
Strengthening the Regional Dimension of Hydromet Services in Southeast Asia

A Policy Note with a Focus on
CAMBODIA, LAO PDR, and VIETNAM



The International Bank for Reconstruction and Development
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Washington, DC 20433, USA

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The World Bank team was led by Zuzana Stanton-Geddes, Disaster Risk Management Specialist, and Henrike Brecht, Senior Infrastructure Specialist. This report was prepared by Alice Soares, Senior Hydrometeorological Specialist and Consultant to the World Bank, and benefited from peer review comments from Makoto Suwa, Senior Disaster Risk Management Specialist; Toru Konishi, Senior Water Economist; Dzung Huy Nguyen, Senior Disaster Risk Management Specialist; and Chusit Apirumanekul and David Rodgers, Hydrometeorological Specialists and Consultants to the World Bank.

The report was edited by Anne Himmelfarb and designed by Johanna Mora.

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ABBREVIATIONS

ADB	Asian Development Bank
APASTI	ASEAN Plan of Action on Science, Technology and Innovation
ASEAN	Association of Southeast Asian Nations
ASEANCOF	ASEAN Climate Outlook Forum
CMA	China Meteorological Administration
CONOPS	Concept of Operations
CORDEX	Coordinated Regional Downscaling Experiment
CREWS	Climate Risk and Early Warning Systems
DCPC	Data Collection or Production Centre
DMH	Department of Meteorology and Hydrology
DOM	Department of Meteorology
ECMWF	European Centre for Medium-range Weather Forecasts
EFAS	European Flood Awareness System
ENSO	El Niño-Southern Oscillation
EPS	Ensemble Prediction System
ESCAP	United Nations Economic and Social Commission for Asia and the Pacific
EUMETNET	European Meteorological Services Network
EWS	Early Warning System
FEWS	Flood Early Warning System
FFGS	Flash Flood Guidance System
FMMP	MRC's Flood Management and Mitigation Programme
GCOS	Global Climate Observing System
GDPFS	WMO Global Data-processing and Forecasting System
GISC	WMO Global Information System Centre
GOS	WMO Global Observing System
GPC-LRF	WMO Global Producing Centre for Long-range Forecasts
GTS	WMO Global Telecommunications System
HKO	Hong Kong Observatory
HRC	U.S. Hydrologic Research Center
HYCOS	Hydrological Cycle Observing System
ICHARM	Centre for Water Hazard and Risk Management
IPCC	Intergovernmental Panel on Climate Change
IRI	International Research Institute for Climate and Society
IWRM	integrated water resources management
JICA	Japan International Cooperation Agency
JMA	Japan Meteorological Agency
KMA	Korea Meteorological Administration
KRA	key results area (Typhoon Committee)
LAMs	limited area models
Lao PDR	Lao People's Democratic Republic
LC-LRFMME	Lead Centre for Long-range Forecast Multi-model Ensemble

ABBREVIATIONS (CONTINUED)

MASAP	Mekong Adaptation Strategy and Action Plan
M-HYCOS	Mekong Hydrological Cycle Observation System
MONRE	Ministry of Natural Resources and Environment
MRC	Mekong River Commission
MSS	Meteorological Service of Singapore
NASA	U.S. National Aeronautics and Space Administration
NCEP	NOAA/National Centers for Environmental Prediction
N-IWRMSP	National Integrated Water Resources Management Support Program
NHMS	National Hydro-Meteorological Service of Vietnam
NMC	National Meteorological Centre
NMHS	national meteorological and hydrological service
NOAA	U.S. National Oceanic and Atmospheric Administration
NUIST	Nanjing University of Information, Science and Technology
NWP	Numerical Weather Prediction
OP	Operating Plan
PTC	WMO/ESCAP Panel on Tropical Cyclone
QPE	Quantitative Precipitation Estimates
QPF	Quantitative Precipitation Forecast
RA	WMO Regional Association
RCC	WMO Regional Climate Centre
RFSC	WMO Regional Forecast Support Centre
RIMES	Regional Integrated Multi-hazard Early Warning System for Africa and Asia
RSMC	WMO Regional Specialized Meteorological Centre
RTC	WMO Regional Training Centre
RTH	WMO Regional Telecommunication Hub
SCMG	ASEAN Subcommittee on Meteorology and Geophysics
SEA	Southeast Asia
SEAFFGS	Southeast Asia Flash Flood Guidance System
SSOP	Synergized Standard Operating Procedures
SWFDP	WMO Severe Weather Forecasting Demonstration Project
SWFDP-SeA	WMO Severe Weather Forecasting Demonstration Project – Regional Subproject in Southeast Asia
UNDP	United Nations Development Programme
UNECAFE	United Nations Economic Commission for Asia and the Far East
WHYCOS	WMO World Hydrological Cycle Observing System
WIGOS	WMO Integrated Global Observing System
WIS	WMO Information System
WMC	WMO World Meteorological Centre
WMO	World Meteorological Organization
WWIS	World Weather Information Service
WWW	WMO World Weather Watch Programme

EXECUTIVE SUMMARY

SOUTHEAST ASIA DISASTER RISK PROFILE

The Southeast Asia (SEA) region is highly vulnerable to the impacts of natural hazards. Hydrometeorological hazards, such as floods, droughts, landslides, and storm surges, pose a direct threat to lives and impact livelihoods by damaging and destroying infrastructure, assets, and land. Underlying processes, including climate change impacts, population growth, land use changes, and urbanization patterns, are increasing the number of people in SEA at risk from hydrometeorological hazards. Despite a long tradition of coping with weather, climate, hydrological variability, and extreme events, the SEA region continues to face serious challenges in managing the risk of disasters. In recent years, a succession of typhoons, floods, and droughts has resulted in major loss of lives, livelihoods, and economic assets in SEA, especially in Cambodia, Lao People's Democratic Republic (Lao PDR), and Vietnam.

Weather, climate, and water know no national borders. The weather and climate conditions over the Indochina Peninsula, along with the very complex air-land-water interactions in the Lower Mekong region (including Cambodia, Lao PDR, and Vietnam), make it one of the most seriously imperiled regions on the planet. It faces an uncertain future due to climate change, with more intense dry seasons, wetter monsoons, more significant floods and storms (with associated heavy precipitation and strong winds), and rising sea levels. It is highly likely that SEA countries already feel the impact of climate change. In 2009, Typhoon Ketsana left a trail of destruction across the Philippines, Vietnam, Cambodia, and Lao PDR, while the powerful 2015/2016 El Niño caused widespread drought in the Lower Mekong region.

IMPORTANCE OF AND CHALLENGES IN INVESTING IN HYDROMETEOROLOGICAL SERVICES

Given the current and expected future impacts of weather-related hazards on countries in the region, governments need high-quality hydromet information to protect people, economies, and development gains. To minimize growing economic losses from hydrometeorological hazards, facilitate the adaptation to climate change, and guide economic development across different sectors, countries have invested in stronger national capacity to improve their multi-hazard early warning systems and weather, climate, and hydrological (hydromet) services. National meteorological and hydrological services (NMHSs) traditionally play a critical role in the provision of these services and in tailoring them to different users. National investments typically include upgrading of observing networks and related information and communication technology (ICT), real-time access to reliable and accurate numerical forecast products, post-processing and dissemination mechanisms, and cross-cutting institutional and technical capacity building.

While countries continue to invest in improved weather information services, challenges remain. The three SEA countries targeted in this report—Cambodia, Lao PDR, and Vietnam—have NMHSs that are able to provide a basic level of services, with Vietnam having higher capacity than the other two; but they all lag behind other countries in the region in terms of core capacities, forecasting technology, development and delivery of value-added services, and research and development. Limited financial, physical, and human resources make it difficult for the Cambodian, Lao, and Vietnamese NMHSs to cope individually with the increasing demand for improved products and better services. National investments are often provided through bilateral support and focus on separate elements of the hydromet infrastructure without making systemic changes to the entire national system, due in part to the lack of compatibility and interoperability among the separate systems.

REGIONAL DIMENSION

Regional initiatives offer many opportunities to support capacities of national hydromet service providers in the SEA region. Cambodia, Lao PDR, and Vietnam face similar challenges in coping with common hydromet hazards. To improve delivery of national hydromet services, it is critical to pursue regional hydromet strategies, as well as effective regional cooperation, collaboration (within and outside the subregion), harmonization of efforts, and cross-boundary

coordination. This approach in turn could help enable appropriate adaptation and mitigation measures to be developed and implemented. Integration of the region's hydromet systems provides opportunities to lower required investment while increasing accuracy of forecasts. Observed data from the hydromet monitoring networks needs to be shared with other NMHSs through regional data exchange in order to improve monitoring of hazardous hydromet conditions, numerical modeling, and forecasting. The design of optimum regional composites for each of the subsystems—hydromet observational networks, modeling, forecasting, and service delivery that meet the existing and future needs of societies—would ensure robust interoperability, efficiencies, and optimization of infrastructure costs, together with a higher level of harmonization, integration, and complementarity within the region.

A number of global and regional initiatives already exist that are relevant for SEA, although there are also challenges in fully benefiting from regional opportunities. The foundations and precedents for regional cooperation exist in SEA through the World Meteorological Organization (WMO), the United Nations Economic and Social Commission for Asia and the Pacific (ESCAP), the Association of Southeast Asian Nations (ASEAN), and the Mekong River Commission (MRC). Cambodia, Lao PDR, and Vietnam are participating in a number of regional initiatives and projects, through which their NMHSs can gain access to satellite-based imagery and regional and global Numerical Weather Prediction (NWP) products and services. However, there are also challenges at the national level—technical, budgetary, and human resource-related—that hinder their uptake and integration into the national systems and keep countries from fully complying with international commitments. Similarly, there are challenges in scaling up these initiatives from demonstrations to operations, ensuring their relevance to national and regional systems, and sustaining national participation.

