Weather Prediction by Numerical Methods Module 4 (WPNM-M4)
7 – 11 October 2024, Singapore

ASMC
ASEAN SPECIALISED METEOROLOGICAL CENTRE

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METEOROLOGICAL SERVICE SINGAPORE
Centre for Climate Research Singapore

# WEATHER PREDICTION BY NUMERICAL METHODS MODULE 4 (WPNM-M4)

# WPNM-M4 REPORT

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# Introduction

Numerical Weather Prediction (NWP) is an important tool used by National Meteorological and Hydrological Services (NMHS) to deliver accurate and timely weather forecasts. Outputs from global and regional NWP systems are often used for nowcasting, short/medium-range and seasonal forecasts. The accuracy of the forecasts relies strongly on effective design, implementation, and evaluation of the various components of NWP systems. These further require an in-depth understanding of the system's conceptualisation and limitations.

While there have been recent improvements in the NWP capability in the ASEAN region, capability building courses on NWP are still much needed. The ASEAN Specialised Meteorological Centre (ASMC) proposed at the 40th Meeting of the ASEAN Sub-Committee on Meteorology and Geophysics (ASCMG-40) held in May 2018 to conduct a training course on NWP and the proposal was well-received. The Meeting welcomed ASMC's offer to deliver such capability building courses on NWP. The Weather Prediction by Numerical Methods (WPNM) series was hence conceptualised as part of the ASMC's 5-year Regional Capability Building Programme for the ASEAN region.

An initial assessment of the training needs was undertaken in collaboration with NMHS through a questionnaire. The proposed modules of WPNM are designed to cover the basic aspects of NWP; they are: (1) Governing equations and numerical methods; (2) Physical parametrisations; (3) Data assimilation; and (4) Predictability.

The inaugural run of Weather Prediction by Numerical Methods Module 1 (WPNM-M1) was held in Singapore from 18$^{th}$ to 22$^{nd}$ November 2019. The second run (WPNM-M2) was held virtually from 3$^{rd}$ to 5$^{th}$ May 2021 in light of the travel restrictions during the COVID-19 pandemic. The third run (WPNM-M3) was help in Singapore from 6$^{th}$ to 10$^{th}$ February 2023. Feedback from participants was positive for all three previous modules, with most participants indicating interest to attend future modules. This report documents the conduct of the fourth run (WPNM-M4), which was held in Singapore from 7$^{th}$ to 11$^{th}$ October 2024. WPNM-M4 was hosted by the ASMC and organised by the Centre for Climate Research Singapore (CCRS). Sponsorship was provided by the Meteorological Service Singapore (MSS).

In line with the proposed module theme, WPNM-M4 focused on Predictability. The aims of WPNM-M4 were as follows:

a) To equip participants with knowledge of the limits of predictability in the atmosphere;
b) To equip participants with knowledge of how an ensemble of NWP model output can help measure uncertainty, as well as how to design such ensembles;
c) To allow participants to experiment with post-processing software in conjunction with ensemble model output to increase the skill and reliability of a probabilistic forecast.

# 1 Day 1: 7th October 2024, Monday

## 1.1 Welcome and Introduction

The module kicked off with a welcome address by Prof Dale Barker, Director of CCRS. Prof Barker summarised CCRS' journey and key research achievements since its inception, including its mission *to advance scientific understanding of tropical climate variability and change and its associated weather systems affecting Singapore and the wider Southeast Asia Region, so that the knowledge and expertise can benefit decision makers and the community*. This underpins CCRS' efforts to actively engage ASEAN NMHS through the organisation of workshops and training modules such as WPNM-M4. He also detailed the progression of NWP modelling at CCRS, including the progress made towards seamless regional weather and climate modelling and the value-add from SINGV (MSS' implementation of the Unified Model for Singapore) compared to the European Centre for Medium Range Weather Forecasting (ECMWF). Prof Barker also highlighted that risk-based decision making requires knowledge of both impact and the likelihood of a particular event occurring. For the latter, estimating forecast uncertainty therefore plays an important role in the ability for a centre to issue weather warnings.


*Snippet of the presentation on CCRS' journey by Prof Dale Barker*

Dr Robert Huva followed with a sharing on the conceptualisation of the WPNM series, its history and the objectives of WPNM-M4. A round of self-introduction was then conducted with a short ice-breaker session to allow participants to familiarise with one another. To conclude the welcome and introduction session, an administrative briefing was delivered by Dr Huva to ensure that the participants had a pleasant experience in Singapore.

## 1.2 Uncertainty and Model Error

A series of 16 lectures was planned for WPNM-M4, delivered by Prof Dale Barker, Dr Joshua Lee, Dr Kalli Furtado, Dr Rachel Lee, Dr Pratiman Patel, Prof Paul Davies and Dr Robert Huva[1]. The morning session started with the first two lectures by Dr Lee on "Recap of the WPNM series" and "Basic concepts of chaos theory".

In "Recap of the WPNM series", Dr Lee described the entire NWP and weather forecasting process chain, which included the three previous modules and how they are linked to produce the raw output from an NWP model. He gave a brief overview of each topic, which included the dynamical equations of an NWP model (WPNM-M1), the types of physical parameterisations typically used inside an NWP model (WPNM-M2), as well as the aim of, and workflow for, data assimilation (WPNM-M3). Dr Lee then summarised by highlighting

[1] See Annex D for designations and affiliations of lecturers and participants.

that the NWP and weather forecasting chain is not complete without post-processing and then verifying the forecast output—thus introducing the rationale for WPNM-M4.

In "Basic concepts of chaos theory", Dr Lee shared some examples of simple systems that can produce seemingly random results—these included the three body and double pendulum problems. He then introduced the Lorenz 63 model, which is a simple model consisting of three spatial dimensions plus time. Dr Lee illustrated how the output of the Lorenz 63 model can be classified into regimes and that these regimes can be analogised to weather regimes from an NWP model.

## 1.3 Error from Initial Conditions

The afternoon session began with Dr Lee presenting "Forecast Errors Arising from Model Initial Condition Errors".


*Dr Joshua Lee delivering the third lecture with Mr Yussof from Brunei helping to predict the outcomes of a Lorenz 63 model*

In the lecture, Dr Lee showed how a 1D advection model can be influenced by error in either the size or advection speed of an initial tracer. He then reintroduced the Lorenz 63 model and gave some examples of how the solution after 20 seconds of integration can be affected by very small changes (0.01% difference) in the initial conditions. During the lecture Dr Lee also sough audience interaction and got Mr Yussof from Brunei to try and predict the state of the Lorenz 63 model after 20 seconds. In particular, it was shown that the solution can be in a completely different regime depending on small changes in the initial conditions. Dr Lee then demonstrated how an ensemble of Lorenz 63 models might be able to capture the future outcomes and linked this work to why ensembles of NWP models are run by NMHSs.

