transboundary work. In particular, representatives from Lao PDR were concerned that the MRC forecasts at times differed from their own, hence causing confusion. Dr Cong acknowledged that improvement was necessary through continued collaboration with member countries to further data collection and understand each country's needs.

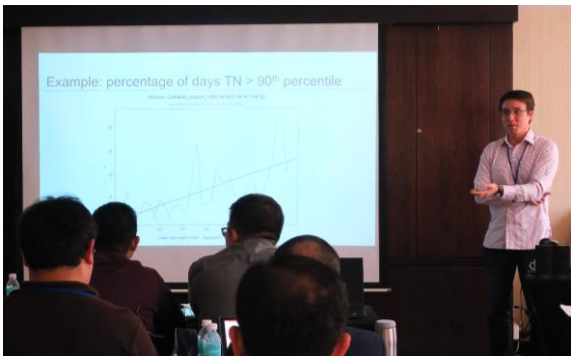
Dr Nguyen Dinh Cong introducing the MRC



Drought monitoring and forecasting for the LMB

Application of ClimPACT2 to Station Data

2.6 **Dr Nicholas Herold, New South Wales OEH, Australia**, introduced the participants to the ClimPACT2 indices. He highlighted that indices make information out of data that might otherwise not be relatable and help with circumventing the barriers to daily data exchange. The standardisation of indices also allows for comparison across different climates and regions, and provide meaning on a global scale. However, Dr Herold also noted that if countries were to share only indices and not data, there must be trust that these indices were calculated using quality data. Building on this point, he emphasised the need for rigorous quality control and homogenisation procedures. He also encouraged countries to combine the indices with sectoral data and work with end-users to determine suitable thresholds. The ET-SCI indices can be broadly divided into four categories: [1] minimum and maximum indices, [2] threshold indices, [3] duration indices, and [4] complex indices, and gave examples for each. Presenting example plots of maximum temperatures above the 90th percentile (insignificant with a slight upward trend) and minimum temperatures above the 90th percentile (significant with a marked upward trend) generated using station data from Changi, Singapore, Dr Herold showed that the indices deemed to be interesting vary with each country. He encouraged the participants to explore a range of indices, and proceeded with a demonstration on calculating indices using ClimPACT2.



Dr Nicholas Herold presenting an example of an extreme index calculated using data from Changi Airport, Singapore

2.7 Participants were given an opportunity to indicate indices that they were interested to explore in greater detail. Responding to requests, the ClimPACT2 experts elaborated on a range of indices, ranging from growing degree days *(GDDgrown)* to daily precipitation intensity *(SDII)*. Drawing from the material presented by the ClimPACT2 and sectoral experts, participants then spent the rest of the day calculating indices from station data brought by the respective countries. Discussion revolved around not only the technicalities of using the software and the resultant plots but also suitable thresholds for user-defined indices. The ClimPACT experts assisted participants whenever necessary and shared examples of their collaborations with sectoral experts. This allowed participants to better appreciate the capabilities of the software and gain a clearer understanding of how they can maximise its utility.

Dr Lisa Alexander explaining the Excess Heat Factor

3 Day 3: 27th March 2019, Wednesday

Summary

On the third day of the workshop, the focus shifted from station data to gridded products. Producers shared their views on the strengths and weaknesses of their products, as well as upcoming developments.

Dr Jean-Noël Thépaut elaborated on the configuration of ERA5 and noted the marked improvement in resolution and input data for the ERA5 over ERA-Interim. He also highlighted upcoming products such as ERA5T and ERA5-Land. Dr Pingping Xie shared that CMORPH_CRT captures convective precipitation during the warm season well, but is weaker with orographic rain and cold season precipitation. While it has good capacity for detecting extreme daily precipitation, it also tends to under-estimate (over-estimate) heavy (light) rainfall. In the pipeline is the second generation CMORPH product, expected to provide 30-minute precipitation estimates on a 0.05° grid.

Focusing on the importance of global historic data recovery in improving reanalysis products, Dr Fiona Williamson presented the Atmospheric Circulation Reconstructions over the Earth project. She introduced participants to the NOAA-CIRES-20th Century Reanalysis Version 3, produced using data recovered through the project, and emphasised the importance of buy-in from the national meteorological and hydrological services for the work to continue.

From the perspective of an end-user, Dr Vijayaraghavan Srivatsan used CHIRPS as a basis of comparison and found that TRMM was slightly positively biased over land in Southeast Asia while CMORPH was negatively biased. A case study on Bhutan also showed extreme underestimation of an order of magnitude by TRMM in mountainous regions. Downward trends in station data were also contrasted by upward trends in ERA-Interim, leading Dr Srivatsan to highlight a few key shortcomings of utilising satellite products as proxies for station data. Dr Joshua Qian shared his experience with using gridded products to evaluate the impacts of ENSO and MJO and rainfall variability. He emphasised the importance of using a variety of products to evaluate climate processes and the need for high-resolution gridded data capable of capturing small-scale phenomena.

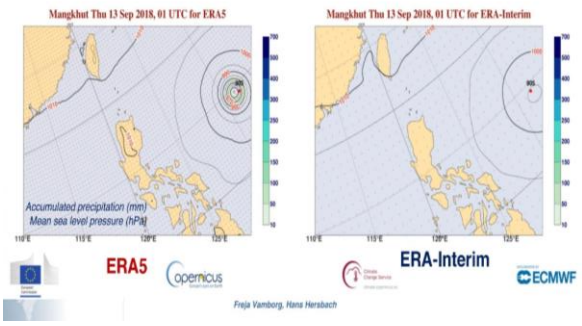
Linking gridded products with extremes, Dr Lisa Alexander introduced participants to the ClimDEX project and datasets such as GHCNDEX and HadEX2, and encouraged the NMHS representatives to contribute to HadEX3. Dr Nicholas Herold then provided a brief overview of the procedure to apply ClimPACT2 to gridded data, before providing participants with a set of indices pre-calculated from the JRA-55 dataset. Participants familiarised themselves with the data visualisation software Panoply through a tutorial, before proceeding to analyse the JRA-55 indices.

The latter half of the afternoon was spent at the InterMET Asia Conference, where participants networked with experts in both the public and private sectors, and attended a panel discussion on the balance between the public sector and commercial services.

Perspectives on Gridded Products and Large-Scale Processes

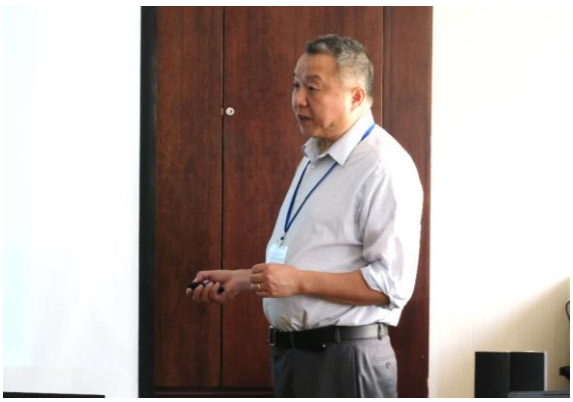
3.1 **Dr Jean-Noël Thépaut, European Centre for Medium-Range Weather Forecasts (ECMWF), United Kingdom**, delivered a remote presentation. During his lecture, he gave an overview of the Copernicus Climate Change Service (C3S) and highlighted the Climate Data Store (CDS), a one-stop portal for users to access, analyse, and visualise climate data, and encouraged the audience to register and explore the portal. Elaborating upon the configuration and performance of ERA5, he stressed that ERA5 is replacing ERA-Interim and encouraged users to make the shift by the end of 2019. Speaking on the improvements compared to ERA-Interim, Dr Thépaut mentioned the higher resolution of 31km compared to 80km, the uncertainty estimate at 62km, more and better input data, and hourly output. Although to date ERA5 is publicly available from 1979 to 2018, data for 1950 to 1978 will be made publicly available by the end of 2019. In addition, through a new preliminary product ERA5T, there is expected to soon be only a 2- to 5-day lag of updates behind real-time as compared to the current lag of two months. Access to ERA5 observations is also expected to soon be made available. Dr Thépaut highlighted that enhanced reanalyses were also being produced for land and introduced the audience to ERA5-Land. Featuring high-resolution downscaling of the land-surface component with a resolution of 9km, the product will be available via the C3S CDS in 2019. Finally, Dr Thépaut shared with the audience ECMWF's vision for C3S post-2020. Reanalysis continues to be highly prioritised, with a centennial global reanalysis going back to 1851 and a full-observing-system coupled reanalysis ERA6 among the many plans being made. Questions raised following the lecture involved the evaluation of extremes and the challenges of downloading large datasets. In response to Dr Lisa Alexander's question on extremes evaluation, Dr Thépaut hoped that while evaluation continues to be carried out using traditional means, the community will develop appropriate statistical tools to evaluate ERA5 in the near future. Dr Thépaut also explained that the team is working to better understand end-user needs to develop in-house calculations. This will enable end-users to download only the results they require instead of the full product, helping to ease concerns expressed by Dr Bertrand Timbal (CCRS, Singapore) regarding data download speeds.