OBJECTIVES AND OUTLINE OF THE POLICY NOTE

Increasing resilience to natural hazards directly supports the World Bank's twin goals of eradicating extreme poverty and boosting shared prosperity. The World Bank and other development partners are supporting SEA countries' efforts modernize their NMHSs, including through the series of Mekong Integrated Water Resources Management Projects, the Lao PDR Southeast Asia Disaster Risk Management Project, the Ayeyarwady Integrated River Basin Management Project, and several projects in Vietnam. Along with project financing and advisory services, the World Bank also provides technical assistance to Cambodia, Lao PDR, and Myanmar under the Developing Strategic Plans for Disaster Risk Financing, Risk Reduction and Hydromet Services in Southeast Asia program.

The objective of this policy note is to contribute to the ongoing discussion on the potential of regional coordination in SEA. This policy note seeks to improve understanding of regional aspects of the development and delivery of hydromet services in SEA; assess regional projects and existing international initiatives to promote regional cooperation; identify gaps in these efforts; and discuss constraints on and opportunities for strengthening the regional dimension of hydromet services, focusing on Cambodia, Lao PDR, and Vietnam. The note concludes with recommendations for the way forward with short-, medium-, and long-term action plans. This analysis draws on the knowledge gathered through ongoing World Bank engagements in the region, a desk review of existing literature, and limited consultations with stakeholders.

KEY FINDINGS AND RECOMMENDATIONS

Current hydromet conditions, including recent extreme hydromet events, along with expected future conditions highlight the need for continued investment in modernizing hydrometeorological services in the SEA region. Given that similar hazards face Cambodia, Lao PDR, and Vietnam, and that the countries have similar data and hydromet information needs, there are benefits to taking a regional approach to monitoring and forecasting hazardous hydromet conditions. The countries have different capabilities, but nonetheless, with more intense hazardous hydromet events taking place and likely to occur in the future, building a regional dimension to hydromet services could save on the cost of capital infrastructure as well as sustainable operation and maintenance.

A number of initiatives that focus on the different stages of the monitoring and forecasting process—such as data collection, forecasting, dissemination of impact-based forecasts and early warnings, and delivery of weather, climate, and hydrological services—could be utilized by subregional and national hydromet service providers, including in the SEA region. Existing regional frameworks and initiatives in the SEA region could help address some of the major challenges that national hydrometeorological service providers face.

There are challenges in making use of these initiatives. These include scaling up specific initiatives from demonstrations, ensuring relevance to national and regional systems, and sustaining national participation. These challenges are linked to constraints in human and financial resources, and to a lack of awareness at the national level of the benefits offered by regional approaches. The sections below list the recommended actions that Cambodia, Lao PDR, and Vietnam could take to address some of these challenges.

SHORT-TERM ACTIONS (ONE TO THREE YEARS)

1. Develop a regional Concept of Operations for the Lower Mekong region.

The development of a Concept of Operations (CONOPS) for the Lower Mekong region could guide the design and development of an optimum regional composite for hydromet observational networks, modeling, forecasting, and service delivery that meet societies' existing and future needs. A well-defined regional CONOPS is intended as a living document that guides the implementation and ongoing operation of the system of subsystems; it should be clearly aligned with national CONOPS documents that address user needs. The national CONOPS document should also evolve with the system.

Actions:

- (i) Task the Management Team of the Severe Weather Forecasting Demonstration Project–Regional Subproject in Southeast Asia (SWFDP-SeA) to develop the regional CONOPS.
- (ii) Encourage donors and development partners to participate in and support the development of the regional CONOPS.

2. Improve harmonization, compatibility, and integration of systems.

Many development partners have supported and will continue to support separate elements of the hydromet infrastructure. Although these efforts could provide significant improvements, staff at NMHSs still struggle with data integration, typically because systems are not compatible or interoperable. This lack of integration creates bottlenecks and inefficiencies in operations. Recent World Bank projects have been focusing on systems' integration, but these have been nationally driven. Noting that harmonization, compatibility, and integration are common challenges among the countries in the Lower Mekong region, the existing World Bank initiative should be scaled up to address this problem at the regional level. This will result in cost saving and promote efficiency and effectiveness in the systems, while contributing to improved monitoring and increased accuracy of forecasts.

Actions:

- (i) As part of the regional CONOPS for the Lower Mekong region, develop standardized technical specifications for the various components of the observation network (including automatic weather stations, radio sounding, radar, etc.)
- (ii) Establish formal agreements between the NMHS and the development partner or donor on the use of such technical specifications, which should be developed in the context of the regional CONOPS to allow integration.
- (iii) Encourage donors and development partners to comply with the technical specifications developed in the context of the regional CONOPS.

3. Enhance data collecting and sharing.

WMO adopted data-sharing policies with the intent of establishing a system for free and unrestricted exchange of weather, climate, and hydrological data and products at the international level; but many NMHSs are not able to comply due to political, technical, and resource issues. Regional policies are more effective, such as those established by MRC for hydrological data sharing among the countries in the Mekong basin. Given that the National Hydro-Meteorological Service (NHMS) of Vietnam is the Regional Forecast Support Centre and acts as a WMO regional hub for forecasting (making available graphical forecast products from global and regional service providers), it could extend its role to coordinate sharing of meteorological observational and forecasting data in the Lower Mekong region.

Actions:

- (i) Assign to the NHMS of Vietnam (as the WMO Regional Forecast Support Centre) the role of coordinator of meteorological observational and forecasting data sharing in the Lower Mekong region.
- (ii) Establish data-sharing protocols and agreements with global and regional service providers in Southeast Asia in order to get access to digital data (not only graphical products).

4. Strengthen ICT assets and infrastructure with the international community.

To ensure that individual NMHSs can quickly access data and products from existing global and regional initiatives, and can also contribute observational data for improving numerical forecast accuracy, a key priority is the acquisition and installation of the WMO Information System (WIS)/Global Telecommunication System (GTS) in individual countries. This allows communication with the international community through the WMO's World Weather Watch (WWW) infrastructure.

Actions:

- (i) Acquire and install the WIS/GTS in individual countries, along with related ICT infrastructure and/or cloud computing.
- (ii) Upgrade to reliable high-speed Internet in individual countries.
- (iii) Establish formal agreements with WMO/WIS centers—e.g., the Data Collection or Production Centre (DCPC) in Bangkok and Global Information System Centres (GISCs) in Beijing and Tokyo—for continuous support and capacity building in ICT system operations.

5. Improve monitoring and nowcasting of hazardous hydromet conditions.

The Southeast Asia Radar Network/Composite project aims to enhance expertise in the field of weather radar within the ASEAN region and provide capacity building on radar observation and its utilization. This project is important for nowcasting (that is, monitoring and extrapolation of weather conditions in the present and immediate future), especially for transboundary hazardous events; it is also important for determining Quantitative Precipitation Estimates (QPE) required for hydrological monitoring and forecasting. However, there have been significant technical challenges associated with its implementation, as NMHSs in SEA must first be able to manipulate and use the relevant radar data.

Actions:

- (i) Establish a formal collaboration mechanism with the WMO Regional WIGOS Centre Tokyo and with the NMHS of Thailand, which has recently been trained in the use and manipulation of radar data, and make data available to the regional radar composite.
- (ii) Work with Hong Kong Observatory to implement SWIRLS (Short-range Warning of Intense Rainstorms in Localized Systems) at the WMO Regional Forecast Support Centre in Vietnam, once the regional radar composite is in place.

6. Run and calibrate a regional numerical model.

With global NWP models now reaching the resolutions served by previous-generation local and regional deterministic limited area models (LAMs), efficient provision of such NWP services is best concentrated in a limited number of regional centers, such as the Regional Forecast Support Centre Hanoi, which has been significantly strengthened both in terms of hydromet infrastructure, equipment and technical skills.

Actions:

- (i) Strengthen the capabilities of Vietnam's NHMS as the Regional Forecast Support Centre to ensure that demonstration functions within the context of the SWFDP-SeA and Southeast Asia Flash Flood Guidance System (SEAFFGS) make the transition to operations.
- (ii) Establish a Lower Mekong Region Consortium for numerical modeling and invite staff from the three NMHSs to participate in the development, testing, and calibration of the regional model.
- (iii) Encourage donors and development partners to support regional functions of the NHMS of Vietnam and the participation of staff from NMHSs of Cambodia and Lao PDR in the consortium.

- (iv) Use model codes and parameterizations being shared within the WMO Regional Association II (Asia), which are supported by World Meteorological Centres (WMCs) in Beijing and Tokyo.
- (v) Establish formal agreements with WMCs in Beijing and Tokyo for continuous support and capacity building.

7. Establish formal collaborations with global and regional centers and universities for capacity building.

Training is an integral and essential part of modernization. Training should be carried out for all staff in their respective areas of expertise and responsibility and could be offered on-the-job, at WMO Regional Training Centres (RTCs), etc. Academia and research institutions are also supporting capacity building.

Actions:

- (i) Establish a formal agreement with global and regional centers—e.g., WMCs in Beijing and Tokyo, Southeast Asia Regional Climate Centre (RCC)-Network—to provide in-country training using the systems and equipment available to center staff, and to introduce the new products and tools made available to them through global and regional initiatives.
- (ii) Have the Vietnamese NHMS (in its capacity as the Regional Forecast Support Centre) provide in-country training at NMHSs of Cambodia and Lao PDR to boost their operational capacities.
- (iii) Have regional centers or institutions (in charge of regional weather, climate, or hydrological forecast support) assess national requirements, coordinate the development of curricula that include the introduction of new products and tools, and coordinate the engagement of relevant experts who could be deployed for a specific time period at the national level.
- (iv) Identify qualified staff from the 3 NMHSs to be trained as trainers of other staff, at the WMO RTCs in Republic of Korea and China.
- (v) Have RTCs in Korea and China review the training curricula to ensure that they are fit-for-purpose and address the requirements of the NMHSs in the Lower Mekong region.
- (vi) Establish protocols with academia and research institutions, including universities, to ensure that research studies are aligned with the research needs of the NMHSs (e.g., verification of numerical forecasts, post-process and calibration of model outputs, etc.)