## 1.4 Practical Session – Forecast Sensitivity to Initial Conditions

Following the afternoon tea break, Dr Robert Huva gave an overview of the hands-on practical sessions. These sessions would involve plotting, post-processing and verifying output from CCRS' SINGV-EPS Ensemble Prediction System. Output from SINGV-EPS had been pre-prepared for each participant and before the first session got underway Dr Rachel Koh introduced the SINGV-EPS model. In the first session, participants worked through the first tutorial sheet, which instructed them to explore the observations and data available followed by plotting temperature output from SINGV-EPS for the Tai Seng observation station. In this task, all members from the latest SINGV-EPS run were plotted against the observations of that day. Participants were then expected to qualitatively analyse the skill and spread of the ensemble. Following this, participants were then instructed to start incorporating previous cycle runs of SINGV-EPS to analyse if adding time-lag ensemble members helped to better predict the temperature.

*Dr Robert Huva assisting Mr Shaari and Mr Shuhani from Met Malaysia during the first practical session*

To round off the evening, a welcome dinner was hosted by MSS for the participants, held at The Landmark Restaurant. This provided opportunities for further interaction between participants and lecturers.

# 2 Day 2: 8th October 2024, Tuesday

## 2.1 Forecast Error

The fourth lecture was given by Dr Kalli Furtado on "Forecast errors arising from model approximations and sub-grid processes". During this lecture Dr Furtado outlined how horizontal resolution can impact the values of an NWP model and how differences in the small scales can cascade to the larger scales. He then discussed why it can be very difficult to represent the small-scale processes in an NWP model. In particular, the type, size, distribution and formation/disaggregation of water (liquid, ice, vapour, snow etc) in a cloud. Dr Furtado also showed how differences in sub-grid processes can lead to quite different outcomes from NWP models with examples from global radiation and the influence of ice shape, aerosol size and the influence on precipitation and how convection is influenced by assumptions of precipitation fall speed.

Dr Rachel Koh followed on from Dr Furtado by discussing "Forecast error growth, resulting uncertainties and the role of ensembles" in lecture five. In this talk, Dr Koh discussed the difference between error and uncertainty, showed examples of error growth versus forecast horizon from various NWP models from around the world and then outlined why ensembles of NWP models are utilised to capture the uncertainty in future atmospheric states. In

particular, Dr Koh emphasised that forecast error in the tropics does not grow linearly but is impacted more by diurnal processes. She then discussed the use of ensembles to provide guidance on the uncertainty of a forecast and how ensemble model output is often visualised.

The final lecture of the morning "Overview of ensemble design at various global centres" was given by Prof Dale Barker. In this talk, Prof Barker outlined the size and resolution of ensembles (both global and regional) at NMHS's from around the world. He also compared the skill of these models and showed how model upgrades have helped to improve skill over time with examples from historical tropical cyclone tracks before and after upgrades. Prof Barker then went on the illustrate how the Met Office regional ensemble was operationalised, followed by examples of the usefulness of ensemble model output for assessing the risk of high impact events.


*Prof Dale Barker delivering the sixth lecture*

## 2.2 Implementing and Using Ensembles

The afternoon session was started by Dr Rachel Koh with the topic "Building an ensemble". In this talk, Dr Koh discussed the various different ways to design an ensemble, which included initial condition perturbations, boundary conditions (for regional models), time-lagging, varying physical parameterisation schemes, as well as multi-model ensembles where the underlying model is changed. Dr Koh went through the rationale for each approach and discussed the ultimate goal of doing so—to sample the future uncertainty as completely as possible.

Following Dr Koh, WPNM-M4 had the pleasure of hearing from visiting scientist Prof Paul Davies, chief meteorologist and principal fellow at the Met Office, who gave a very useful lecture on "Forecaster use of ensembles". In this talk, Prof Davies described how the information from an ensemble might be fully utilised—this included probability fields, scenarios and most-likely versus alternative low probability outcomes. Prof Davies also discussed how the risk matrix only considers a single variable and threshold, where in reality there can be multiple risks from a single storm. Importantly, Prof Davies detailed his experience as chief meteorologist and the process of convincing forecasters to use ensemble information. He described this process of change as involving: awareness, desire, knowledge, application and then reinforcement.

*Prof Paul Davies discussing forecaster use of ensembles in front of the whiteboard detailing his trust equation:* $Trust = \frac{Reliability * Credibility * Empathy}{Self\ Interest}$

## 2.3 Introduction to METplus and Ensemble Verification

Day two continued with Dr Pratimal Patel giving two lectures on verification. In his first lecture, titled "Introduction to METplus evaluation at verification", Dr Patel gave an overview of the METplus (Module Evaluation Tools plus) package. METplus is a wrapper tool that can be used to execute MET code, which is a repository of python programs that performs tasks like reading in forecast or observation data, regridding if necessary, and then comparison of model and observation. During his first talk, Dr Patel showed the overall structure of METplus, how the output can be easily visualised through inbuilt plotting programs, as well as how to run METplus with a configuration file. In his second lecture, titled "Ensemble verification", Dr Patel focussed on tools and methods specific to assessing the quality of an ensemble forecast. Dr Patel first outlined the attributes of an ensemble forecast: sharpness (degree of spread from the ensemble), resolution (how well the observations are "sorted" among the different forecasts), discrimination (how well the forecasts discriminate between events and non-events) and reliability (how closely the forecast probabilities correspond to the conditional frequency of the event). He then detailed how to measure the quality of these attributes by defining metrics like brier score, reliability and the Relative Operating Characteristic (ROC) curve. Dr Patel wrapped up his talk by illustrating some examples of good quality ensemble forecasts.

# 3 Day 3: 9th October 2024, Wednesday

## 3.1 Practical Session – Building and Verifying an Ensemble

The morning session of day three was spent continuing with the practical material for building and verifying an ensemble of temperature forecasts. Participants were guided through tutorial sheets two and three where they included up to three previous cycles of the SINGV-EPS model to help sample possible values of temperature at the Tai Seng station. Participants were tasked to both subjectively evaluate the combined ensemble of forecasts (visually compare the observed and forecasted values), as well as run code to objectively verify. Objective measures of forecast skill included root-mean squared error and bias using the ensemble mean and the observed values. Participants were then tasked with assessing if the subjective and objective measures agreed, or not, and if they had more time to consider verifying other locations to see if/how the performance of the ensemble differed across Singapore.