Workshop participants watching the remote presentation by Dr Jean- Noël Thépaut

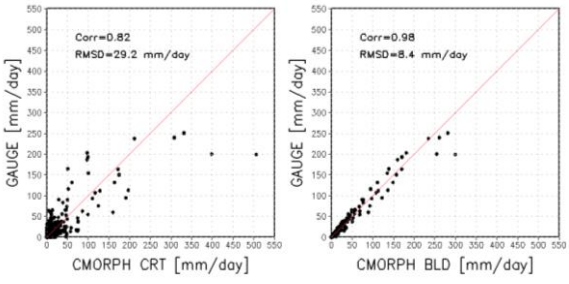


Example of ERA5's improvements over ERA-Interim; ability to better resolve Typhoon Mangkhut

3.2 **Dr Pingping Xie, National Oceanic and Atmospheric Administration (NOAA), United States**, provided an overview of the CPC Morphing Technique (CMORPH), which integrates information from satellite observations as well as in-situ measurements and model simulations to construct a high quality and high resolution global precipitation analysis. He introduced the bias-corrected CMORPH product CMORPH_CRT and explained how this is combined with gauge observations though optimal interpolation to produce the blended product CMORPH_BLD. Both products are available from 1998 to present, with the last set of gauge-satellite precipitation analysis being the CPC unified daily gauge analysis, available from 1979 to present. Elaborating on the performance of CMORPH_CRT, Dr Xie shared that comparison with gauge data over land from 1998-2015 showed good agreement for convective precipitation during the warm season, but poor performance for orographic rain and cold season precipitation, especially over snow- or ice-covered regions. Comparisons with data from the Global Precipitation Climatology Project (GPCP) revealed the long-term CMORPH_CRT mean closely matches the pentad GPCP merged analysis over the ocean, and the product also performed well quantifying oceanic precipitation over tropical oceans when compared with buoy measurements. Compared with radar over the continental United States, CMORPH_CRT has a higher daily correlation than TMPA V7 over many regions, especially the central Midwest. CMORPH_CRT also has a good capacity for detecting extreme daily precipitation at 0.25° resolution, however it tends to under-estimate (over-estimate) heavy (light) rainfall. Highlighting some of the applications of CMORPH, Dr Xie shared that it can be used to quantify mean and extreme precipitation climatology, verify model precipitation climatology, monitor ENSO and MJO, examine the precipitation diurnal cycle, and monitor hurricanes and other weather events. In the pipeline are an updated version of the CPC daily gauge analysis with new sources of daily gauge reports, and a second generation CMORPH product providing 30-minute precipitation estimates stretching from pole to pole on a 0.05° latitude and longitude grid. The latter is expected to date back to at least 1998, and possibly to 1991 at a coarser temporal resolution. Concerns raised by the audience include the underestimation of mean rainfall over the Philippines by CMORPH as compared to other products. Dr Xie attributed this to the possible known bias of heavy rainfall under-estimation, and noted that the performance in quantifying heavy rainfall will be improved in the upcoming CMORPH2.



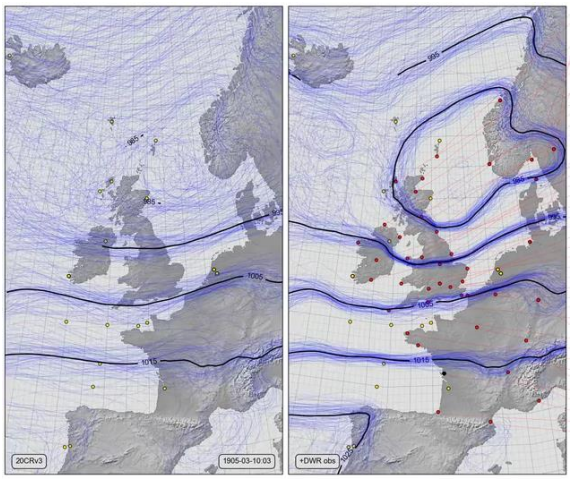
Dr Pingping Xie discussing the performance of the CMORPH products



Improvement of CMORPH_BLD over CMORPH_CRT in capturing heavy rainfall over the tropics

3.3 **Dr Fiona Williamson, Singapore Management University (SMU), Singapore**, focused on global historic data recovery and introduced the audience to the Atmospheric Circulation Reconstructions over the Earth (ACRE) and ACRE Southeast Asia (ACRE SEA) initiatives. With a worldwide network largely based on volunteers, ACRE functions as a link between disparate data recovery projects, and recovered data are freely given to international data repositories. She emphasised the importance of long-term climate datasets, explaining that historical data recovery will extend current datasets further back in time past the current mid-20th century norm, thus improving reanalysis products and enabling researchers to more reliably assess variations in extremes or large-scale processes such as ENSO. Dr Williamson shared that ACRE works closely with NOAA-CIRES to produce 4-dimensional reanalysis datasets extending back to the 19th century using recovered data. An example is the NOAA-CIRES-20th Century Reanalysis Version 3, which runs from 1836 to 2015 and offers more realistic extremes and quantified uncertainties at a 0.7° resolution. Elaborating on the regional initiatives, Dr Williamson focused on ACRE SEA, an initiative that has focused thus far on Singapore, Malaysia, Cambodia, and Lao PDR. The group has close links with ACRE China and ACRE Japan, and historians familiar with Southeast Asian topics and archives. Highlighting the cross-disciplinary nature of the initiative, Dr Williamson shared how weekly and daily observations have been uncovered for Singapore from 1820-1845 and 1861-1925, using newspapers, private records, and formal meteorological records. Challenges such as the frequent storage of archived data in other countries were also discussed. In the coming years, ACRE hopes to focus on the archives and libraries of ex-British colonies, and Dr Williamson emphasised the importance of buy-in from regional NMHSs for the work to continue. Through a new urban heat island project funded by the Singapore Ministry of Education, urban data for Singapore, Hong Kong, Delhi, and Wuhan will also be recovered, digitised, and analysed in the coming years.

Dr Fiona Williamson introducing the ACRE project



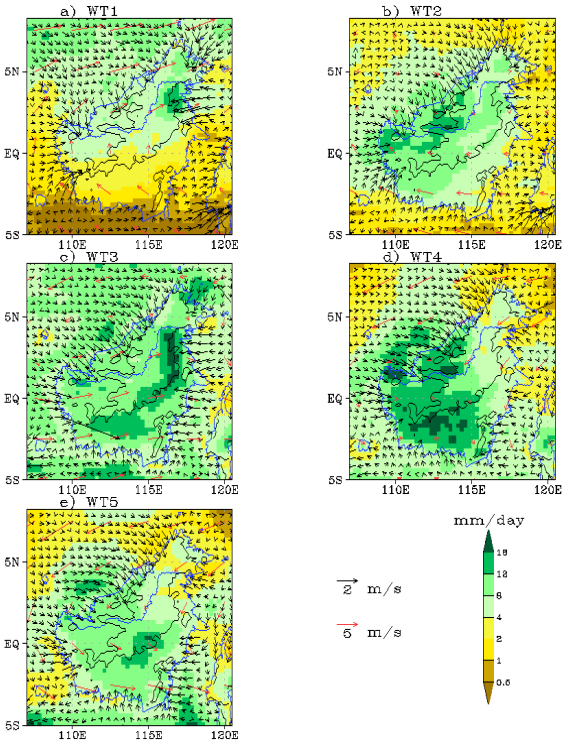
Improvement in the 20CRv3 MSLP analysis at 9.00AM on 15th March 1905 before (left) and after (right) the assimilation of 43 new station observations

3.4 **Dr Vijayaraghavan Srivatsan, Tropical Marine Science Institute (TMSI), Singapore**, assessed the accuracy of gridded rainfall observations over Southeast Asia. Using the Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) dataset as a basis for comparison, Dr Srivatsan showed that the Tropical Rainfall Measuring Mission (TRMM) dataset was slightly positively biased, while CMORPH was negatively biased over land. Focusing on a study done on Bhutan in which 20 years of temperature and precipitation

station data were compared to a range of gridded products, Dr Srivatsan highlighted the extreme underestimation (10 times less) by TRMM over the mountainous areas of Bhutan. Further, upward trends in ERA-Interim were contrasted by downward trends in station data. Concluding his presentation, Dr Srivatsan discussed if gridded products could be seen as good proxies for station data when the latter is unavailable, and highlighted a few key shortcomings. Dr Pingping Xie (NOAA, United States) commented that more station observations need to be made available to calibrate satellite estimates. He also strongly recommended that a unified analysis of all available station data be constructed, so as to work towards a gridded data framework for Southeast Asia. Mr Raizan Rahmat (CCRS, Singapore) highlighted the presence of the Southeast Asia RCC-Network, which currently serves to deliver regionally-focused high-resolution products.