MEDIUM-TERM ACTIONS (FOUR TO FIVE YEARS)

8. Focus on data quality and availability.

One of the functions of the WMO Regional WIGOS Centres is to carry out performance monitoring and incident management (under the WIGOS Data Quality Monitoring System) and follow up with data providers (i.e., the NMHSs) in case of data availability or data quality issues. Data quality and availability (which are crucial for hydromet monitoring and forecast verification) are critical issues for NMHSs in developing countries.

Actions:

- (i) Establish a good connection between the NMHSs of Cambodia, Lao PDR, and Vietnam and the Regional WIGOS Centre Tokyo, which would assist and support capacity development in this area.
- (ii) Promote the introduction of routine quality assurance/quality control of observations at individual NMHSs, as part of existing and future projects supported by donors and development partners.

9. Improve harmonization of warning criteria and of efforts to share warnings among the three countries in the region.

In line with the development of regional capacity for disaster risk management in SEA, there is a need to harmonize the warning criteria for hydromet hazards within the Lower Mekong region. It is important for individual countries to share and display the alerts and warnings for at least 48 hours, in a manner understandable for professionals and the public, using a dedicated regional web platform. An example of such a platform is Meteoalarm, which was developed under the framework of the European Meteorological Services Network (EUMETNET) (and which recently incorporated hydrological warnings).

Actions:

- (i) Harmonize the warning criteria for hydromet hazards within the Lower Mekong region.
- (ii) Share and display the alerts and warnings from individual countries for at least 48 hours, and do so in a manner that is understandable for professionals and the public using a dedicated regional web platform.
- (iii) Over the longer term, build on strengthened coordination with the regional and national disaster risk management community to harmonize these warnings toward impact-oriented warnings.



LONG-TERM ACTIONS (6 TO 10 YEARS)

10. Improve technical skills, operations and maintenance capacity, and engagement with the private sector.

To contribute to efficiencies and optimization of infrastructure costs and facilitate integration and complementarity within the region, the approach to investing in modernization of NMHSs should be rethought. Efforts to modernize should take into account the national and regional CONOPS, shift the focus from infrastructure to a service-based approach at the national level, support the regional hydromet dimension through the short- to medium-term actions suggested above, and engage with the private sector. These steps could also contribute to affordable operation and maintenance costs to be supported by governments.

Actions:

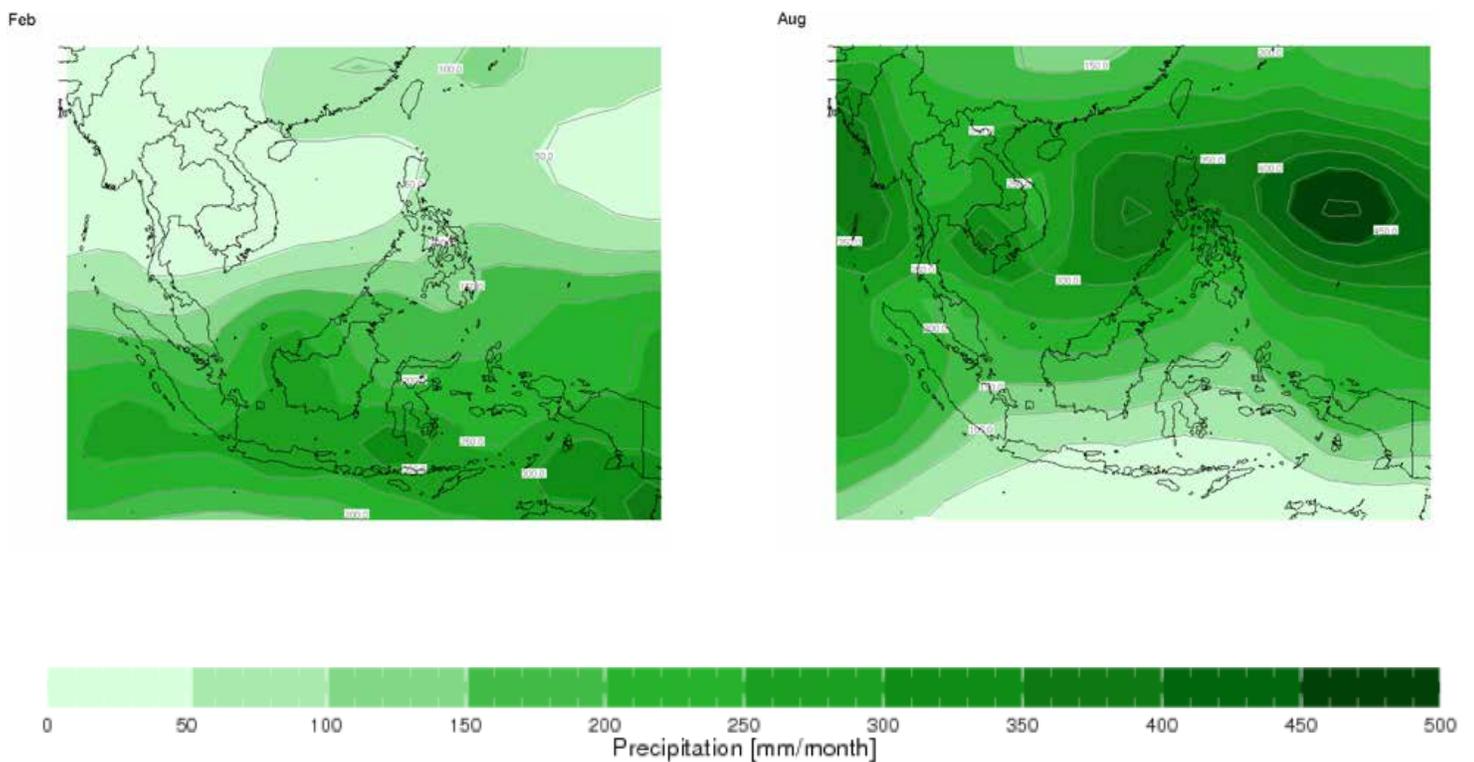
- (i) Develop new business models for the NMHSs by shifting focus from infrastructure to a service-based approach at national level, supporting the regional hydromet dimension through the short- to medium-term actions suggested above, and engaging with the private sector.
- (ii) Develop a program for mobilization of staff to fill in the technical capacity gaps among the three countries in the Lower Mekong region, while building the capacity of new staff through a comprehensive education and training program.



Photo: World Bank. Location: Luang Prabang, Laos

In the northern part of the SEA region (i.e., Cambodia, Lao PDR, Myanmar, northern Philippines, northern Thailand, and Vietnam), the northeast monsoon is characterized by a dry season (with <50 mm/month of precipitation; see lightest green area over the Indochina Peninsula for the rainfall climatology for February in Figure 2), while during the southwest monsoon, a wet season prevails (with 300–350 mm/month of precipitation over the Indochina Peninsula; see rainfall climatology for August in Figure 2). The converse applies for the southern SEA region (i.e., Brunei Darussalam, Indonesia, Malaysia, southern Philippines, Singapore, and southern Thailand). During the southwest monsoon, the northern part of the SEA region (including the Indochina Peninsula) is particularly at risk of being affected by typhoons (see Technical Insight 1). During the intermonsoon season, diurnal-type weather conditions, characterized by afternoon and evening showers with light variable winds along the tropical belt, predominate across the SEA region.

FIGURE 2: SOUTHEAST ASIA RAINFALL CLIMATOLOGY FOR FEBRUARY (LEFT) AND AUGUST (RIGHT)