## 3.2 Post-processing and IMPROVER

After lunch, the focus of the workshop shifted to post-processing. Much of the content thus far had covered the need for ensembles, how to build an ensemble and methods for verifying an ensemble forecast. However, it is well known that raw NWP model output can contain biases, or other systematic errors, which can be corrected via post-processing. Dr Robert Huva introduced this concept in his first lecture "Introduction and rationale for post-processing". During the talk, Dr Huva gave some examples of post-processing at various NMHSs from around the world, as well as detailing a typical deterministic or probabilistic post-processing chain. Dr Huva followed up this talk by introducing the open-source post-processing package IMPROVER (Integrated Model Post-PROcessing and VERification). In his talk titled "Overview of post-processing in the IMPROVER package", Dr Huva described how to download and install IMPROVER, how IMPROVER can be used for both deterministic and ensemble forecasts, as well as detailing the methods inside IMPROVER for both site-specific and grid-wide corrections. Dr Huva then went on to show how IMPROVER is typically used with some worked examples. With this knowledge, participants were then well equipped to take on the rest of the practical sessions where IMPROVER was routinely used.


*Dr Robert Huva presenting on post-processing in the IMPROVER package*

## 3.3 Practical Session – Thresholding and Neighbourhooding

After the tea break, participants were guided through tutorial sheet four. In this tutorial, participants shifted focus to experiment with IMPROVER. Utilising rainfall forecasts from SINGV-EPS and gridded observations from the Global Precipitation Measurement (GPM) product, participants started creating probabilistic rainfall forecast maps for a recent event. By first thresholding the rainfall (creating a map of 1s and 0s) and then blending the ensemble members together (taking the average), participants were able to create an ensemble-consensus forecast map of the likelihood to exceed various rainfall thresholds. These maps would be used in the following hands-on session to verify the probabilistic rainfall forecast.

# 4 Day 4: 9th February 2023, Thursday

## 4.1 Practical Session – Thresholding and Neighbourhooding

Day four started with two practical sessions where participants verified the thresholded rainfall products they created the day before and then delved deeper into the typical probabilistic post-processing chain by incorporating neighbourhood processing. Verification was conducted using a combination of brier score and ROC diagram to give participants a flavour of both the error and ability of the forecast to discriminate events. The verification of the thresholded rainfall served as a baseline for subsequent IMPROVER steps to ensure that further processing improved the quality of the forecast. In the second practical session of the morning, participants experimented with one such common step: 'neighbourhooding' the rainfall. The process of neighbourhooding involves averaging the probability over a spatial area to consider the spatial uncertainty in the location of rainfall events. By testing and then verifying many neighbourhood sizes, participants were able to identify the "best" neighbourhood length for this event. Participants were expected to determine the best neighbourhood length by considering a balance between brier score and ROC diagram metrics. Subsequent practical sessions would then use this result to experiment with further processing of the forecasted rainfall probabilities.

*Dr Robert Huva helping Eng Hong Ang from MSS during one of the practical sessions.*

## 4.2 Grid vs Point Post-processing and Calibration

The afternoon session of day four switched back to lecture content by Dr Robert Huva. In his first lecture of the afternoon titled "Post-processing across a grid versus at a point" Dr Huva outlined how and why post-processing of NWP output might be done at a site as opposed to across a whole grid. Specifically, it was mentioned that site-specific post-processing can generally achieve higher accuracy while also being able to generate site-specific output like

renewable electricity, but at the expense of spatial consistency. For grid-wide post-processing, Dr Huva outlined methods such as bias correction, reliability calibration and analogue ensembles, which can preserve spatio-temporal associations but often requires errors to be systematic in order to be effective. Concepts of bias correction and calibration in this first talk were then expanded upon in the second talk of the afternoon titled "Methods for calibration and bias correction". In this talk, Dr Huva touched on the need for calibration—to correct the tendency of an NWP model to systematically under or over-predict certain forecasted probabilities—and then common methods for addressing such tendencies. He outlined methods such as reliability calibration and Bayesian Model Averaging, as well as newer machine-learning based methods like RainForests. Dr Huva also outlined how these methods fit into the IMPROVER package and how to implement them on the command line with worked examples.

## 4.3 Practical Session – Calibrating an Ensemble

The final session of day four had participants go through tutorial sheet 6 on calibrating the ensemble prediction of rainfall probabilities from SINGV-EPS. Participants utilised the neighbourhooded rainfall probabilities and a pre-calculated reliability table (using historical SINGV-EPS rainfall tendencies versus GPM) to calibrate the probability to exceed each rainfall threshold. Participants were then expected to both visually compare and verify pre- and post-calibration output to measure the effect of calibration on the forecasted probabilities. In general, the calibration was shown to reduce the occurrence of higher probability values (to correct for over-confidence) and participants were asked to discuss if the post-calibration forecast was a "better" forecast or not.

# 5 Day 5: 11th October 2024, Friday

## 5.1 Probabilistic vs Deterministic Information

The last two lectures of the workshop were given by Dr Robert Huva on the morning of day five. Day five started with Dr Huva discussing "Can we compare deterministic and probabilistic forecasts?". This talk was motivated by fact that most NMHSs on their journey toward issuing probabilistic forecasts will inevitably have to face the question of whether a probabilistic forecast is adding value, or not, over the existing deterministic forecasts. This talk focussed on metrics that can verify both types of forecasts, methods for converting between probabilities and expected values, some literature comparing the performance of an ensemble mean with a deterministic forecast, but ultimately concluded by showing the advantages of having both the most likely outcome and the range of possible outcomes (i.e. to have both types of forecasts). The conclusion from this talk also linked with the final lecture of the workshop titled "Communicating probabilistic information". In this talk Dr Huva showed how an ensemble of forecasts can be used to give likely outcomes, as well as storylines or low probability but still realistic scenarios. Dr Huva gave examples of how probabilistic forecasts are currently being communicated to the public at various NMHSs. He also detailed a decision tree for how to present ensemble information depending on the end user and concluded with suggestions on how ensemble forecasts might be communicated in the future.