Dr Vijayaraghavan Srivatsan comparing various gridded rainfall products

3.5 **Dr Jian-Hua (Joshua) Qian, Centre for Climate Research Singapore (CCRS), Singapore**, shared his research on using gridded products to evaluate the impacts of ENSO and MJO on regional rainfall variability. Introducing the audience to the topic, he highlighted various studies focusing on the relationship between daily synoptic weather types and their relationship to climate variability. He explained that precipitation tends to be concentrated over islands and mountainous regions in the Maritime Continent due to sea breeze convergence, mountain-valley breezes, and cumulus mergers in the sea breeze convergence zone. Highlighting the ENSO-related dipolar pattern of rainfall variability over Borneo, Dr Qian attributed this to the wake-effect associated with the five weather types, whose individual frequencies are strongly influenced by ENSO. This results in the concentration of rainfall on the shielded wake-side of large islands. In assessing the ENSO impacts on rainfall variability in Sumatra and the Malay Peninsula, he noted the need to consider not only the daily weather types, but also the diurnal cycle and monsoonal damping effects. Dr Qian highlighted the vanguard effect of MJO on rainfall variability and noted the relevance of both the monsoonal damping effect and wake-effect. He also emphasised the importance of utilising various sources of gridded information to evaluate climate processes



Five weather types (red arrows are 850hPa winds, black arrows are QuikSCAT sea-breezes, and averaged CMORPH precipitation is shaded)

and the need for high-resolution gridded data capable of capturing small-scale phenomena. Following the lecture, Dr Pingping Xie (NOAA, United States) raised the point that while reanalysis products capture circulation fields well, satellite products are still needed to capture precipitation and cloud cover. Hence, there is a need for both products to be combined in climate process studies.

Extreme Indices and Gridded Products

3.6 **Dr Lisa Alexander, UNSW Sydney, Australia**, introduced the audience to the ClimDEX project, which allows users to access the Expert Team on Climate Change Detection and Indices (ETCCDI) indices (a subset of the indices calculated by ClimPACT) for various countries in the form of plots of ASCII files. Gridded extreme indices datasets such as GHCNDEX and HadEX2 are also currently available through the site, and new in-situ, satellite, and reanalysis datasets are expected to be included in the near future, to allow for a better understanding of observational uncertainties. Dr Alexander highlighted that GHCNDEX was built from a large number of stations with little quality control, while HadEX2 was based on fewer stations but with higher quality data. While both datasets have made significant contributions to the IPCC reports, there has been little improvement in coverage between the IPCC assessments. This gap will hopefully be filled by the upcoming HadEX3 and other datasets. Dr Alexander elaborated upon the expected improvements of HadEX3 over HadEX2, including a higher resolution, better spatial and temporal coverage, and more station data. She highly recommended that the ASEAN NMHSs contribute the indices calculated using ClimPACT2, noting that 1st July 2019 will be the cut-off for inclusion of station data and that contributors will be granted co-authorships on future publications.

Dr Lisa Alexander explaining the difference between GHCNDEX and HadEX2

3.7 **Dr Nicholas Herold, New South Wales OEH, Australia**, provided a brief overview of the installation and execution process for running gridded data through ClimPACT2. He highlighted that ClimPACT2 accepts only CF-compliant NetCDF files for gridded data and that the calculation requires significant computing power and either Linux or MacOS. Full instructions can be found at https://github.com/ARCCSS-extremes/climpact2. Due to computing constraints at the workshop, Dr Herold distributed selected indices pre-calculated from the Japanese 55-year reanalysis JRA-55, with base period 1961-1990. He reminded the audience to conduct thorough research on products before drawing conclusions from them, citing the example of precipitation being a forecast variable in JRA-55 and hence not appropriate for analysing trends in extremes. He also highlighted that care should be taken when comparing indices from station and gridded data as the former is likely to be more

extreme and variable as compared to the latter. A Panoply tutorial was also distributed to guide the participants in visualising gridded data.

3.8 Under the guidance of the three ClimPACT2 experts, participants worked through the Panoply tutorial on data visualisation before proceeding to analyse the selected JRA-55 indices provided by Dr Herold. The goal was to gain experience and a basic understanding of applying ClimPACT2 to gridded data as well as working with Panoply. This was to ensure that participants had sufficient knowledge to execute the software and visualise the results once back in their home countries with the appropriate computing resources.

Dr Lisa Alexander, Dr Cédric Van Meerbeeck, and Dr Nicholas Herold guiding participants

InterMET Asia

3.9 At the invitation of the InterMET Asia team, the ARCDAP-2 participants spent the afternoon at the InterMET Asia Conference. Participants toured the exhibition and attended the panel discussion 'Public Sector – Commercial Services?' moderated by Dr David Rogers (Consultant, World Bank). Participants were then invited to an official reception and dinner hosted by Earth Networks and InterMET Asia, where they had the opportunity to network with experts in both the public and private sectors.

Participants gathering for a group photo following the official reception and dinner (left) and conversing with providers of meteorological products and services at the exhibition (right)

4 Day 4: 28th March 2019, Thursday

Summary

Concluding the ClimPACT2 training sessions, Dr Cédric Van Meerbeeck shared how the ET-SCI indices are used for operational monitoring and the prediction of climate hazards and impacts in the Caribbean. Both the drought early warning system and monitoring network are based on the Standardised Precipitation Index *(SPI)* and Standardised Precipitation Evapotranspiration Index *(SPEI)*. Studies have also shown strong correlations between the ET-SCI indices and factors such as rice production and acute respiratory infections.

Participants were given the rest of the morning to prepare 15-minute summary presentations and written summaries of their results. They were encouraged to share their quality control process and include plots from the hands-on sessions. Comparisons between the trends derived from JRA-55 and station data were also encouraged.

A common quality control procedure amongst the NMHSs was to identify values of maximum temperature, minimum temperature, and total precipitation that were abnormal for a given season or month. Participants also checked for minimum temperatures that exceeded maximum temperatures, and corrected these either by changing them to missing values or rectifying them by checking on data at nearby stations. Participants noted that most of the change points identified by RHtestV4 during homogeneity assessment could be attributed to ENSO events, with exceptions necessitating further metadata checks.

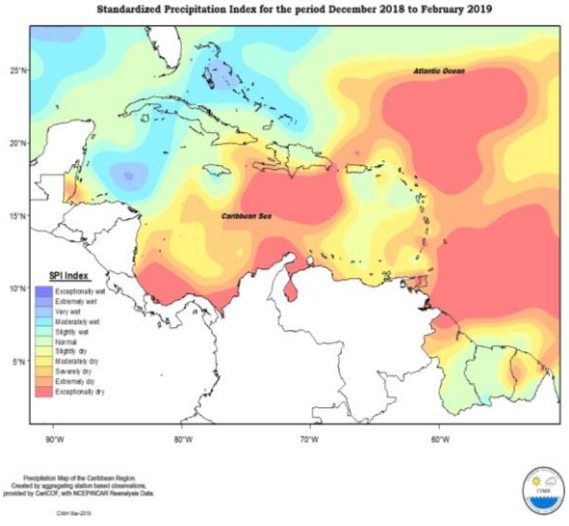
The NMHSs each explored a range of indices, but common across Cambodia, Lao PDR, and the Philippines were significant increasing trends in warmest daily maximum temperatures and coldest daily minimum temperatures. Brunei, Myanmar, the Philippines, and Thailand also reported an increasing trend in *SPI* and *SPEI* for varying time scales. Most countries did not observe significant differences between the trends derived from JRA-55 and those from station data, with the exception of Singapore, which noted that station precipitation trends were reversed for JRA-55. This was attributed to model resolution given Singapore's small land area, and its position between two grid cells.