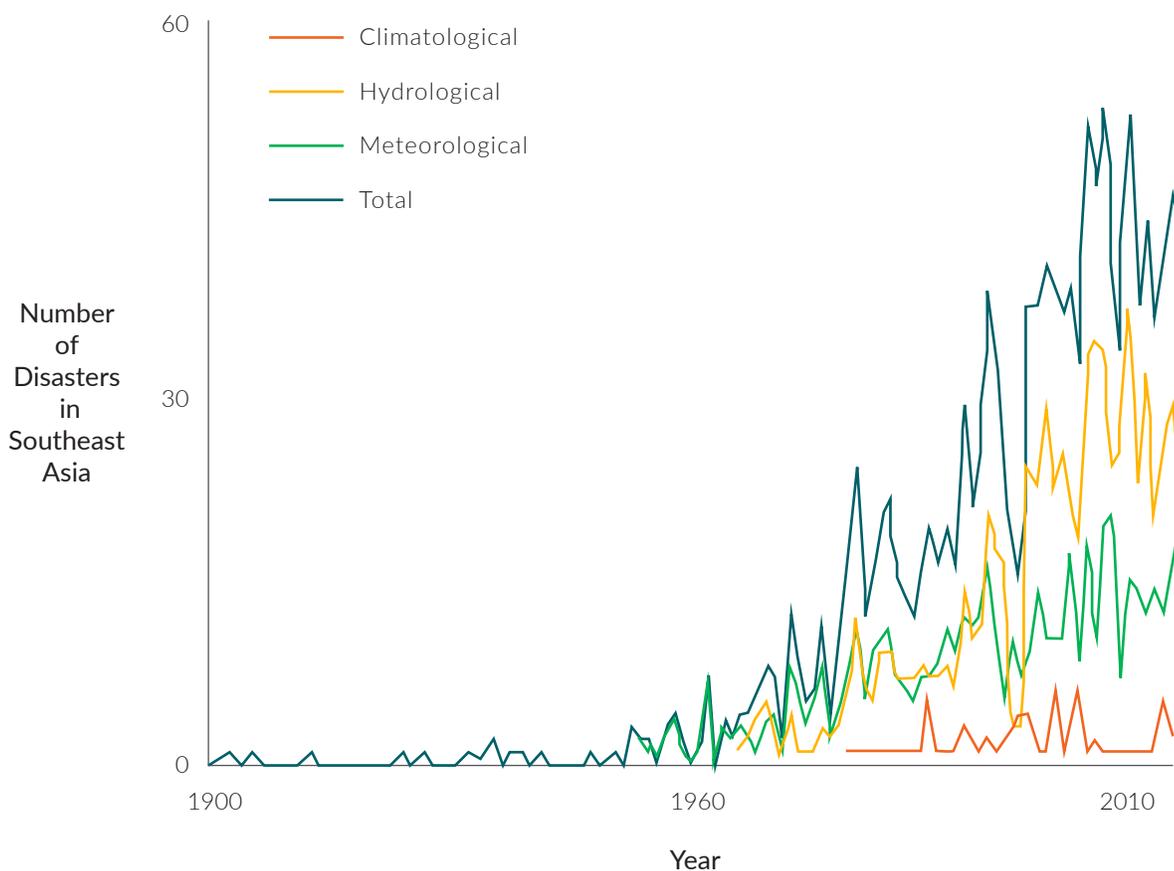


Source: ASEAN Specialized Meteorological Centre (ASMC), "ASEAN Regional Climate Outlook Forum: What Is the Climate of the Southeast Asia Region?," http://asmc.asean.org/asmc_asean_cof_about/.

A CHANGING CLIMATE

Seneviratne et al. (2012) shows that a changing climate in general leads to changes in the frequency, intensity, spatial extent, duration, and timing of weather and climate events. Many countries in the SEA region are already feeling the impact of climate change (Yusuf and Francisco 2009), including more frequent heat waves, more intense tropical storms, and coastal inundation resulting from sea-level rise. Sea levels are expected to rise at least 1 m during this century, according to IPCC (2014), and this increase can be temporarily intensified by storm surges primarily caused by typhoons approaching land. **Figure 3** shows a moderate increased trend in hydromet disasters, especially hydrological disasters, in SEA in the last three decades.

FIGURE 3: NUMBER OF METEOROLOGICAL, CLIMATOLOGICAL, AND HYDROLOGICAL DISASTERS IN SOUTHEAST ASIA, 1900 TO 2017



Source: EM-DAT: The Emergency Events Database—Université catholique de Louvain (UCL) CRED, D. Guha-Sapir—www.emdat.be, Brussels, Belgium.

Note: Meteorological disasters include extreme temperatures, fog, and storms; climatological disasters include droughts and wildfires; and hydrological disasters include floods and landslides.

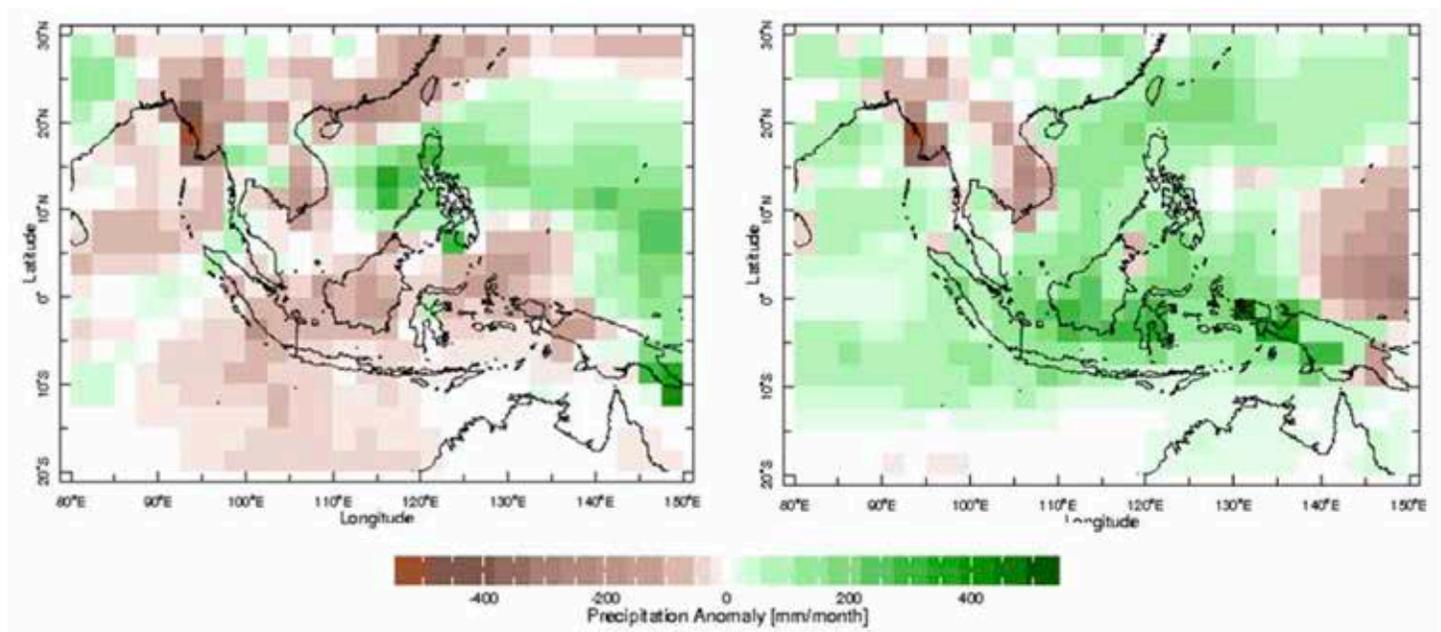
However, the link in SEA between global warming and the seasonal atmospheric flow during the monsoon seasons remains fuzzy. In general, changes in monsoon-related extreme precipitation and winds due to climate change are not well understood (Seneviratne et al. 2012). While there is little consensus among climate models and hence low confidence in projections of change in monsoons, there is evidence of disruptions in the normal monsoon cycle. These disruptions are typically caused by the El Niño-Southern Oscillation (ENSO), whose impacts are detailed in **Box 1**.

BOX 1: EL NIÑO-SOUTHERN OSCILLATION (ENSO)

The El Niño-Southern Oscillation (ENSO) is a natural fluctuation of the global climate system caused by equatorial ocean-atmosphere interaction in the tropical Pacific Ocean (Philander 1990). The term “Southern Oscillation” refers to a tendency for above-average surface atmospheric pressures in the Indian Ocean to be associated with below-average pressures in the Pacific, and vice versa. This oscillation is associated with variations in sea surface temperatures in the east equatorial Pacific. The oceanic and atmospheric variations are collectively referred to as ENSO. An El Niño episode is one phase of the ENSO phenomenon and is associated with abnormally warm central and east equatorial Pacific Ocean surface temperatures, while the opposite phase, a La Niña episode, is associated with abnormally cool ocean temperatures in this region. Both phases are associated with a characteristic spatial pattern of droughts and floods. Recent research (e.g., Zhang et al. 2010) has demonstrated that different phases of ENSO (El Niño or La Niña episodes) also are associated with different frequencies of occurrence of short-term weather extremes, such as heavy rainfall events and extreme temperatures. The relationship between ENSO and interannual variations in tropical cyclone activity is well known (see e.g. Kuleshov et al. 2008).

In SEA, in particular in the Indochina Peninsula, the El Niño episode brings warmer and dryer weather and typically exacerbates the dry season with prolonged dry spells, often leading to droughts and sometimes intense forest fires (see [Technical Insight 1](#)). In a La Niña episode, the climate anomalies are usually the opposite of those in an El Niño—that is, a La Niña episode is characterized by higher-than-normal rainfall, which may result in an increased occurrence of floods. The correlation between El Niño/La Niña and its associated weather impacts in SEA differs by place and by season. Figure 4 shows the precipitation anomalies (in relation to the climatology) averaged over the El Niño and La Niña years during the months of June to October. During these months, the impact of El Niño (i.e., dryer weather) is typically stronger over the southern and eastern part of SEA (including the Indochina Peninsula).