*Dr Robert Huva detailing how the information from an ensemble forecast can be fully utilised*

## 5.2 Practical Session – Calibrating an Ensemble

In the final practical session prior to the lunch break, participants were given the opportunity to finish any steps they had yet to complete from sessions 1-6, as well as complete optional further work. The optional further work included time-lag ensembling where the final probability field had previous cycles added to the mix, as well as conducting in-vicinity neighbourhood processing instead of the usual neighbourhood averaging process. In-vicinity processing converts a grid point to the value 1 if any occurrence above the threshold occurs within a radius/vicinity and will generally lead to higher probability values at the expense of false alarms.

## 5.3 Recap and Discussion on Future Directions

In the afternoon, the key learning points from WPNM-M4 were consolidated and recapped in a plenary session. The session aimed to recognise the main ideas, which were the most prominent for the participants, but also to test the participants on their understanding of the important concepts. Dr Robert Huva started with a short interactive "word-cloud" activity with the participants. Key themes were flashed on the screen and participants were expected to share their immediate recollection of words or phrases related to the themes. Frequently input words or phrases would appear larger in the cloud, which suggested that participants had a deeper impression of those pointers. The key themes were: Predictability, Ensemble NWP, and Post-processing. The results of the activity are included in Annex A. Next, participants were tasked with filling out a survey. The survey covered both the participant's satisfaction with the event and its contents, as well as questions on what type of collaboration participants would like to see going forward. Dr Hugh Zhang would follow on from these question of future directions after the tea break.


*Dr Hugh Zhang and Dr Robert Huva discussing future directions with Mr Shaari from Met Malaysia*

In final session of WPNM-M4, Dr Hugh Zhang shared his thoughts on what could be done to further build the NWP capability in ASEAN countries following the knowledge and experiences gained from the very successful WPNM training series. Suggestions from Dr Zhang included forming an ASEAN regional NWP forum to regularly share operational NWP system performance and Research and Development (R&D), exploring the possibility of jointly developing R&D projects (such as Artificial intelligence (AI) in NWP and postprocessing), and leveraging the R&D programs in the World Weather Research Program/World Climate Research Program and partners. Dr Zhang suggested that through such collaborations the region could build a centre akin to an ASEAN ECMWF, which would jointly develop an NWP model that is best tailored to weather forecasting in our region. He also briefly shared CCRS/MSS plan of developing our next generation model, including AI NWP and regional reanalysis, and welcomed other ASEAN members to include their local observations in a high-resolution reanalysis. During this session there was active discussion amongst the fellow ASEAN representatives. In particular, there was positive feedback on the idea of a regional forum and collaboration/coordination with a vision towards an ASEAN ECMWF if it had backing from high levels. Broadly, there was support for such a concept, which could also tie in with the idea of developing a regional NWP model as one of the first objectives. During the discussion session the microphone was passed around the room and representatives from each country were given the opportunity to detail their current and future efforts towards NWP, ensemble model development and post-processing. Mr Shaari from Met Malaysia detailed that there is a plan to implement an ensemble of WRF models for Malaysia

in 2025. Mr Bin Haji Awang Yussof from Brunei indicated that their forecasting is still deterministic but that following the learning from WPNM-M4 they might look at quick wins such as time-lag ensembling. Ms Thamalangsy from Lao PDR mentioned that they currently issue a deterministic forecast based on the Korean model (KIM) as they find this model to be the most accurate for their region. Dr Zhang noted that this is an interesting result, which could be investigated scientifically, linking it to the idea of collaborating on a regional NWP model. Mr Miro from PAGASA also shared that they have plans to operationalise an ensemble system based on WRF, but that the project has been delayed due to computational constraints.

# WPNM-M4 Feedback and Outcomes

Overall, the training module was well-received by participants. Based on the feedback survey responses (Annex B), participants indicated that WPNM-M4 had achieved its three objectives. Following previous WPNM modules, the lecture contents, practical sheets and code used throughout the tutorials was made available on a cloud storage location accessible by participants. In general, many of the participants found the lectures and hands-on practical sessions useful and relevant to their job. Participants also strongly supported the continuation of WPNM, or something similar, in the future with particular interest for topics covering Artificial Intelligence or Machine Learning applications in NWP (see Annex B questions 25 and 26).

In the closing plenary session, it was highlighted that all of the participating ASEAN NMHSs were not currently running an ensemble system and many were issuing deterministic forecasts only. It is hence highly recommended that the community continues to share their experience in running and/or using ensemble model output. Furthering the use of ensemble model output will ultimately benefit society through quantification of the uncertainty of future outcomes and by giving users of meteorological data the ability to prepare for such possible outcomes. In general, there was broad support for collaboration on developing a regional NWP model and the possibility of using such a model for a regional reanalysis. However, it was acknowledged that such an effort would require funding and buy-in from enough NMHSs to be feasible.

Following the positive feedback, CCRS will need to consolidate the main ideas concerning future capability building and forum for collaboration and propose them at subsequent meetings of the ASEAN Sub-Committee on Meteorology and Geophysics.

The CCRS organising committee would like to extend our appreciation to the Unified Model partners that developed, and continue to develop, the IMPROVER code used throughout the tutorials. The CCRS organising committee would also like to extend our appreciation to Prof Paul Davies for his insightful talk on Forecaster Use of Ensembles. Much of the content delivered at WPNM-M4 was scientific in nature and the perspective of Prof Davies as a forecaster using ensemble model output was very much welcomed.

# List of Abbreviations

| | |
|---|---|
| **AI** | Artificial Intelligence |
| **ASCMG** | ASEAN Sub-committee on Meteorology and Geophysics |
| **ASEAN** | Association of Southeast Asian Nations |
| **ASMC** | ASEAN Specialised Meteorological Centre |
| **CCRS** | Centre for Climate Research Singapore |
| **DMC** | Department of Meteorology, Cambodia |
| **ECMWF** | European Centre for Medium-range Weather Forecasts |
| **GPM** | Global Precipitation Measurement |
| **IMPROVER** | Integrated Model Post-PROcessing and Verification |
| **MSS** | Meteorological Service Singapore |
| **METplus** | Model Evaluation Tools plus |
| **NMHS** | National Meteorological and Hydrological Services |
| **NWP** | Numerical weather prediction |
| **PAGASA** | Philippine Atmospheric, Geophysical and Astronomical Services Administration |
| **R&D** | Research and Development |
| **ROC** | Relative Operating Characteristic |
| **SINGV** | MSS' implementation of the Unified Model for Singapore |
| **SINGV-EPS** | The Ensemble Prediction System of SINGV |
| **WPNM** | Weather Prediction by Numerical Methods |