Application of ClimPACT2 to Gridded Products

4.1 Participants were given more time to continue their analysis of indices produced using JRA-55 and to experiment with data visualisation using Panoply. They were also encouraged to draw preliminary comparisons between station and gridded data wherever possible and identify particularly interesting trends, in preparation for their summary presentations later in the day.

Example of Study using ClimPACT2

4.2 **Dr Cédric Van Meerbeeck, CIMH, Barbados**, shared on how indices calculated using ClimPACT2 are being used for the operational monitoring and prediction of climate hazards and impacts in the Caribbean. The region is especially vulnerable to drought due to its dependence on rain-fed agriculture and the coincidence of the tourism season with the dry season, with conditions occasionally exacerbated by El Niño. Dr Van Meerbeeck shared that both the drought early warning system established in 2010 and the Caribbean Drought and Precipitation Monitoring Network (CDPMN) established in 2009 utilise the Standardised Precipitation Index *(SPI)* and Standardised Precipitation Evapotranspiration Index *(SPEI)*, both of which are indices included in ClimPACT2. The biannual Caribbean Climate Outlook Forum (CariCOF) provides outlooks for the wet and dry seasons, with monthly drought alert maps being produced in the interim. For maximum effectiveness, CIMH strives to ensure drought forecasts are actionable, timely, understandable, and relevant. Linking ClimPACT2 indices to sectoral outcomes, Dr Van Meerbeeck shared studies showing a negative correlation between rice production in Suriname and the number of days where maximum temperature exceeded 35°C *(TXge35)*, and a positive correlation between acute respiratory infections in Cuba and the maximum 5-day precipitation total *(RX5day)*. The audience was curious about data sharing in the Caribbean, and Dr Van Meerbeeck clarified that countries are only considered participants to CariCOF if they consent to sharing monthly meteorological and sectoral data with CIMH and neighbouring countries. Ms Thelma Cinco (PAGASA, Philippines) questioned how varying definitions of above- and below-normal rainfall across the seasons could be accounted for. Dr Van Meerbeeck recommended the definition of an *SPI* threshold based on drought impacts for various sectors.



SPI for December 2018 to February 2019

Preparation of Presentations and Written Summaries by NMHSs

4.3 The rest of the morning was allocated to the preparation of a 15-minute summary presentation and a brief write-up by the respective NMHSs. Templates for each task were provided to the participants. For the presentation, participants were encouraged to include plots from the hands-on ClimPACT2 sessions (both station and gridded data), their learning outcomes, and any feedback they had on the software. The aim of the written summary was to provide a basis for the upcoming publication on extreme indices.

NMHS representatives preparing their presentations and written summaries, with guidance from experts

Presentations of Results by ASEAN NMHSs

TABLE 2. Summary of significant trends across countries

Country	Station	Period	Variable	Trend
Brunei	Brunei International Airport	1980 – 2018	TMm	↑
			SPI-3	↑
Cambodia	Kampong Cham	1985 – 2015	TXx	↑
			TNn	↑
Lao PDR	Pakse	1971 – 2018	TXx	↑
			TNn	↑
Malaysia	Kota Bharu	1989 – 2018	R20mm	↑
Myanmar	Dawei	1971 – 2018	TXm	↑
			TX10p	↓
			SU	↑
			HWF-Tx90	↑
			HWN-EHF	↑
	Mandalay	1972 – 2018	SPI-3	↑
			SPI-/SPEI-6/12	↑
Philippines	Loaog	1951 – 2017	TXx	↑
			TNx	↑

			TXm	↑
			RX1day, RX5day	↑
			PRCPTOT	↑
			SPEI-3/6/12	↑
Singapore	Changi	1981 – 2018	TN90p	↑
			R95pTOT	↓
	Tengah	1980 – 2018	TX90p	↑
			TN90p	↑
			PRCPTOT	↑
Thailand	Bangkok	1981 – 2018	TXge32	↑
			WSDI	↑
			SPI-12	↑
Vietnam	Ha Noi	1979 – 2018	TN10p	↓
			TX90p	↑
			HWF-Tx90	↑
	Dong Hoi	1979 – 2018	TN10p	↓
	Buon Me Thuot	1979 – 2018	TN10p	↓
			HWF-Tx90	↑
	Can Tho	1979 – 2018	TN10p	↓
			TX90p	↑
			HWF-Tx90	↑
			CWN-ECF	↓
			CWF-ECF	↓
			SPEI-6	↓

4.4 **Mr Monichoth So Im, DOM, Cambodia**, focused on the Kampong Cham station, located in southeast Cambodia. Quality control was conducted by first using ClimPACT2 to identify points in the record where minimum temperatures exceed maximum temperatures. Points where the absolute change in daily minimum temperature exceeded 20°C were also identified. Comparisons with indices derived from JRA-55 showed that the results from the reanalysis were consistent with that from the Kampong Cham station. The standardised precipitation index *(SPI)* was also highlighted as a useful index for rice cultivation, prevalence of skin disease in children, and water.

4.5 **Mr Sengduangduan Phouthanoxay, DMH, Lao PDR**, presented on the Pakse station in southern Lao. Drawing from knowledge on the local climatology, quality control was conducted by identifying abnormally high values for daily maximum temperatures and total rainfall and reflecting these as missing values instead. Significant trends were coupled with the

lack of significance for the coldest daily maximum temperature *(TXn)*, the warmest daily minimum temperature *(TNx)*, the number of days where precipitation exceeded 20mm *(R20mm)*, the maximum 1-day total rainfall *(RX1day)*, and the maximum 5-day total rainfall *(RX5day)*. Mr Phouthanoxay concluded that while there has been significant warming, there has been no significant change in the rainfall pattern over the last 30 years at Pakse.

4.6 **Dr Tin Mar Htay, DMH, Myanmar**, focused on Dawei, a station in southern Myanmar and Mandalay in central Myanmar. She highlighted periods of missing data revealed during the quality checks, as well as unrealistic values. Homogenisation using RHtestV4 revealed no change points in the maximum temperature series, and two major change points in the minimum temperature series in 1975 and 2006. These were matched to La Niña and El Niño occurrences respectively. Analysed indices pertaining to rainfall *(PRCPTOT, R99p, R200mm, CDD, CWD)* did not show any significant trends. There was in general good agreement between station-derived indices and those from JRA-55.

4.7 **Dr Chalump Oonariya, TMD, Thailand**, presented the results from Bangkok station, situated in a highly-populated area and exposed to the UHI effect. Quality control was carried out by identifying missing or abnormal values and correcting them wherever possible. Dr Oonariya shared that the significant and positive trend in the number of very heavy rain days signals the need for traffic planning, as average speed decreases in heavy rain. The significant and positive trends in the number of days where maximum temperatures exceed 32°C *(TXge32)* and the warm spell duration indicator *(WSDI)* indicate that the amount of cooling required is increasing – valuable information for air-conditioning retailers to encourage consumers to invest in more energy-saving models. A positive *SPI-12* trend also indicates that recent years have seen wetter than normal conditions at the annual time scale.

4.8 **Mrs Pham Thi Cham, NCHMF, Vietnam**, focused on four stations, representing the four regions in Vietnam – Ha Noi (north), Dong Hoi (central), Buon Me Thuot (central highlands), and Can Tho (south). She shared that reformatting the data to the RClimDex format allowed for quick identification of missing dates. Where daily maximum temperature was equivalent to daily minimum temperature, temperature data at the nearest station was checked to determine if both or either was correct. The erroneous temperature was then recorded as missing. No significant trends were observed in the number of days when precipitation was at least 10mm *(R10mm)*, 20mm *(R20mm)*, or 50mm *(R50mm)*, indicating that the rainfall trend at all four stations has not changed significantly. Commenting on the increasing (decreasing) frequency of days contributing to heatwaves (coldwaves), Mrs Cham shared that a 'hot day' is defined as when maximum temperatures are at least 35°C and a 'very hot day' is defined as when maximum temperatures are at least 37°C. These thresholds are applicable nationwide, as opposed to in Myanmar, where Dr Tin Mar Htay explained that thresholds varied regionally. Dr Van Meerbeeck raised that while location-specific thresholds are helpful, centralised thresholds allow for efficient implementation of mitigation strategies. At Ha Noi and Can Tho there has been a significant increase in the number of hot days, while the trend for very hot days is less clear. The *SPEI* also shows a significant negative trend for Can Tho, indicating increasing dryness in the south.