FIGURE 4 : DISTRIBUTION OF PRECIPITATION ANOMALIES OVER SOUTHEAST ASIA (JUNE-OCTOBER) FOR EL NIÑO (LEFT) AND LA NIÑA (RIGHT) YEARS

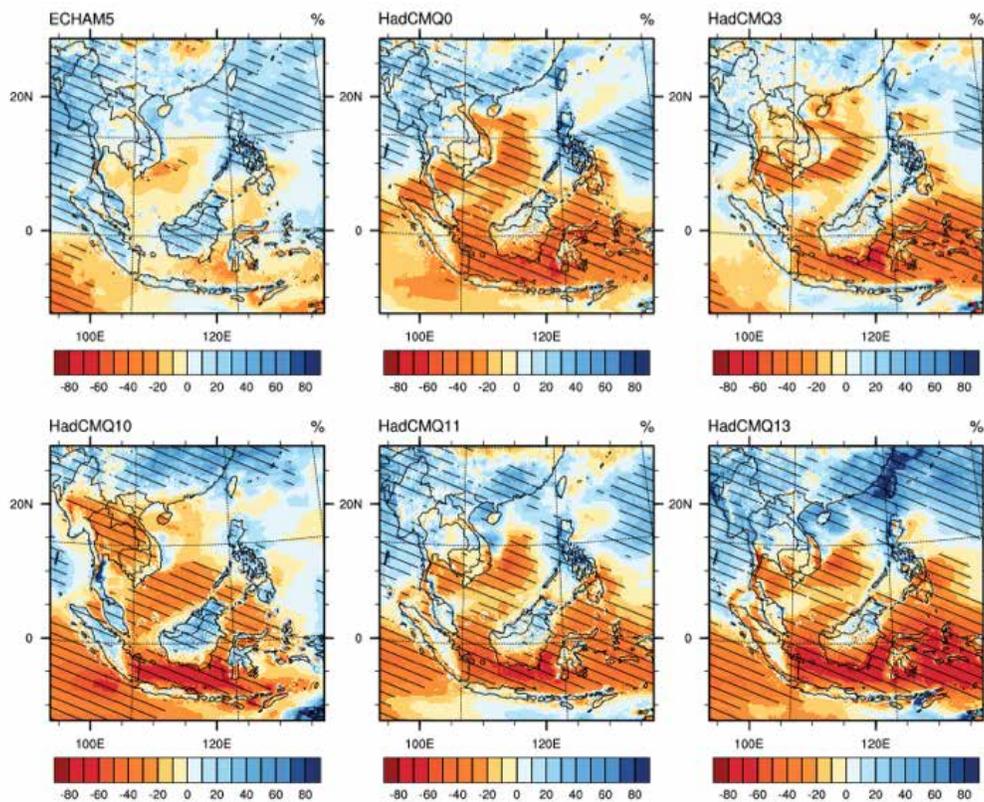


Source: ASEAN Specialized Meteorological Centre (ASMC), “ASEAN Regional Climate Outlook Forum: What Is the Climate of the Southeast Asia Region?,” http://asmc.asean.org/asmc_asean_cof_about/.

The fifth IPCC Report (IPCC 2014) indicates that warming is very likely to continue in SEA, with substantial subregional variations. There is medium confidence in a moderate increase in rainfall over the Indochina Peninsula, but to the south there is generally a drying tendency, although this may not be significant relative to the natural decadal variations in this region. Strong regional variations are expected because of SEA's topographic characteristics and land-ocean configuration. The complex geographic features of SEA (i.e., land, ocean, mountains, etc.) make it difficult to understand climate change scenarios in the region. To address this difficulty, numerous research studies have been carried out in the context of the Southeast Asia Coordinated Regional Downscaling Experiment (CORDEX) project, which have significantly contributed to understanding climate change scenarios at the regional level. Rahmat et al. (2014) conclude that relative to the baseline period of 1971–2000, the annual cycle change in temperature was around 2°C for the mid-term projections (that is, for the 30-year period between 2031 and 2060) and around 4°C for the long-term (the 30-year period between 2071 and 2100).

In contrast, the projections for precipitation show large spatial and seasonal variations, which lead to difficulties in understanding the annual cycle. But generally, the projections show drier climate over the sea and wetter climate over land. During the southwest monsoon (June to August), generally more rainfall is projected in the northern part of the region (from approximately 20°N and northward), whereas drier conditions are projected for the Maritime Continent (see Figure 5). For the northeast monsoon (December to February), the scale of projected changes in precipitation (e.g., increases over land) for extremes is not as significant as for the southwest monsoon.

FIGURE 5: FUTURE PERCENTAGE CHANGE IN SEASONAL MEAN RAINFALL FOR END-CENTURY (2071–2100) RELATIVE TO THE BASELINE PERIOD (1971–2000) IN JUNE-JULY-AUGUST FOR SIX DIFFERENT MODEL SCENARIOS



Source: Rahmat et al. 2014.

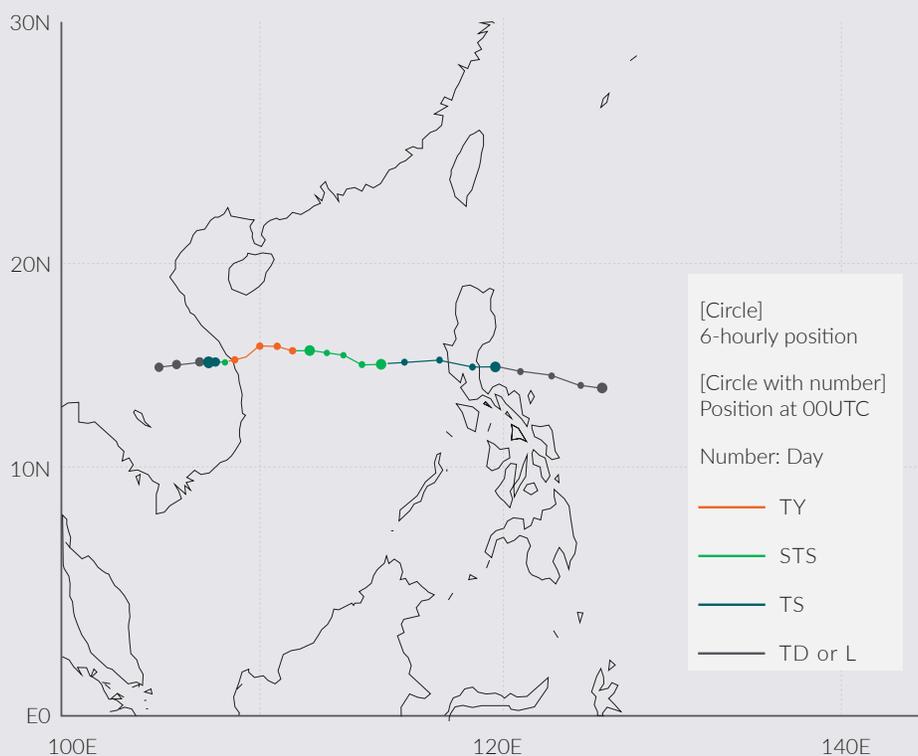
Note: Blue (red) shades show projected wetter (drier) locations. Hatching shows areas with significant changes.

Technical Insight 1: The regional nature of hydromet hazards in the Lower Mekong region

The Lower Mekong region (including Cambodia, Lao PDR, and Vietnam) is predominately influenced by the dry-season northeast monsoon (from December to March) and by the wet-season southwest monsoon (from June to September). Associated with very complex air-land-water interactions in the Mekong basin, and the natural fluctuations of the global climate system (such as El Niño/La Niña), these two seasons often bring extreme hydromet conditions to SEA, which is one of the most disaster-prone areas on the planet. While there is medium confidence in the climate projections for the region, these countries are already feeling the impact of climate change, including more frequent heat waves, prolonged dry spells leading to drought, more intense tropical storms, and severe floods. Two recent examples of the serious regional impacts are described below. They highlight the need for regional investments to improve the quality of hydrometeorological information in this region.

Typhoon Ketsana (September 2009)—In the last few decades, the countries of the SEA region have been exposed to rising land and ocean surface temperatures, along with weather and climate events of increased intensity and frequency. The year 2009 proved to be no exception to that trend. In the western North Pacific Ocean basin, 22 named tropical storms were recorded, 13 of which reached the intensity of typhoon. One of these storms, Typhoon Ketsana, was the world's second deadliest tropical cyclone of that year (WMO 2009). According to press reports, strong winds and heavy rain associated with Typhoon Ketsana caused severe flooding in SEA, triggering significant casualties and damage across the Philippines, Vietnam, Cambodia, and Lao PDR (see Figure 6 for the Typhoon Ketsana track analysis).

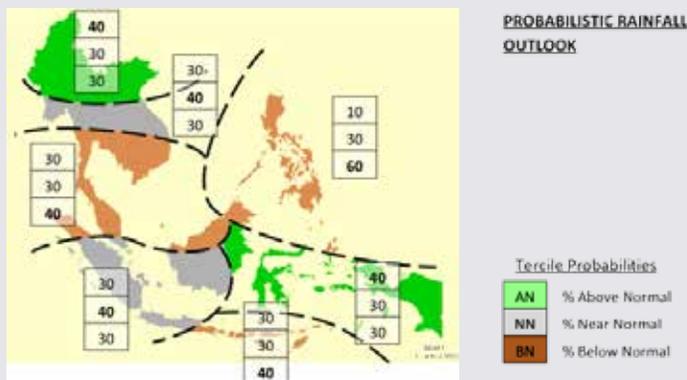
FIGURE 6: TYPHOON KETSANA TRACK ANALYSIS



Source: Analysis archive of the RSMC-Typhoon Center Tokyo, hosted by the Japan Meteorological Agency, <http://www.jma.go.jp/en/typh/>; also available in JMA 2009.

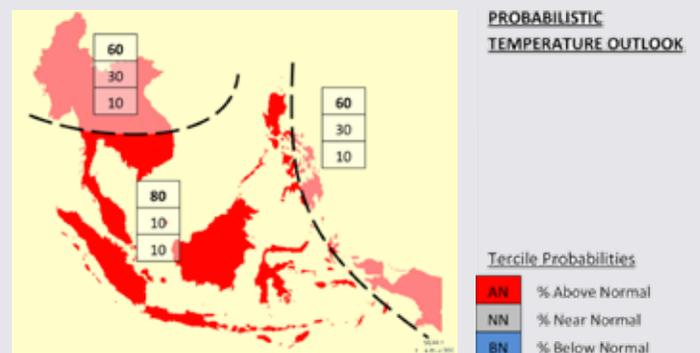
Drought in the Lower Mekong region (2015/2016)—The Fifth Session of the ASEAN (Association of Southeast Asia Nations) Climate Outlook Forum (ASEANCOF-5), held in November 2015, indicated an enhanced likelihood for the Lower Mekong region to experience drier-than-normal conditions in December-January-February 2015/2016, due to the strong and mature 2015/2016 El Niño event. The regional consensus maps showing the probabilistic rainfall outlook (Figure 7) and temperature outlook (Figure 8) that were issued in November 2015 clearly show below-normal rainfall and well-above-normal temperatures in the Lower Mekong region. This common outlook for rainfall and temperature highlights the importance of regional cooperation to improve resilience and adaptation to climate change in preparation for naturally occurring disaster events, such as this powerful 2015/2016 El Niño, which caused widespread drought with significant impact in various sectors in the Indochina Peninsula.