# Annex A: Plenary Session Word-Cloud Results

## Predictability

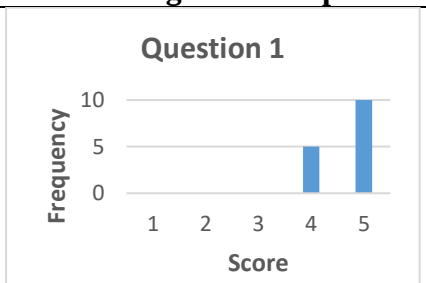
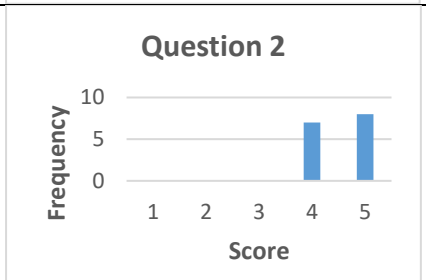
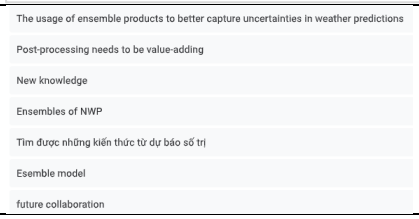
22 responses

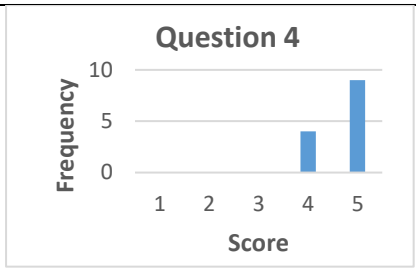
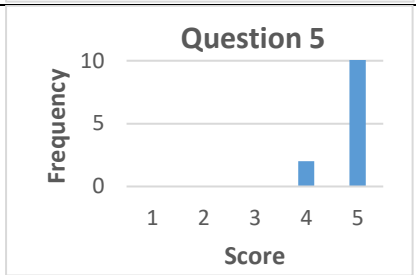
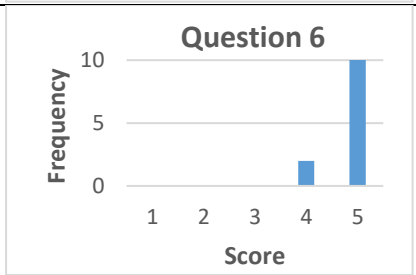
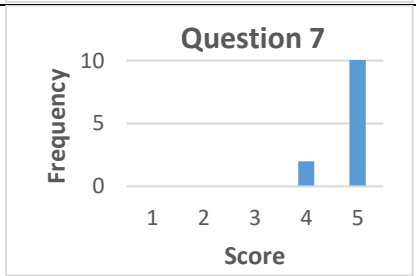
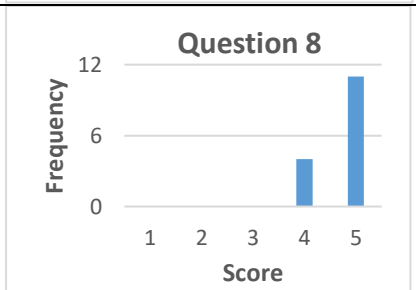

## Ensemble NWP

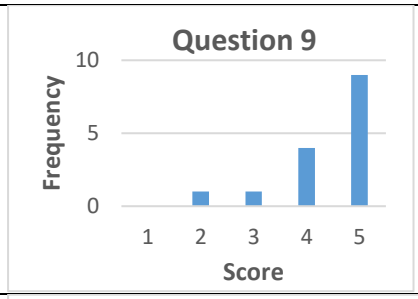
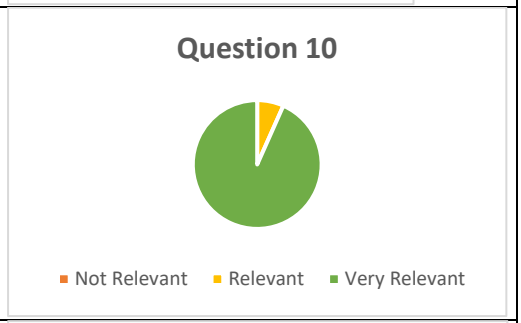
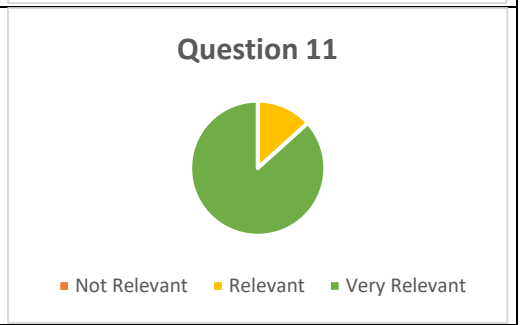
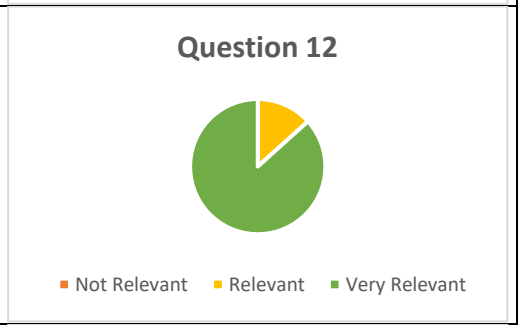
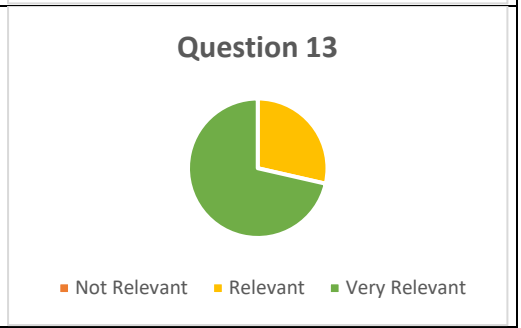
32 responses