4.9 **Mr Arifin Yussof, BDMD, Brunei**, presented on the results for the station located at Brunei International Airport. Homogeneity tests revealed change points in the data – some could be attributed to El Niño events and others were hypothesised to be due to instrument changes and necessitated checks with the metadata. Analysis using ClimPACT2 showed the station was increasingly warm and wet. However, precipitation indices such as the maximum 5-day precipitation total *(Rx5day)*, number of days when precipitation was at least 1mm *(R1mm)* and at least 30mm *(R30mm)* showed increasing but insignificant trends. Mr Yussof explained that this could be due to the need for more data. Concluding his presentation, he shared that BDMD hoped to develop new indices for weather hazards that were relevant to stakeholders and use the current indices for seasonal forecasts. He suggested two new indices – the frequency of occurrence for 3 consecutive days where rainfall is greater than a given threshold, and the number of consecutive days when rainfall is greater than a given threshold.

4.10 **Ms Wan Maisarah Wan Ibadullah, MMD, Malaysia**, presented the results for Kota Bharu, located in northeast Malaysia. Quality control was conducted by ensuring that maximum temperatures exceeded minimum temperatures. Focusing on trends in precipitation, Ms Wan Ibadullah shared that while the number of days with at least 20mm of precipitation was increasing, the trends for annual total precipitation *(PRCPTOT)* and the number of days when precipitation is at least 50mm *(R50mm)* were insignificant. She noted that the variability in precipitation could be attributed to large-scale processes such as ENSO and MJO, and that the goal of MMD would be to utilise ClimPACT2 to improve early warning systems.

4.11 **Ms Thelma Cinco, PAGASA, Philippines**, focused on the Loaog station, located in northern Philippines. Homogeneity checks revealed a series of change points, most of which could be attributed to ENSO events, with the exception of one in 2011, which would require further metadata checks. Results showed that the annual warmest minimum temperature *(TNx)* was increasing at 0.1°C per decade and mean daily maximum temperature *(TXm)* was increasing at 0.2°C per decade. Analysis of precipitation indices and *SPEI* at the various time scales pointed to wetter conditions in recent years. Ms Cinco voiced concerns that increasing *TXx* and *TNx* could have adverse impacts on the agriculture and health sectors, and that increasing intensity of precipitation could cause flooding and landslides.

4.12 **Mr Jin Zheng Ng, MSS, Singapore**, shared results from Changi station, located in the east of Singapore, and Tengah station, located in the west. Quality control and homogenisation checks flagged suspicious values such as abnormally low minimum temperatures in March 2010 and June 2013. These were cross-checked with nearby stations and ascertained to be accurate. Results showed that annual total precipitation was increasing significantly at Tengah but not at Changi. Indices derived from JRA-55 however showed no trend at Tengah and decreasing annual total precipitation at Changi. Mr Ng attributed this to model resolution, given Singapore's small land area and its position between two grid cells. The increase in the number of hot days and warm nights observed from station data was however replicated in JRA-55, and Mr Ng attributed this to the increase of built-up areas over the region. Concluding his presentation, Mr Ng suggested the inclusion of hourly indices, an index linking rainfall duration to mean temperature, and alternative file types when outputting plots.

5 Day 5: 29th March 2019, Friday

Summary

Participants were invited to suggest new indices for ClimPACT2, focusing in particular on the variables and time scales that would be effective for their respective countries. To facilitate the discussion, participants each joined one of three breakout groups, focusing on floods, heatwaves, and droughts respectively. These hazards were highlighted as the most prevalent during the workshop, and each group was led by a ClimPACT2 trainer.

Suggestions included the ability to calculate compound indices by allowing users to add more variables through an additional data column. This would allow users to better quantify hazard risk, as non-extreme individual events frequently combine to produce devastating results. Also suggested was the inclusion of humidity in the calculation of heatwave indices, building on Dr Jason Kai Wei Lee's seminar on the importance of humidity in determining thermal comfort. Participants also noted that thresholds such as 1.0mm for the consecutive dry days *(CDD)* index was not suitable for the tropics, where high evaporation rates can result in a daily minimum plant water requirement of 2.5mm. Key hazards that were not discussed but were raised in a subsequent discussion included landslides, storm surges, sea level rise, and soil erosion.

Elaborating on the expected workshop outcome of a peer-reviewed publication focusing on extreme indices, Dr Lisa Alexander emphasised the importance of documenting work done in the region to fill current gaps in the literature and increase the region's profile on the global stage. She suggested that NMHSs take the first step by contributing to the upcoming HadEX3 dataset, stating that this will give participants a better idea of the number of stations they wish to eventually contribute to the peer-reviewed publication.

In terms of large-scale processes, participants primarily indicated interest in analysing ENSO and MJO using results from ClimPACT2. Other processes highlighted include equatorial waves and the Indian Ocean Dipole.

A live poll conducted to gather the participants' perceptions on gridded products showed that TRMM and ERA-Interim were the preferred products to analyse long-term rainfall trends. However, APHRODITE was preferred for validations against station observations. In discussing regional goals, participants agreed that countries should focus on producing national gridded products utilising a specific interpolation method and eventually contribute the product to the global dataset. Participants were also interested to grid the ET-SCI indices to produce a regional product.

Discussions concluded with final recommendations for ClimPACT2 software improvements, including improving the ease of performing batch operations and allowing users to alter the y-axis. The workshop concluded with a presentation of certificates of appreciation and participation to the experts and participants respectively.

Suggestions for New Extreme Indices

5.1 **Dr Lisa Alexander, UNSW Sydney, Australia**, shared with the audience the importance of sector-specific indices. She elaborated on the strong relationships between the number of days with at least 20mm of precipitation *(R20mm)* and *SPI* with wheat yields in New South Wales. She also shared how humidity and extreme temperatures were associated with higher mortality and hospital admission rates.

5.2 The audience was encouraged to suggest new indices for ClimPACT2 relevant to their respective countries, considering in particular the variables and time scales that would be effective. To facilitate this, participants were invited to divide themselves into three breakout groups based on their interests. Each group focused on indices for one of the three key hazards cited by the ASEAN NMHSs throughout the workshop – floods, heatwaves, and droughts.

5.3 The breakout group focusing on floods was led by Dr Lisa Alexander. The group felt that it was important to distinguish between flash floods and long-term floods and suggested specific indices (Table 3). They highlighted the importance of considering compound events, noting that non-extreme individual events frequently combine to produce devastating results, such as a high tide coinciding with a rainfall surplus. In addition, they noted that rainfall was only a single component, and suggested that users be allowed to combine the three existing variables with others such as vegetation, land-use, and drainage through an additional data column. Variables such as tidal data, wind, and model-based moisture fluxes were also highlighted. The importance of transboundary cooperation for large river catchments was also emphasised.

Breakout group discussion focusing on flood-related indices

The breakout group focusing on heatwaves was led by Dr Nicholas Herold and comprised representatives from Singapore and Thailand. They noted that it was important to define an upper and lower temperature boundary, citing the differences in thresholds between the two countries. Key to suggestions (Table 1) was the inclusion of humidity in the calculation of heatwave indices, but the group recognised the challenge in setting a wet bulb temperature threshold given the limited regional research on the relationship between heat and the various sectors. The group also emphasised the need for country-specific indices, and Dr Herold cited the example of inappropriate indices resulting in Darwin and Sydney recording heatwave conditions for most of the year. Also suggested was to combine reanalyses with observations to define new indices. Dr Cédric Van Meerbeeck agreed the inclusion of humidity would be helpful, but recommended first ensuring that temperature and humidity do not co-vary in time.

Breakout group discussion focusing on heatwave-related indices

The breakout group focusing on droughts was led by Dr Cédric Van Meerbeeck. They highlighted the need for country-specific indices, citing the differences between Myanmar and the Philippines in declaring a drought. The group recommended that the current 1.0mm threshold for the consecutive dry days *(CDD)* index be customised, as high evaporation rates result in a daily minimum plant water requirement of 2.5mm in the Philippines. They also hoped for customisable time scales. Noting that *CDD* is of limited sectoral use, the group also recommended the addition of a dry spell frequency index (Table 1). Focusing on the *SPI* and *SPEI*, the group noted that the indices do not consider transboundary watersheds. Further, they emphasised the need for both indices to be converted into terms relatable to policy-makers, citing Vietnam's K-index as a successful example. The group recommended that further studies be done to ascertain if the K-index, an aridity index derived from dividing precipitation by evaporation, could be useful and potentially included in ClimPACT2.