FIGURE 7: PROBABILISTIC RAINFALL OUTLOOK ISSUED IN NOVEMBER 2015



Source: ASEANCOF-5, “Consensus Bulletin for December-January-February (DJF) 2015-16 Season,” <http://asmc.asean.org/wp-content/uploads/2015/11/ASEANCOF-5-Outlook-Bulletin-for-DJF-2015-16-FINAL.pdf>.

FIGURE 8: PROBABILISTIC TEMPERATURE OUTLOOK ISSUED IN NOVEMBER 2015



Source: ASEANCOF-5, “Consensus Bulletin for December-January-February (DJF) 2015-16 Season,” <http://asmc.asean.org/wp-content/uploads/2015/11/ASEANCOF-5-Outlook-Bulletin-for-DJF-2015-16-FINAL.pdf>.

KEY TAKEAWAYS

SEA is highly vulnerable to the impacts of a range of natural hazards, including floods, droughts, landslides, and storm surges. Cambodia, Lao PDR, and Vietnam often face common meteorological and hydrological hazards. Disasters pose a direct threat to lives; they impact livelihoods by damaging and destroying infrastructure, assets, and land; and they ultimately disrupt development outcomes. Given existing risks and projected changes in the region’s climate conditions, countries urgently need access to accurate and timely weather information.



Photo: World Bank photo collection/Flickr.com Location: Vietnam.

THE SOUTHEAST ASIAN HYDROMET SERVICES IN A NUTSHELL

This chapter provides a brief overview of the state of the hydromet service providers in the SEA region. Specifically, it looks at the capabilities of the national meteorological and hydrological services (NMHSs) in Cambodia, Lao PDR, and Vietnam and at ongoing major initiatives led by respective governments, donors, and development partners. The current state of these services highlights the need for investments at the national level to ensure a unified approach and improve synergies between different initiatives, as well as the potential benefits of strengthening the regional dimension of these services to bring them in line with international practice.

ROLE OF NATIONAL METEOROLOGICAL AND HYDROLOGICAL SERVICES

To minimize growing economic losses from hydrometeorological hazards, facilitate adaptation to climate change, and guide economic development across different sectors, countries invest in national capacity to provide improved multi-hazard early warnings as well as weather, climate, and hydrological (hydromet) services. The NMHSs are the national institutions responsible for observing and understanding weather and climate and for providing related services in support of national needs, especially as they pertain to (a) protecting life and property; (b) safeguarding the environment; (c) contributing to sustainable development; (d) promoting long-term observation and collection of meteorological, hydrological, and climatological data, including related environmental data; (e) promoting endogenous capacity development; (f) meeting international commitments; and (g) contributing to international cooperation (WMO 2015b).

While countries in the Indochina Peninsula are impacted by common meteorological and hydrological hazards, a close look at the hydromet services in Cambodia, Lao PDR, and Vietnam reveals different capacities among the NMHSs (Table 1). Various development partners have made and will continue to make investments in observational infrastructure, forecasting, and service delivery in these individual countries, but there are still challenges and gaps in the existing systems, which could be addressed through—and benefit from—building a regional dimension to hydromet services (see Technical Insight 2). A summary of the investments being made to strengthen the capabilities of NMHSs in Cambodia, Lao PDR, and Vietnam is provided below. Information on the capacities and the investments of these services is based on existing literature and recent reviews conducted on behalf of the World Bank.

CAMBODIA

Cambodia's Department of Meteorology (DOM), under the Ministry of Water Resources and Meteorology, is responsible for the operation and maintenance of all meteorological observations and for issuance of weather forecasts, severe weather warnings to support disaster risk management, and climate information. It provides weather services to aviation and land transportation, agriculture, and other sectors. In dealing with hydrometeorological hazards, DOM partners with the Department of Hydrology and River Works (also under the Ministry of Water Resources and Meteorology), which maintains and monitors hydrological stations along the river systems of Cambodia.

Compared to most of the NMHSs in SEA countries, DOM and the Department of Hydrology and River Works have relatively limited technical expertise, human resources, and financial resources to carry out their mission. Their observation networks, production system, and current financial resources have been improved with the support of the Government of Cambodia and various development partners; however, they are still not adequate to ensure weather, climate, and hydrological information and services that meet the rapidly growing and demanding needs of the different sectors, including socioeconomic needs and those of the public (from community to national level).

In particular, the Government of Cambodia has sought to upgrade DOM's capabilities by providing the budget for S-band radar that covers most of the country, and for modern forecaster workstations and communication systems that allow access to global and regional Numerical Weather Prediction (NWP) and satellite products. However, DOM still faces many difficulties, notably the lack of experience and dedicated staff needed to operate the new systems. In addition, strengthening the surface observation networks is still required for both monitoring and radar data calibration. This would ensure improved quality of its data.

Several steps have been taken to strengthen hydrology in Cambodia. The Mekong River Commission (MRC) supported the Mekong Hydrological Cycle Observation System (M-HYCOS) project with the installation of 12 hydrological stations in Cambodia. The Asian Development Bank (ADB) financed establishment of the National Flood Forecasting System and capacity technical assistance designed to (a) manage water resources through strengthening the strategy, policy, and legal framework for integrated water resources management (IWRM), and (b) promote IWRM and climate change adaptation. The World Bank has supported a regional series of Mekong Integrated Water Management Projects that aims to strengthen the capacity of governments in the Lower Mekong (Cambodia, Lao PDR, and Vietnam) to better manage water resources; projects have focused on hydromet network modernization and the transboundary elements of the Mekong river basin, among other concerns.

Other activities and projects in Cambodia include the following:

- ADB's Greater Mekong Subregion Flood and Drought Risk Management and Mitigation Project (2013–2019). This project has a component that supports the development of design criteria for flood and drought risk mitigation schemes and water control infrastructure in the Mekong Delta and elsewhere, the assessment of cross-border flood management options in Vietnam and Cambodia, and the strengthening of the National Flood Forecasting Center (ADB 2012).
- United Nations Development Programme (UNDP)/ Global Environment Facility project Strengthening Climate Information and Early Warning Systems in Cambodia to Support Climate Resilient Development and Adaptation to Climate Change (2014-2018). This project aims to establish an effective early warning system (EWS) to allow timely preparation for extreme events, as well as climate-resilient development planning.
- Typhoon Committee's Synergized Standard Operating Procedures for Coastal Multi-hazards Early Warning System Project. This project is supported by the United Nations Economic and Social Commission for Asia and the Pacific (ESCAP) trust fund.

LAO PDR

The Department of Meteorology and Hydrology (DMH), under the Ministry of Natural Resources and Environment (MONRE), is responsible for meteorological and hydrological observations, forecasting, and early warning of hydrological and meteorological hazards. As part of its mandate, DMH provides hydromet information and services to a wide range of water resource planning and management activities. It also provides weather services to aviation and land transportation and supports decision making with climate outlooks.

The DMH has received financial support from various entities—the World Bank, ADB, Global Environment Facility, Food and Agriculture Organization of the United Nations, and others—to strengthen the national capacity to observe, forecast, and provide early warnings of hydrometeorological hazards. In particular, the World Bank has funded the regional Mekong Integrated Water Resources Management Project to promote IWRM along the Mekong River. The Lao portion of the Mekong Integrated Water Management Project has the following two components: (a) institutional support for various departments in MONRE for water resources management, and (b) on-the-ground IWRM actions for selected priority basins, including hydromet strengthening and model developing for river basin planning. In addition, the World Bank is also supporting the Lao PDR Southeast Asia Disaster Risk Management Project to reduce the impacts of flooding in Muang Xay and enhance the government's capacity to provide hydrometeorological services and disaster response. Component 2 of this project—Hydromet Modernization and Early Warning Systems—is implemented by DMH, and includes among other goals (a) strengthening early warning systems and service delivery systems, and (b) modernizing the observing, forecasting, and communications systems.

ADB is building capacity for the MONRE. The program, named the National Integrated Water Resources Management Support Program (N-IWRMSP), has 10 components; under the fourth component, support is provided to the DMH to strengthen its surface observing network. In addition, the Mekong River Commission supported the installation of 11 hydrological stations in Lao PDR as part of the Mekong Hydrological Cycle Observation System (M-HYCOS) project.

The Japan International Cooperation Agency (JICA) has been supporting DMH for many years, including through installation of the C-band Doppler radar and long-term expert attachment to DMH to support radar operations. JICA has also supported the Project for Improvement of Equipment and Facilities on Meteorological and Hydrological Services, which aims to reduce the damage caused by meteorological and hydrological disasters in Lao PDR by strengthening DMH observational and telecommunication systems.

The Food and Agriculture Organization of the United Nations has recently initiated a project for Strengthening Agro-climatic Monitoring and Information Systems to Improve Adaptation to Climate Change and Food Security in Lao PDR. This project will enhance DMH monitoring, analysis, communication, and use of agro-meteorological data and information for decision making in relation to agriculture and food security at national and provincial levels.

VIETNAM

The National Hydro-Meteorological Service (NHMS) of Vietnam is under MONRE's newly established Directorate of Hydro-Meteorology. Although the NHMS's vision is not articulated, its mission is to assist the minister of MONRE to manage and exploit national meteorological and hydrological networks (including basic research activities, forecasts, and meteorological and hydrological data management); and to monitor air and water environments in support of natural disaster prevention and preparedness, socioeconomic development, and national security and defense.