# Annex B: Feedback Survey Responses

The feedback survey was based on 15 responses to 28 questions. Nine questions asked participants to give a score from 1 (strongly disagree) to 5 (strongly agree). The mean and histogram of these score-based responses are indicated below, along with summaries of the other questions:

| No. | Question | Mean score | Histogram of responses |
|---|---|---|---|
| 1 | How satisfied were you with the event? | 4.67 |   |
| 2 | How relevant and helpful do you think it was for your job? | 4.53 |   |
| 3 | What were your key take aways from this event? | |   |

| | | | |
|---|---|---|---|
| | | | Emsembles<br>Tools (software, methods), ideas for communicating uncertainty, different views on ensembles and their adoption by users<br>Understanding Predictability better and how to build an ensemble system<br>Ensemble forecast and improver package<br>Ensemble technique and post possessing<br>Ensemble NWP<br>Post-processing can improve forecasts relatively quick compared to incremental improvements from the NWP model itself. It plays an important role in making NWP forecasts more relevant for users and stakeholders. |
| 4 | How satisfied were you with the accommodation? | 4.07 |  |
| 5 | How satisfied were you with the information pack? | 4.87 |  |
| 6 | How satisfied were you with the communication emails? | 4.87 |  |
| 7 | How satisfied were you with the venue? | 4.87 |  |
| 8 | How satisfied were you with the lecture content? | 4.73 |  |

| | | | |
|---|---|---|---|
| 9 | How satisfied were you with the practical sessions? | 4.40 |  |
| 10 | How relevant was the session on Uncertainty and Model Error? | |  |
| 11 | How relevant was the session on Error from Initial Conditions? | |  |
| 12 | How relevant was the session on Forecast Error? | |  |
| 13 | How relevant was the session on Implementing & Using Ensembles? | |  |

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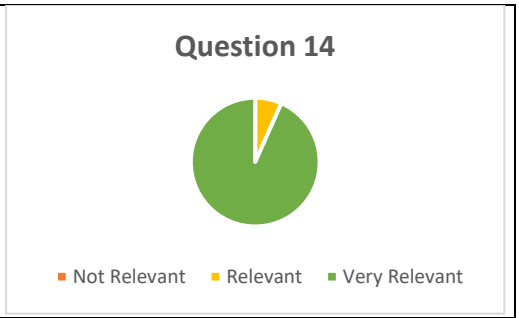
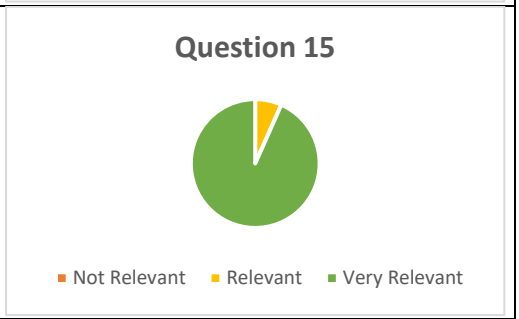
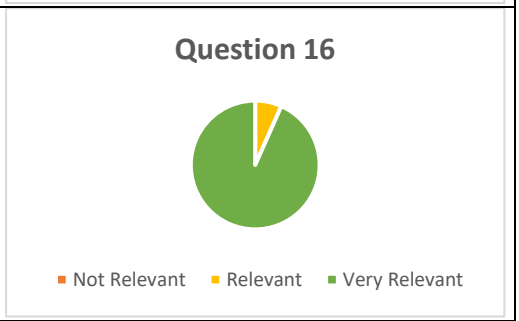
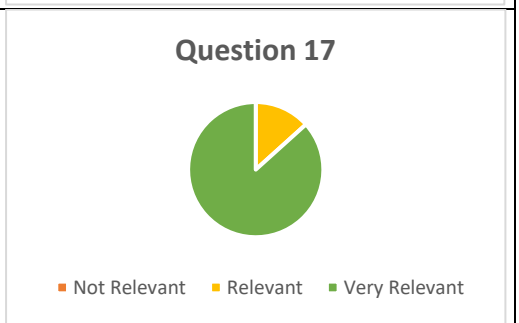
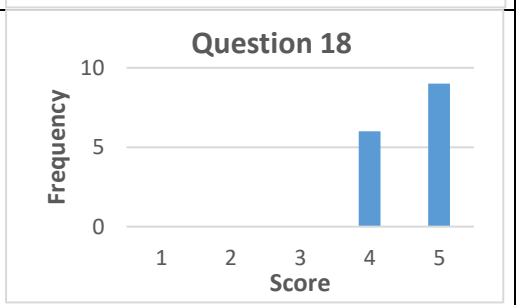
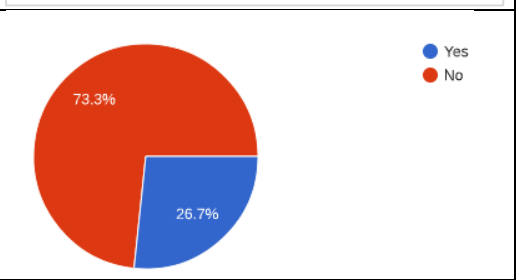
|---|---|---|---|
| 14 | How relevant was the session on Ensemble Verification? | |  |
| 15 | How relevant was the session on Post-Processing and IMPROVER? | |  |
| 16 | How relevant was the session on Grid vs Point Post-processing and Calibration? | |  |
| 17 | How relevant was the session on Probabilistic vs Deterministic Information? | |  |
| 18 | How satisfied were you with the session content? | 4.60 |  |
| 19 | Does your national centre run an ensemble every day? | |  |