Breakout group discussion focusing on drought-related indices

TABLE 3. Recommended additional indices

Flood Indices	Heatwave Indices	Drought Indices
n consecutive days/hours over *x* threshold	*n* days with wet bulb temperature over *x* threshold	Dry spell frequency
n days/hours required to reach *x* threshold	Compound indices (e.g. temperature and humidity)	Aridity index (e.g. Vietnam's K-index)
Maximum accumulated precipitation over *n* days/hours		Customisable time scales and thresholds for CDD and SPI
Compound indices (e.g. tide and precipitation)		Air pollution index (e.g. for PM2.5)
Return periods		Bushfire index

5.4 Following the reporting from the breakout groups, participants were invited to raise any additional hazards they felt were important. Ms Thelma Cinco (PAGASA, Philippines) mentioned the importance of having thresholds for landslides and storm surges, but acknowledged possible challenges due to variances in landslide extent and cause and the possible lack of data required for a storm surge index. Dr Bertrand Timbal (CCRS, Singapore) suggested the inclusion of a sea level index. Ms Cinco agreed, sharing that sea level rise is among the top priorities for communities. Dr Nguyen Dinh Cong (MRC, Lao PDR) suggested a soil erosion index, elaborating that it could be based largely on rainfall as variables such as land use and topography tend to remain constant over longer time scales. Mr Monichoth So Im (DOM, Cambodia) recommended including Intensity-Frequency-Duration (IFD).

Extreme Indices Publication and HadEX3 Contribution

5.5 **Dr Lisa Alexander, UNSW Sydney, Australia**, emphasised the importance of the workshop and of documenting the results for the region. Providing an overview of previous workshops held in Vietnam (December 2007), South Korea (February 2008), Singapore (June 2011 and May 2012), and China (March 2013), she highlighted that while regional workshops in the past had focused solely on trends, ARCDAP-2 has taken this a step further and looked into sectoral impacts as well. Elaborating on the current gaps in the literature, Dr Alexander shared that no publication thus far contained analyses for every ASEAN country and that previous workshops focused solely on the ETCCDI indices, while the improved ET-SCI indices have a greater sector focus. The publication of a peer-reviewed paper discussing the results from ClimPACT2 for ASEAN is hence crucial, and will also help to maintain transboundary collaborations and raise the international profile of the region. She suggested that countries complete quality control and homogenisation and calculate the ET-SCI indices for one station by July 2019. The station should cover the 1961 to 1990 period, the 1981 to 2010 period, or both. This will facilitate contribution of the results to the HadEX3 dataset and will hopefully allow the NMHSs to make an informed decision as to the number of stations they will commit to the eventual peer-reviewed paper.

Analysis of Large-Scale Processes

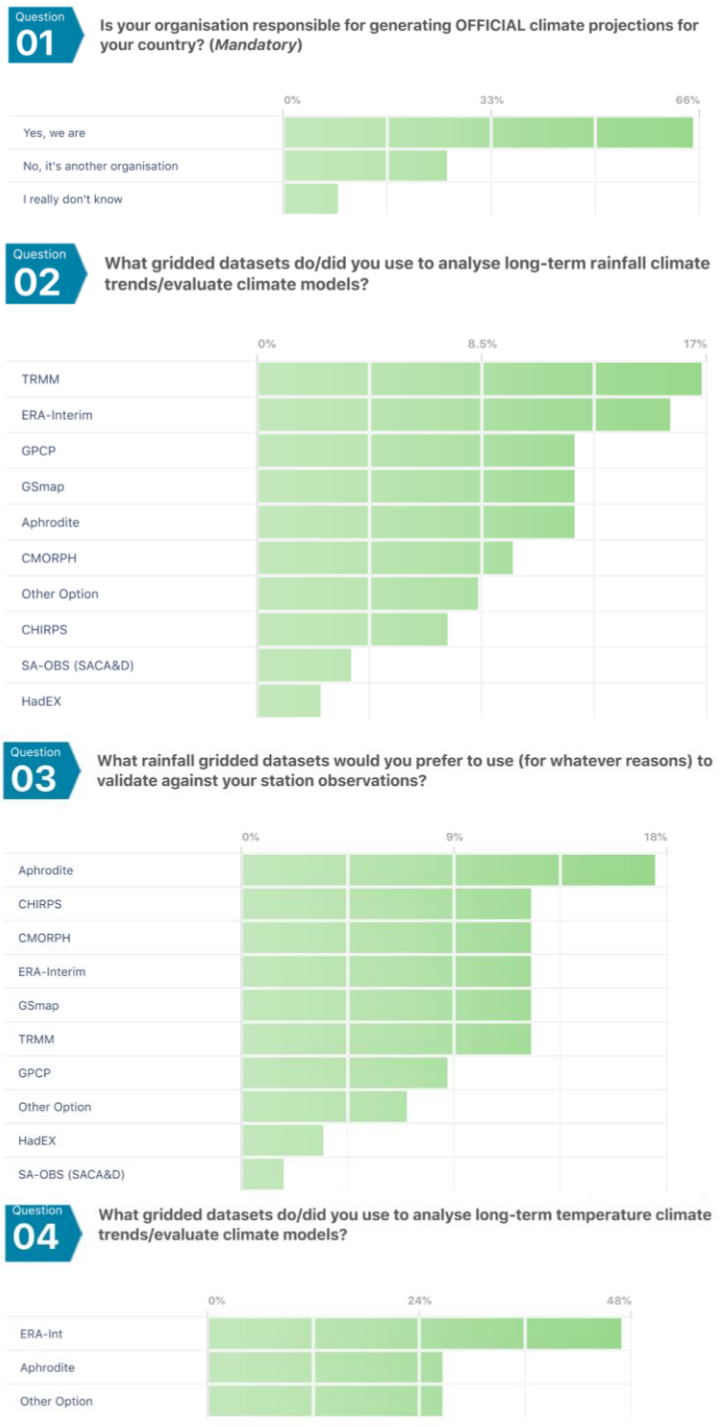
5.6 Participants discussed the large-scale processes they hoped to analyse using results from ClimPACT2. ENSO and MJO were at the forefront of the discussion, with Ms Thelma Cinco (PAGASA, Philippines) sharing that the Philippines looked at both, while Mr Monichoth So Im (DOM, Cambodia) noted that Cambodia utilises only ENSO for outlooks, and has limited experience with MJO. Dr Muhammad Eeqmal Hassim (CCRS, Singapore) highlighted that the analysis of equatorial waves would be beneficial for the region, and Dr Kanoksri Sarinnapakorn (HII, Thailand) expressed interest in the analysis of the Indian Ocean Dipole (IOD).

Regional Perceptions on Gridded Products

5.7 **Mr Raizan Rahmat, CCRS, Singapore**, opened the discussion on gridded products by providing a brief summary of recommendations from ARCDAP-1 and key products, strengths, and limitations mentioned in the course of ARCDAP-2. He highlighted initiatives such as the Joint WCRP Grand Challenge on Weather and Climate Extremes and the Space-based Weather and Climate Extremes Monitoring Demonstration Project (SEMDP). A live poll was then conducted to better understand the audience's perceptions of gridded datasets.

The poll revealed that the majority of participants used TRMM and ERA-Interim to analyse long-term rainfall climate trends and evaluate climate models. However, APHRODITE was the preferred rainfall product for validations against station observations. Other products mentioned included ERA5, and it was raised that GPCC outperforms other products when validated against station observations in Thailand. For the analysis of long-term temperature trends, most participants used ERA-Interim, with APHRODITE and ERA5 also mentioned.

The poll prompted discussions, with Dr Pingping Xie (NOAA, United States) and Dr Lisa Alexander emphasising the need for caution when using gridded products to analyse long-term trends. Dr Xie noted that there is currently no gridded rainfall product capable of resolving a long-term trend of 30 years or more. Further, he noted that current reanalysis products are reliable with large-scale circulations, but less so with surface variables such as rainfall. He also warned that in long-term reanalysis products, satellite data only begins to be included in the late 1970s,



Poll results on the perceptions of gridded products

resulting in inconsistencies. Hence, he recommended the use of gridded products for short-term climate analysis, a view echoed by Dr Alexander.