The NHMS operates and maintains more than 90 percent of all weather, climate, and hydrological observation networks in Vietnam. Hydrological forecasts and warnings are issued by the NHMS covering rivers in the northern, central, central highland, and southern regions of Vietnam, including the transboundary river that traverses the country—the Mekong River. Weather service for aviation is carried out by the Institute of Transportation, a government agency under the Institute of Transport Science and Technology in the Ministry of Transport. The institute maintains meteorological stations at all airports in Vietnam. Climate prediction services are carried out by the Vietnam Institute of Meteorology, Hydrology and Environment of MONRE through climate outlooks, agro-meteorological outlooks, and crop yield forecasts that are used by the agricultural sector.

In comparison to Cambodia's DOM and Lao PDR's DMH, the NHMS has good technical and support staff. However, its existing office premises, observation networks, and forecasting systems are fragmented, and its financial resources in particular are still not adequate to meet the increasing needs of regional and local forecasting of weather- and climate-related hazards, including the issuance of early warning for the public and different socioeconomic sectors. The Government of Vietnam has been investing millions of dollars in the modernization of NHMS facilities. This funding has allowed NHMS to start its commercialization program to extend hydromet services to other development sectors, such as energy, agriculture, and transport in addition to its traditional public service in emergency response. NHMS has to facilitate the full implementation of its cost-recovery measures to help sustain its operation and maintenance budget. Its cost-recovery program is approximately 10 percent of the total budget of the NHMS (World Bank and UNISDR 2013).

On regional cooperation, the NHMS has established a bilateral cooperation agreement with the NHMSs of Cambodia and Lao PDR for data sharing, strengthening of forecasting capability, and training of staff. At the same time, the Vietnam NHMS has also actively participated in the regional flood forecast established by the Flood Management and Mitigation Programme (FMMP) of the Mekong River Commission (MRC). Under the WMO Severe Weather Forecasting Demonstration Project (see Chapter 4), the Vietnam NHMS has been acting as a Regional Forecast Support Centre (RFSC).

The NHMS has received financial support in various forms of lending and grant technical assistance from various entities—including the World Bank, ADB, and governments of Italy, Japan, Finland, Denmark, United Kingdom, Norway, and Republic of Korea—to strengthen the national capacity to observe, forecast, and provide early warnings of hydrometeorological hazards. Among the supported projects are (a) the Natural Disaster Risk Management Project and Vietnam Managing Natural Hazards Project (World Bank); (b) Improving of Flood Forecasting and Warning System in Vietnam – II Phase (Italy); (c) strengthening of capacity to cope with natural disasters caused by climate change (Japan); (d) Promoting Modernization of Hydrometeorological Services in Vietnam, Phase II (Finland); (e) upgrading of NHMS's ability to measure and monitor rain, storm, and lightning (Finland); (f) development of technology for urban flood and inundation real-time forecasting in Hanoi (Denmark); (g) modernization of natural disaster forecasting and warning system for Northeast Hydro-meteorology Regional Centre (Korea); (h) Flood Forecasting and Warning System for Hoi An and Vu Gia-Thu Bon River Basin (ADB); (i) Urban Flood Forecasting Ho Chi Minh City (World Bank), (j) Mekong Integrated Water Management Project to enhance IWRM in Vietnam, focusing on central highland region; and (k) M-HYCOS project (MRC) for the installation of 12 hydrological stations in Vietnam. These projects introduce different systems that do not necessarily “talk” to each other. To address this issue, the World Bank is supporting System Integration and Technical Assistance for Strengthening of Weather Forecasting and Early Warning Systems in Vietnam; the project is part of Component 2 of the Vietnam Managing Natural Hazards Project.

STATE OF CAPABILITIES IN SEA AND REGIONAL DIMENSION

NMHSs in a geographical region (i.e., neighboring countries) typically face similar (or even identical) problems and have similar (or identical) needs for data, products, and services. A summary of the different capacities of Cambodia, Lao PDR, and Vietnam to cope with common meteorological and hydrological hazards is included in Table 1. In this context, there would be efficiency gains in coordinating their requirements and collective needs. Given similar user requirements, a regional dimension to hydromet services would provide a forum for sharing data, expertise, and experiences among NMHS staff, including on how to deal or liaise with intragovernment communications, emergency services, the media, etc. Further opportunities for considering regional dimensions are included in Technical Insight 2.

TABLE 1: SUMMARY OF THE CAPACITIES OF NMHSS IN CAMBODIA, LAO PDR, AND VIETNAM

Functions	Cambodia	Lao PDR	Vietnam
Weather monitoring	L	L	M
Hydrological monitoring, including both water-level and discharge measurements	L	L	M
Quality assurance/quality control of observations	NIL	NIL	L
Nowcasting	NIL	NIL	L
Short- to medium-range weather forecasting	L	L	M
Numerical Weather Prediction	VL	L	H
Ensemble Prediction Systems (use of probabilistic forecasts)	VL	VL	M
Hydrological forecasting	VL	VL	H
Seasonal forecasting (including monsoon outlook)	L	L	M
Climate services, including climatological normals, maps, etc.	VL	VL	L
Public weather services, including dissemination of forecasts and warnings	L	L	M
Agro-met services	L	L	M
Marine forecasting	L	NA	M
Aviation forecasting	L	L	M
Quality management systems	Nil	Nil	L
Forecast verification	Nil	Nil	L

Source: Based on recent reviews conducted on behalf of the World Bank and on existing literature; see Jha and Stanton-Geddes (2013) and papers prepared for WMO-organized meetings in Hanoi, November 20–23, 2017, https://www.wmo.int/pages/prog/www/DPFS/Meetings/RAII-SeA-SWFDP-RSMT_Hanoi2017/DocPlan_001.html. Functions are described according to the World Meteorological Organization's terminology database METEOTERM, https://www.wmo.int/pages/prog/lsp/meteoterm_wmo_en.html.

Notes: Nil = no capacity; VL = very low capacity; L = low capacity; M = medium capacity; H = high capacity; NA = not applicable.

Technical Insight 2: Advantages of a regional dimension to hydromet services in the Lower Mekong region

Given similar user requirements in SEA, a regional dimension to hydromet services would provide a forum for sharing data, expertise, and experiences among NMHS staff, including on how to deal or liaise with intragovernment communications, emergency services, the media, etc. A regional dimension would also provide a coordinated, harmonized, and consistent approach to address hazards (including high-impact weather situations in a geographical region), as well as a continuous learning environment through (for example) twinning arrangements. Moreover, since observational data are typically more widely shared among NMHSs within a region or subregion (directed by regional data policies and/or bilateral agreements), a regional dimension to hydromet services in SEA could lead to significant regional forecast improvements.

Assessment of the existing systems in individual NMHSs and design of optimum regional composites for each of the subsystems—hydromet observational networks, modeling, forecasting, and service delivery that meet the existing and future needs of societies—would ensure robust interoperability, efficiencies, and optimization of infrastructure costs. It would also ensure a higher level of integration and complementarity within the region, which is a critical function and a major challenge in the region.

Greater integration is particularly important for the Lower Mekong region (including Cambodia, Lao PDR, and Vietnam), where significant investments have been made and will continue to be made to strengthen the capacities of and modernize individual NMHSs. Because these investments are mainly through bilateral support and focused on specific elements of the overall end-to-end hydromet system, they typically bring additional challenges associated with lack of compatibility/interoperability of the various systems. This lack of integration may result in bottlenecks and inefficiencies in the operational monitoring and forecasting processes.

The Mekong region is among the most seriously imperiled regions on the planet. It faces an uncertain future due to climate change (see Chapter 1), with more intense dry seasons and wetter monsoons, along with floods, storms, and rising sea levels. In particular in this region, building a regional dimension to hydromet services will result in savings: It would lower the infrastructure costs during the implementation of individual projects, and these saving could be channeled to longer-term operations and maintenance of the various subsystems to ensure sustainability of the investments. It would also reduce the government budget required for sustainable operations and maintenance of the overall modernized NMHS system after the completion of the project.

KEY TAKEAWAYS

Given current and expected future impacts of hydromet-related hazards, governments need high-quality hydromet information to protect people, economies, and development gains. In the context of similar natural hazards facing Cambodia, Lao PDR, and Vietnam, as well as similar data and information needs, all three countries could benefit from stronger collaboration on hydrometeorological services, particularly monitoring and forecasting of hazardous conditions. Cambodia, Lao PDR, and Vietnam have different capabilities; but with more intense hydromet-related disaster events occurring, a regional dimension to hydromet services could result in savings in capital infrastructure as well as sustainable operations and maintenance costs.



Photo: World Bank photo collection/Flickr.com.

THE WMO'S CASCADING MONITORING AND FORECASTING PROCESS AND HOW IT RELATES TO SOUTHEAST ASIA

This chapter briefly outlines the roles and responsibilities of global, regional, and national hydromet service providers in line with international practice, and highlights major initiatives relevant to SEA

THE EXPANDED WMO'S WORLD WEATHER WATCH (WWW) INFRASTRUCTURE

To predict the weather, modern meteorology depends upon near instantaneous exchange of weather information across the entire globe. Established in 1963, World Weather Watch (WWW) is a unique international cooperation program that combines observing systems, telecommunication facilities, and data-processing and forecasting centers, all operated by WMO members, to make available the meteorological and related environmental information needed to provide efficient services in all countries. Originally focused on weather, the current WWW has been expanded to address climate and hydrological aspects. In doing so, it respects data-sharing policies and helps ensure high data-quality standards and benefits (see Box 2).

The infrastructure underpinning WWW includes the following (WMO 2017a):

BOX 2: DATA SHARING IN WMO

Data sharing in WMO has been articulated specifically over the last 20 years—in WMO Resolution 40, adopted at the 12th World Meteorological Congress (Cg-XII) for weather, Resolution 25 (Cg-XIII) for water, and Resolution 60 (Cg-17) for climate. These resolutions were adopted with the intent of establishing a system for free and unrestricted exchange of data and products, which is a unique international hallmark of WMO. Many commercial operators also rely on the capability that is built on top of global data-sharing arrangements.