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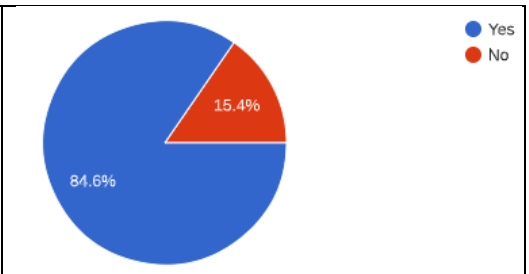
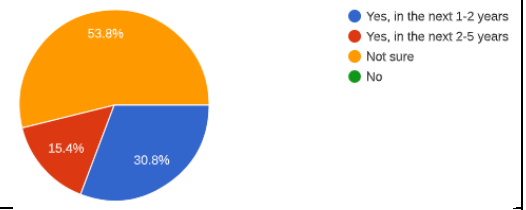
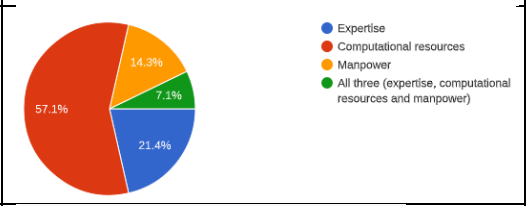
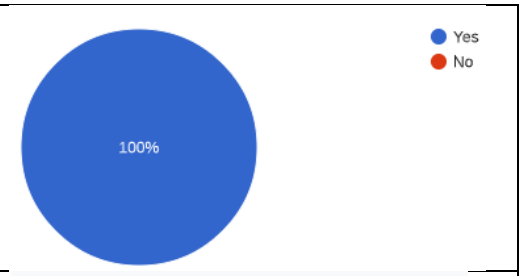
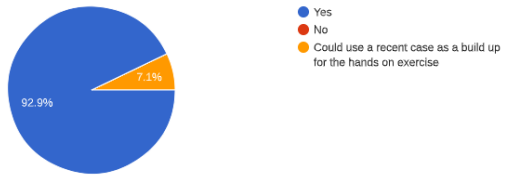
|---|---|---|---|
| 20 | If no, does your centre analyse any ensemble information from elsewhere? | |  |
| 21 | If your centre does not run an ensemble every day, do you plan to in the future? | |  |
| 22 | What are the main challenges in running an ensemble at your centre? | |  |
| 23 | What types of weather, or weather variables, would benefit most from having an ensemble in your country? | | Jma,ecmwf.kma<br>Heavy rain, storm<br>Heavyrain, tropical storm<br>Rainfall temperature<br>rainfall, temperature, wind, rh<br>precipitation , temperature , pressure , wind speed<br>Extremes, convection<br>Rainfall and temperature<br>Rainfall temperature tropical cyclone<br>Extreme weather conditions and storms forecast<br>Thunder Storm<br>rainfall, severe winds, sea level pressure, heat index<br>Rainfall, temperature, wind |
| 24 | If you have/had an ensemble of NWP output, how do/would you communicate the uncertainty/probabilities to the public or downstream users? | | Daily weather forecast<br>Web. Email<br>Videos, website<br>Read forecast values correctly and update them to use in weather forecasting and warning so that people are aware<br>intranet and website<br>Website and on-site meeting.<br>By stressing the predictability of the event happening and how probabilistic forecast information can give an indication of the level of forecast uncertainty. Also for risk-based approaches, response levels or action plans can be developed for different levels of probabilities<br>A range of values or alternative scenarios<br>Uppon government policy<br>Depends on the end user<br>Use of more graphics for public. For specific stakeholders, would need to sit down with them and discuss their needs. |

| | | | |
|---|---|---|---|
| 25 | Do you want another WPNM series? | |  |
| 26 | If yes, what topics would you like to be covered? | | Coupled modelling, since most of us are not into this yet; In depth topics on NWP output post-processsing, something we can immediately work on or explore in applying with our own NWP outputs<br>Data assimilation<br>Using improver<br>Improver<br>Improver post-processing<br>Enhancing the knowledge of weather forecaster in the use of NWP products how to analyze each parameter in NWP in weather forecasting<br>include new technology such as AI at least machine learning for short coming future. looking forward for air quality modelling application for at least few pollutants such as pm10 or pm25<br>Up to lacturer I will learning everything.<br>Futuristic topics like AI / ML<br>Specify training for data assimilation<br>Data assimilation technique for operational NWP and other any more NWP training<br>NWP for Medium-Range Forecast.<br>More advanced topics like coupled modelling, or AI and ML in weather prediction. Also focusing on tangible outcomes from the workshop for application to the home country, or collaboration outcomes after the modules.<br>Applications of AI/ML in NWP |
| 27 | If no, what kind of collaboration would you like to see in the future? | | Operational ASEAN High Resolution Regional NWP<br>-<br>In case no WPNM, I think research collaborations for the region could work. Experience sharing is also good.<br>Evalution and verification<br>AI in forecasting<br>AI or mechine learning for weather forecasting<br>exchanging ideas in output data verification between both country, this is because the setting difference for wps and wrf input might difference from others. im also looking forward to further discussion regarding ensemble or other settings like improver and further application of improver and metplus |
| 28 | Would you consider a series that focussed more on weather events (like a recent hard to predict storm/cyclone) and collaborating on how to predict that event better? | |  |

# Annex C: WPNM-M4 Programme

| Day 1: Monday, 7th October 2024<br>Chair: Robert Huva<br>Notetaker: Rachel Koh | | |
|---|---|---|
| **Welcome and Introduction** | | |
| 0800 – 0900 | Registration | |
| 0900 – 0915 | Welcome address | Dale Barker |
| 0915 – 0935 | Workshop overview and objectives | Robert Huva |
| 0935 – 1000 | Administrative brief | Robert Huva |
| 1000 – 1030 | Coffee break and group photo | |
| **Uncertainty and Model Error** | | |
| 1030 – 1130 | **Lecture 1:** Recap of WPNM series | Joshua Lee |
| 1130 – 1230 | **Lecture 2:** Basic concepts of chaos theory | Joshua Lee |
| 1230 – 1400 | Lunch | |
| **Error from Initial Conditions**<br>**Practical Session: Forecast Sensitivity to Initial Conditions** | | |
| 1400 – 1500 | **Lecture 3**: Forecast errors arising from model initial condition errors | Joshua Lee |
| 1500 – 1530 | Introduction to practical sessions | Robert Huva |
| 1530 – 1600 | Coffee break | |
| 1600 – 1730 | Hands-on practical session using SINGV-EPS | CCRS facilitators |
| 1730 | End of Day 1 | |
| 1830 | Welcome dinner @ The Landmark Restaurant | |

| Day 2: Tuesday, 8th October 2024<br>Chair: Robert Huva<br>Notetaker: Robert Huva | | |
|---|---|---|
| **Forecast Error**<br>**Capturing Uncertainty with Ensembles** | | |
| 0900 – 1000 | **Lecture 4**: Forecast errors arising from model approximations and sub-grid processes | Kalli Furtado |
| 1000 – 1030 | Coffee break | |
| 1030 – 1130 | **Lecture 5**: Forecast error growth, resulting uncertainties and the role of ensembles | Rachel Koh |
| 1130 – 1215 | **Lecture 6:** Overview of ensemble design at various global centres | Dale Barker |
| 1215 – 1345 | Lunch | |
| **Implementing & Using Ensembles**<br>**Practical Session: Generating Ensembles** | | |
| 1345 – 1430 | **Lecture 7:** Building an ensemble | Rachel Koh |
| 1430 – 1530 | **Lecture 8:** Forecaster use of ensembles | Paul Davies |
| 1530 – 1600 | Coffee break | |
| 1600 – 1645 | **Lecture 9:** Introduction to METplus evaluation and verification | Pratiman Patel |
| 1645 – 1730 | **Lecture 12:** Ensemble verification | Pratiman Patel |
| 1730 | End of Day 2 | |