Looking ahead, Dr Vijayaraghavan Srivatsan (TMSI, Singapore) asked if the NMHSs planned to create their own gridded datasets. Representatives from Philippines and Myanmar shared that they aspired to do so and Dr Srivatsan noted that the process might require a couple of years while countries continue to expand and improve their observation networks. Dr Xie highlighted the importance of a common gridding technique, stating that this will allow countries to contribute their gridded results to a regional product, since the ASEAN region experiences similar large-scale processes. Dr Srivatsan suggested that a questionnaire be circulated to the participants to consolidate perceptions on gridded products and to guide the peer-reviewed publication. Ms Thelma Cinco (PAGASA, Philippines) shared results from a validation study conducted by the Philippines, noting that the analysed products ranked from most accurate to least were APHRODITE, GSMaP, CMORPH, TRMM, and CHIRPS.

When discussing whether the focus should be on temperature or rainfall for the upcoming peer-reviewed publication, participants agreed that there were clear gaps in the latter. However, Dr Xie highlighted the importance of a gridded product for maximum and minimum temperatures. The consensus was that a focus on extremes would complement work at the station-level, while focusing on the mean would be crucial for the evaluation of climate models. Dr Xie noted that the Climate Prediction Centre (CPC) was open to sharing their interpolation method with the NMHSs, so as to allow the injection of nationally gridded data into the global product. The audience agreed that this would be of great help, and two key foci emerged:

1. To interpolate station data nationally using a given interpolation method and contribute the resultant grid to a global product;
2. To grid the ET-SCI indices produced by each country, creating a regional product.

Recommendations for ClimPACT2 Software Improvement

5.8 **Dr Nicholas Herold, New South Wales OEH, Australia**, kicked off the final discussion session on improvements the participants would like to see in ClimPACT2. Ms Thelma Cinco (PAGASA, Philippines) recommended that batch operations be made easier to execute. Dr Kanoksri Sarinnapakorn (HII, Thailand) asked if the y-axis could be manually altered to facilitate comparison. She also suggested that varying spatial scales be allowed, to enable analysis across a region or river basin. Conveying concerns about the traceability of data alterations, Ms Sarinnapakorn also asked if the software could show a list of all changes made during the quality control process. Dr Nguyen Dinh Cong (MRC, Lao PDR) and Mr Kritanai Torsri (HII, Thailand) voiced concerns about the strict missing data requirements in ClimPACT2, suggesting that they could be relaxed to enable the use of more datasets. Dr Cédric Van Meerbeeck mentioned that while the code for the ggplot package has been included in ClimPACT2, the code to make the plots more presentable had yet to be included. Dr Herold noted these concerns and thanked the participants for the feedback and suggestions.

Annex B: Workshop Programme

Day 1: Monday, 25th of March 2019			
Welcome and Introduction			**Chair: Dr Thea Turkington** **Notetaker: Mr Raizan Rahmat**
08:00 - 09:00	1.1	Registration	
09:00 - 09:50	1.2	Welcome Address - Director, CCRS, Singapore	Dr Erland Källén (Centre for Climate Research Singapore - CCRS)
	1.3	Opening Address - Director, WMO Regional Office for Asia and the South-West Pacific (RAP)	Dr Chung Kyu Park (World Meteorological Organisation - WMO)
	1.4	Introduction to the WMO Climate Services Information System - WMO, Geneva	Ms Anahit Hovsepyan (World Meteorological Organisation - WMO)
	1.5	Workshop Overview and Objectives - CCRS, Singapore	Dr Bertrand Timbal (Centre for Climate Research Singapore - CCRS)
09:50 - 10:20	Group Photo and Coffee Break		
Introductory Presentations by NMHSs (Continental and Maritime SEA)			**Chair: Dr Thea Turkington** **Notetaker: Mr Raizan Rahmat**
10:20 - 10:35	1.6	Cambodia: Department of Meteorology	Mr Monichoth So Im
10:35 - 10:50	1.7	Lao PDR: Department of Meteorology and Hydrology	Mr Bounteum Sysouphanthavong
10:50 - 11:05	1.8	Myanmar: Department of Meteorology and Hydrology	Dr Tin Mar Htay
11:05 - 11:20	1.9	Thailand: Thai Meteorological Department	Dr Chalump Oonariya
11:20 - 11:35	1.10	Vietnam: Vietnam National Centre for Hydro-Meteorological Forecasting	Mr Nguyen Duc Hoa
11:35 - 11:50	1.11	Brunei: Brunei Darussalam Meteorological Department	Mr Izzat Ibrahim
11:50 - 12:50	Lunch		
Introductory Presentations by NMHSs (Maritime SEA), Introduction and Installation of ClimPACT2			**Chair: Dr Jian-Hua (Joshua) Qian** **Notetaker: Mr Raizan Rahmat**
12:50 - 13:05	1.12	Malaysia: Malaysian Meteorological Department	Ms Wan Maisarah Wan Ibadullah
13:05 - 13:20	1.13	Philippines: Philippine Atmospheric, Geophysical and Astronomical Services Administration	Ms Rosalina De Guzman
13:20 - 13:35	1.14	Singapore: Meteorological Service Singapore	Mr Wee Leng Tan
13:35 - 13:55	1.15	Introduction to ClimPACT2 *Overview: features of software, required inputs, and outputs*	Dr Nicholas Herold *(New South Wales Office of Environment and Heritage)*
13:55 - 14:40	1.16	Installation of ClimPACT2 software package and dependencies *Guided installation of ClimPACT2, R, and Panoply, if not already installed*	Dr Nicholas Herold and NMHS Representatives *(New South Wales Office of Environment and Heritage)*
14:40 - 15:10	Coffee Break		
Quality Control using ClimPACT2			**Chair: ClimPACT2 Experts** **Notetaker: Mr Raizan Rahmat**
15:10 - 16:10	1.17	Quality control with ClimPACT2 *Demonstration of the inefficiency of QC using Excel and the usefulness of ClimPACT's QC functionality*	Dr Cédric Van Meerbeeck *(Caribbean Institute for Meteorology and Hydrology - CIMH)*
16:10 - 18:00	1.18	Hands-on quality control of station data using ClimPACT2 *Guided quality control session, data to be formatted to RClimDex format if required*	ClimPACT2 experts and NMHS representatives *(NMHS representatives to be divided into country-specific groups)*
18:00	End of Day 1		
19:00	Dinner Reception at The Landmark Restaurant, Village Hotel Bugis		

Day 2: Tuesday, 26th of March 2019			
Homogenisation using RHtestV4 **Chair: Dr Bertrand Timbal** **Notetaker: Dr Thea Turkington**			
09:00 - 10:30	2.1	Introduction to homogeneity assessment *Concept of homogenisation, why it is necessary, and introduction to RHtestV4*	Dr Lisa Alexander *(Climate Change Research Centre, UNSW Sydney)*
10:30 - 11:00	2.2	Hands-on quality control and homogenisation of data using ClimPACT2 and RHtestV4 *Guided quality control and homogenisation of station data brought by participants*	ClimPACT2 experts and NMHS representatives *(NMHS representatives to be divided into country-specific groups)*
11:00 - 11:30	Coffee Break		
Perspectives on Extreme Indices **Chair: Dr Bertrand Timbal** **Notetaker: Dr Thea Turkington**			
11:30 - 11:55	2.3	Impact of heat on human productivity and health - holistic assessment of thermal stress	Dr Jason Kai Wei Lee *(National University of Singapore - NUS)*
11:55 - 12:20	2.4	Weather extremes and water and food security: A case study in Thailand	Dr Kanoksri Sarinnapakorn *(Hydro and Agro Informatics Institute - HAII)*
12:20 - 12:45	2.5	Extreme indices and adaptation in the Mekong river basin	Dr Nguyen Dinh Cong *(Mekong River Commission - MRC)*
12:45 - 13:45	Lunch		
Application of ClimPACT2 to Station Data **Chair: Dr Bertrand Timbal** **Notetaker: Dr Thea Turkington**			
13:45 - 14:15	2.6	Calculation of ET-SCI indices using ClimPACT2 and station data *Demonstration: using ClimPACT2 to calculate ET-SCI indices from station data*	Dr Nicholas Herold *(New South Wales Office of Environment and Heritage)*
14:15 - 17:30	2.7	Explanation of selected indices and hands-on calculation of indices using station data *Guided application of ClimPACT2 to station data for calculation of ET-SCI indices*	ClimPACT2 experts and NMHS representatives
15:30 - 16:00	Flexible Coffee Break (participants may leave the room for snacks and drinks as they prefer)		
17:30	End of Day 2		