| Day 3: Wednesday, 9th October 2024<br>Chair: Robert Huva<br>Notetaker: Arun | | |
|---|---|---|
| **Ensemble Verification**<br>**Practical Session: Verifying Ensembles** | | |
| 0900 – 1000 | Hands-on practical session building an ensemble | CCRS facilitators |
| 1000 – 1030 | Coffee break | |
| 1030 – 1230 | Hands-on practical session verifying ensemble approaches | CCRS facilitators |
| 1230 – 1400 | Lunch | |
| **Post-Processing and IMPROVER**<br>**Practical Session: Using IMPROVER** | | |
| 1400 – 1500 | **Lecture 10:** Introduction and rationale for post-processing | Robert Huva |
| 1500 – 1600 | **Lecture 11:** Overview of post-processing in the IMPROVER package | Robert Huva |
| 1600 – 1630 | Coffee break | |
| 1630 – 1730 | Hands on practical session thresholding and neighbourhooding | CCRS facilitators |
| 1730 | End of Day 3 | |

| Day 4: Thursday, 10th October 2024<br>Chair: Robert Huva<br>Notetaker: Arun | | |
|---|---|---|
| **Ensemble Verification**<br>**Practical Session: Using IMPROVER** | | |
| 0900 – 1000 | Hands on practical session thresholding and neighbourhooding cont. | CCRS facilitators |
| 1000 – 1030 | Coffee break | |
| 1030 – 1230 | Hands on practical session thresholding and neighbourhooding cont. | CCRS facilitators |
| 1230 – 1400 | Lunch | |
| **Grid vs Point Post-Processing & Calibration**<br>**Practical Session: Calibration of Ensembles** | | |
| 1400 – 1500 | **Lecture 13:** Post-processing across a grid versus at a point | Robert Huva |
| 1500 – 1600 | **Lecture 14:** Methods for calibration and bias-correction | Robert Huva |
| 1600 – 1630 | Coffee break | |
| 1630 – 1730 | Hands-on practical session calibrating an ensemble with IMPROVER | CCRS facilitators |
| 1730 | End of Day 4 | |

| Day 5: Friday, 11th October 2024<br>Chair: Robert Huva<br>Notetaker: Arun | | |
|---|---|---|
| **Probabilistic vs. Deterministic Information**<br>**Practical Session: Calibration of Ensembles** | | |
| 0900 – 0945 | **Lecture 15:** Can we compare deterministic and ensemble forecasts? | Robert Huva |
| 0945 – 1045 | **Lecture 16:** Communicating probabilistic information | Robert Huva |
| 1045 – 1115 | Coffee break | |
| 1115 – 1230 | Hands-on practical session calibrating an ensemble cont. | CCRS facilitators |
| 1230 – 1400 | Lunch | |
| **Conclusion** | | |
| 1400 – 1500 | Plenary session: Recap of topics covered and learning consolidation activities | Robert Huva |
| 1500 – 1530 | Coffee break | |
| 1530 – 1630 | Plenary session: Discussion of future NWP capability building in ASEAN region | Hugh Zhang |
| 1630 – 1700 | Feedback survey and certificate presentation | Robert Huva |
| 1700 | End of Day 5 | |

# Annex D: List of Participants and Organising Committee

| Name | | Organisation |
|---|---|---|
| Mr | Awang Mohamad Noor'Arifin bin Haji Awang Yussof | *Meteorological Officer*<br>Brunei Darussalam Meteorological Department, Brunei |
| Mr | Man Hai Vu | *Deputy Head of Division*<br>Vietnam Meteorological and Hydrological Administration, Vietnam |
| Prof | Dale Barker | *Director*<br>Centre for Climate Research Singapore, Singapore<br>Organising Committee |
| Mr | Gabriel Miro | *Weather Specialist II*<br>Philippine Atmospheric, Geophysical and Astronomical Services Administration, Philippines |
| Ms | Joan Cher | *Assistant Manager*<br>Meteorological Service Singapore, Singapore<br>Organising Committee |
| Dr | Joshua Lee | *Research Scientist*<br>Centre for Climate Research Singapore, Singapore<br>Organising Committee |
| Dr | Rachel Koh | *Research Scientist*<br>Centre for Climate Research Singapore, Singapore<br>Organising Committee |
| Dr | Pratiman Patel | *Research Scientist*<br>Centre for Climate Research Singapore, Singapore<br>Organising Committee |
| Dr | Kalli Furtado | *Deputy Principal Research Scientist*<br>Centre for Climate Research Singapore, Singapore<br>Organising Committee |
| Dr | Hugh Zhang | *Deputy Director*<br>Centre for Climate Research Singapore, Singapore<br>Organising Committee |
| Dr | Arun Ramanathan | *Research Scientist*<br>Centre for Climate Research Singapore, Singapore<br>Organising Committee |
| Prof | Paul Davies | *Chief Meteorologist/Principal Fellow*<br>Met Office, United Kingdom |

| | | |
|---|---|---|
| Dr | Tin Mar Htay | *Deputy Director*<br>Department of Meteorology and Hydrology, Myanmar |
| Ms | Chaw Su Hlaing | *Staff Officer*<br>Department of Meteorology and Hydrology, Myanmar |
| Ms | Heinritz Majella Miguel | *Weather Specialist II*<br>Philippine Atmospheric, Geophysical and Astronomical Services Administration, Philippines |
| Mr | Eng Hong Ang | *Meteorologist*<br>Meteorological Service Singapore, Singapore |
| Mr | Krirerk Phungsara | *Meteorologist*<br>Thai Meteorological Department, Thailand |
| Mr | Peeranat Longsombun | *Meteorologist*<br>Thai Meteorological Department, Thailand |
| Ms | Akhom Thamalangsy | *Deputy Head of Weather Forecasting and Early Warning Division*<br>Department of Meteorology and Hydrology, Lao PDR |
| Ms | Khaemuey Chao | *Technical Staff*<br>Department of Meteorology and Hydrology, Lao PDR |
| Mr | Manh Dung Le | *Forecaster*<br>Vietnam Meteorological and Hydrological Administration, Vietnam |
| Dr | Robert Huva | *Research Scientist*<br>Centre for Climate Research Singapore, Singapore<br>Organising Committee |
| Dr | Efthmyia Pavlidou | *Assistant Director*<br>Meteorological Service Singapore, Singapore |
| Mr | Noor Azam Shaari | *Meteorological Officer*<br>Malaysian Meteorological Department, Malaysia |
| Mr | Shamshumar Shuhani | *Meteorological Officer*<br>Malaysian Meteorological Department, Malaysia |