Day 3: Wednesday, 27th of March 2019			
Gridded Observational and Reanalysis Products - Producers' Perspectives **Chair: Dr Vijayaraghavan Srivatsan** **Notetaker: Dr Muhammad Eeqmal Hassim**			
09:00 - 09:30	3.1	ECMWF renalysis (ERA) products [remote presentation] *Overview, strengths, weaknesses, validation, extremes, and large-scale processes*	Dr Jean-Noël Thépaut *(European Centre for Medium-Range Weather Forecasts - ECMWF)*
09:30 - 10:00	3.2	Monitoring weather and climate with the CMORPH satellite precipitation estimates *Overview, strengths, weaknesses, validation, extremes, and large-scale processes*	Dr Pingping Xie *(National Oceanic and Atmospheric Administration - NOAA)*
10:00 - 10:30	3.3	The ACRE & ACRE SEA initiative: Global historic data recovery for climate science & applications *ACRE, ACRE SEA, and the importance of historical data and data digitalisation*	Dr Fiona Williamson *(Singapore Management University - SMU)*
10:30 - 11:00	Coffee Break		
Gridded Products: Strengths, Weaknesses, and Large-Scale Processes - End-Users' Perspectives **Chair: Dr Fiona Williamson** **Notetaker: Dr Muhammad Eeqmal Hassim**			
11:00 - 11:45	3.4	How good are gridded rainfall observations over Southeast Asia - and what's the way forward? *Assessment of observational and reanalysis rainfall products relevant to the region*	Dr Vijayaraghavan Srivatsan *(Tropical Marine Science Institute - TMSI)*
11:45 - 12:30	3.5	Multi-scale climate processes and rainfall variability in the Maritime Continent *Using gridded products to analyse the impacts of MJO and ENSO on regional rainfall variability*	Dr Jian-Hua (Joshua) Qian *(Centre for Climate Research Singapore - CCRS)*
12:30 - 13:30	Lunch		
Extreme Indices and Gridded Products **Chair: Ms Li-Sha Lim** **Notetaker: Dr Muhammad Eeqmal Hassim**			
13:30 - 14:00	3.6	The ClimDEX project and HadEX3 dataset *Overview, importance of HadEX3 dataset, and the need for data contributions*	Dr Lisa Alexander *(Climate Change Research Centre, UNSW Sydney)*
14:00 - 15:00	3.7	Gridded ET-SCI indices with ClimPACT2 *Software required and procedure, overview of JRA-55 dataset used for pre-calculation*	Dr Nicholas Herold *(New South Wales Office of Environment and Heritage)*
15:00 - 15:30	3.8	Hands-on analysis of ET-SCI indices calculated from a gridded product *Participants to be provided with several pre-calculated indices from the JRA-55 dataset*	Dr Nicholas Herold *(New South Wales Office of Environment and Heritage)*
15:00 - 15:30	Flexible Coffee Break (participants may leave the room for snacks and drinks as they prefer)		
Visit to InterMET Asia			
15:30 - 16:00	3.9	Board shuttle and travel to InterMET Asia *Shuttle service from Village Hotel Albert Court to Suntec City Convention & Exhibition Centre*	-
16:00 - 17:00	3.10	Tour of the InterMET Asia Exhibition	-
17:00 - 18:00	3.11	Panel discussion: Public Sector - Commercial Services? *Topics to include: understanding customer needs and funding of public sector services*	Moderator: Dr David Rogers (Consultant, World Bank) *Participants to include: Peter Lennox, Patrick Benichou, Michael Staudinger*
18:00 - 19:30	3.12	Official Reception and Dinner *Hosted by Earth Networks and InterMET Asia, to be held at the Delegate Lounge*	-
19:30 - 20:00	3.13	Board shuttle and travel back to hotel *Shuttle service from Suntec City Convention & Exhibition Centre to Village Hotel Albert Court*	-
20:00	End of Day 3		

Day 4: Thursday, 28th of March 2019			
ClimPACT2 and Gridded Data - Analysing Pre-Calculated Indices **Chair: Ms Li-Sha Lim**			
09:00 - 11:00	4.1	Exploration of indices pre-calculated from the JRA-55 gridded dataset *Analysis of pre-calculated indices, with comparison to station-derived indices if possible*	ClimPACT2 experts and NMHS representatives
11:00 - 11:30	Coffee Break		
ClimPACT2 Case Study, Preparation of Presentations and Summary of Results **Chair: ClimPACT2 Experts** **Notetaker: Dr Jian-Hua (Joshua) Qian**			
11:30 - 12:00	4.2	Case study of ClimPACT2 application in the Caribbean *Climate indices for operational monitoring and prediction of climate hazards and impacts in the Caribbean*	Dr Cédric Van Meerbeeck *(Caribbean Institute for Meteorology and Hydrology - CIMH)*
12:00 - 13:45	4.3	Preparation of country-based presentations and written summaries on results *Results from ClimPACT sessions (station and gridded), learning outcomes, software feedback*	NMHS representatives
13:45 - 14:45	Lunch		
Presentations of Results by NMHSs (Continental SEA) **Chair: ClimPACT2 experts** **Notetaker: Dr Jian-Hua (Joshua) Qian**			
14:45 - 15:00	4.4	Cambodia: Department of Meteorology	Mr Monichoth So Im
15:00 - 15:15	4.5	Lao PDR: Department of Meteorology and Hydrology	Mr Sengduangduan Phouthanoxay
15:15 - 15:30	4.6	Myanmar: Department of Meteorology and Hydrology	Dr Tin Mar Htay
15:30 - 15:45	4.7	Thailand: Thai Meteorological Department	Dr Chalump Oonariya
15:45 - 16:00	4.8	Vietnam: Vietnam National Centre for Hydro-Meteorological Forecasting	Mrs Pham Thi Cham
16:00 - 16:30	Coffee Break		
Presentations of Results by NMHSs (Maritime SEA) **Chair: ClimPACT2 Experts** **Notetaker: Dr Jian-Hua (Joshua) Qian**			
16:30 - 16:45	4.9	Brunei: Brunei Darussalam Meteorological Department	Mr Arifin Yussof
16:45 - 17:00	4.10	Malaysia: Malaysian Meteorological Department	Ms Wan Maisarah Wan Ibadullah
17:00 - 17:15	4.11	Philippines: Philippine Atmospheric, Geophysical and Astronomical Services Administration	Ms Thelma Cinco
17:15 - 17:30	4.12	Singapore: Meteorological Service Singapore	Mr Ng Jin Zheng
17:30	End of Day 4		

Day 5: Friday, 29th of March 2019			
Conclusion - Extreme Indices and Large-Scale Processes **Chair: Dr Lisa Alexander** **Notetaker: Ms Li-Sha Lim**			
09:00 - 09:15	5.1	Sectoral value of ClimPACT2 *Brief overview of sectoral applications of ET-SCI indices*	Dr Lisa Alexander *(Climate Change Research Centre, UNSW Sydney)*
09:15 - 10:30	5.2	Breakout group discussion on possible new ET-SCI indices *Suggestions for new indices, variables, and time scales based on three hazards: floods, heatwaves, droughts*	-
10:30 - 11:00		Coffee Break	
11:00 - 11:30	5.3	Breakout session reports *Floods (led by Dr Lisa Alexander), heatwaves (led by Dr Nicholas Herold), droughts (led by Dr Cédric Van Meerbeeck)*	-
11:30 - 12:00	5.4	General discussion on additional hazards relevant to Southeast Asia *Participants to be given opportunity to discuss hazards not previously mentioned*	-
12:00 - 12:40	5.5	Extreme indices publication and HadEX3 contribution *Overview of previous workshops and publications, and plans for upcoming paper and HadEX3 contribution*	Dr Lisa Alexander *(Climate Change Research Centre, UNSW Sydney)*
12:40 - 13:00	5.6	General discussion on the analysis of large-scale processes *Participants to highlight large-scale processes they feel are important and relevant to the region*	-
13:00 - 14:00		Lunch	
Conclusion - Gridded Products **Chair: Mr Raizan Rahmat** **Notetaker: Ms Li-Sha Lim**			
14:00 - 15:30	5.7	Regional perceptions on gridded observational and reanalysis products *Poll on perceptions, and plans for national and regional gridded product development and upcoming paper*	Mr Raizan Rahmat *(Centre for Climate Research Singapore - CCRS)*
Conclusion - ClimPACT2 **Chair: Dr Nicholas Herold** **Notetaker: Ms Li-Sha Lim**			
15:30 - 16:00	5.8	Recommendations for ClimPACT2 software improvement *ClimPACT2 feedback, evaluations, and recommendations*	Dr Nicholas Herold *(New South Wales Office of Environment and Heritage)*
16:00		Conclusion of Workshop and Presentation of Certificates	