The WMO Global Integrated Observing System (WIGOS). This system enables the collection of observational data from 17 satellites, hundreds of ocean buoys, thousands of aircrafts and ships, and nearly 10,000 land-based stations. WIGOS is a comprehensive, coordinated, and sustainable system of observing systems, which is based on the observational requirements of all WMO programs and applications. It ensures the availability of required data and information and facilitates access through the WMO Information System according to identified temporal, geographical, and organizational requirements, including those for real-time, near-real-time, and delayed modes. The surface- and space-based components of WIGOS (see Box 3) include weather observing networks; atmospheric composition observing networks; radiation observing networks; marine meteorological networks and arrays; hydrological observing networks; and the various atmospheric, hydrological, oceanographic, and terrestrial observing systems contributing to the Global Climate Observing System (GCOS). Improved monitoring through the integration of surface- and space-based observations is essential for understanding weather and climate as well as the components of the global weather and climate systems, which include atmosphere, hydrology, ocean, land surface,

and cryosphere. WMO is establishing regional WIGOS centers to support and assist WMO members and regions in their national and regional WIGOS implementation efforts.

The Global Telecommunication System (GTS). This is a dedicated network of surface and satellite-based telecommunication links and centers operated around the clock all year round. It interconnects all NMHSs for collection and distribution of all meteorological and related data, forecasts, and alerts, including tsunami and seismic information and warnings. More than 50,000 weather reports, several thousand charts, and various digital data and products are disseminated through the GTS daily.

The WMO Information System (WIS). In response to the growth of the computer industry and the rise of the Internet, which have enabled the use of meteorological information online in a variety of nonoperational and interdisciplinary activities, WIS was conceived to fill existing gaps and support the intercommunity exchange of data and information beyond the GTS. WIS encompasses three types of centers. For regional and global connectivity, **Global Information System Centres (GISCs)** collect and distribute the information meant for routine global dissemination; they also serve as collection and distribution centers in their areas of responsibility and provide entry points, through unified portals and comprehensive metadata catalogs, for any request for data held within the WIS. **The Data Collection or Production Centres (DCPCs)** are connected to the GISCs and are responsible for collecting or generating sets of data, forecast products, and processed or value-added information and for providing archiving services. National Centres collect and distribute data on a national basis, and coordinate or authorize the use of the WIS by national users, normally under a policy established by the respective permanent representative with WMO, who is typically the director-general of the NMHS.

The Global Data-processing and Forecasting System (GDPFS). This is the coordinated global system of centers operating under established arrangements to analyze, forecast, process, store, and retrieve meteorological, climatological, hydrological, oceanographic, and environmental-related information. It encompasses a global network of **World Meteorological Centres (WMCs)**, **Regional Specialized Meteorological Centres (RSMCs)**, and **National Meteorological Centres (NMCs)** to meet the weather, climate and water forecasting needs of WMO members. This system processes observations through data assimilation and produces forecast information on global, regional, national, and local scales. Its generalized and specialized products can be used by NMHSs to develop routine weather, climate, and water forecasts and warnings for the protection of life and property during high-impact weather, climate, and water events. A WMC issues meteorological analyses and prognoses, including probabilistic information and long-range forecasts on a global scale. An RSMC specializes in a specific activity of the GDPFS and provides tailor-made information and products to serve users in a particular area of activity. The GDPFS also includes the **Global Producing Centres for Long-range Forecasts (GPCs-LRF)** and the **Regional Climate Centres (RCCs)**. The NMC is responsible for carrying out required functions to meet the national and international requirements and commitments of the WMO member under the GDPFS.

Within the framework of WMO projects and initiatives such as the **Severe Weather Forecasting Demonstration Project (SWFDP)** and the **Flash Flood Guidance System (FFGS)** (see Chapter 4, regional centers are either established (in regions not covered by the GDPFS centers) or strengthened (where existing RSMCs are not fully functional).

In addition, **WMO supports a network of Regional Training Centres (RTCs)**, which are national education and training institutions, or groups of institutions, recognized by WMO as (a) providing education and technical training in management and operations for WMO members in the region, particularly staff of NMHSs; (b) providing advice and assistance on education and training to other WMO members; and (c) promoting education and training opportunities in weather, water, and climate for WMO members.

BOX 3: MAJOR COMPONENTS OF THE WMO INTEGRATED GLOBAL OBSERVING SYSTEM (WIGOS)

The Global Observing System (GOS)^a provides observations on the state of the atmosphere and ocean surface from land-based and space-based instruments. These data are used for the preparation of weather analyses, forecasts, advisories, and warnings, and for the climate monitoring and environmental activities carried out through other WMO programs and by other international organizations. GOS is operated by NMHSs and by national or international satellite agencies and involves several consortia dealing with specific observing systems or specific geographic regions.

WMO Hydrological Observing System (WHOS)^b is a portal to the online holdings of National Hydrological Services around the world that publish their historical observations and/or real-time data without restrictions or cost, according to WMO Resolution 25 (Cg-XIII). It represents the hydrological component of WIGOS.

World Hydrological Cycle Observing System (WHYCOS)^c is a framework program dedicated to improving basic observation activities, strengthening international cooperation, and promoting the free exchange of data in the field of hydrology. It exists to develop networks (HYCOS) on basin, subregional, or regional scales within an overarching framework. It was created in response to the scarcity, or even absence, of accurate data and information on freshwater resources in many parts of the world. The program addresses developing countries in particular, where accessing existing data is difficult because observing networks have deteriorated or because data management capabilities are insufficient. The ultimate objective of the WHYCOS program is to promote and facilitate the collection, analysis, exchange, dissemination, and use of water-related information by employing the most appropriate technologies that meet the needs of the countries involved and are economically sustainable and supported over the longer term.

a. See WMO, "Global Observing System," <https://public.wmo.int/en/programmes/global-observing-system>.

b. See WMO, "WHOS: World Hydrological Observing System," <http://www.wmo.int/pages/prog/hwrp/chy/whos/index.php>.

c. See the WHYCOS portal at <http://www.whycos.org/whycos/>.

ROLES AND RESPONSIBILITIES OF GLOBAL AND REGIONAL SERVICE PROVIDERS IN SOUTHEAST ASIA

Within the framework of the expanded WMO's World Weather Watch, a number of global and regional centers coordinate regional activities, act as a central or regional hub, and/or provide products and services for SEA. Main users are staff of NMHSs. The list of such centers below includes descriptions of their roles, responsibilities, and activities, by thematic area. Based on these descriptions, Table 2 summarizes the activities of global and regional centers that can benefit the NMHSs in SEA, highlighting the functions that have a potential to strengthen the NMHSs' capacities within the context of a regional hydromet dimension.



Observing systems

The Regional WIGOS Centre Tokyo, hosted by the **Japan Meteorological Agency (JMA)**, acts as a regional hub for the coordination of the SEA WIGOS projects, provides guidance and oversight, and supports the WIGOS implementation and routine/operational activities at the regional and national levels. It is designated to assist NMHSs in enhancing the availability and quality management of their surface, climate, upper-air, and hydrological observations. Mandatory functions include (a) regional WIGOS metadata management, which consists of working with national data providers (primarily the NMHSs) to facilitate collecting, updating, and providing quality control of observational metadata; and (b) regional WIGOS performance monitoring and incident management (under the WIGOS Data Quality Monitoring System) and follow-up with data providers in case of data availability or data quality issues. Other functions include (a) assistance with the coordination of regional/subregional and national WIGOS projects; (b) assistance with regional and national observing network management; and (c) support for regional capacity development activities.



Information systems

The **Global Information System Centres (GISCs)** in Tokyo and Beijing, hosted by JMA and **China Meteorological Administration (CMA)** respectively, act as regional coordinators for the real-time operations of the WMO Information System network and provide entry points to WIS through (a) the GISC Cache Services function, which relates to the exchange of data and products (including weather bulletins and warnings) intended for global distribution; and (b) the Discovery, Access and Retrieval (DAR) Catalog, consisting of metadata to be collected from the entire WIS. Connected to the GISC Tokyo and hosted by the **Thai Meteorological Department (TMD)**, the **Data Collection or Production Centre (DCPC)** Bangkok is responsible for coordinating the area meteorological telecommunication network—i.e., it serves as a **Regional Telecommunication Hub (RTH)** within the framework of the WMO GTS. Under defined transmission rates and protocols, DCPC Bangkok collects and disseminates meteorological data and products within its geographical area of responsibility (which includes Cambodia, Lao PDR, and Vietnam) and exchanges such data and products with other RTHs and GISCs for their global distribution.



Data-processing and forecasting systems and services

WMO has eight designated **World Meteorological Centres**: Beijing (hosted by CMA), Exeter (hosted by the UK Met Office), Melbourne (hosted by the Australian Bureau of Meteorology), Montreal (hosted by the Canadian Meteorological Centre of Environment Canada), Moscow (hosted by Roshydromet), Tokyo (hosted by JMA), Washington (hosted by the U.S. National Weather Service), and the European Centre for Medium-range Weather Forecasts. Through the WIS, these centers provide a limited range of forecast products (in digital form) based on their global models for both medium-range and seasonal ensemble forecasts, following the protocols described in the WMO Manual on the Global Data-processing and Forecasting System (WMO 2017b). They also provide relevant documentation and verification to demonstrate the quality of their forecasts. In addition, the **European Centre for Medium-range Weather Forecasts (ECMWF)** also provides WMO members with access to its entire catalog of ECMWF forecast data and products (in digital and graphic forms) with a noncommercial license. ECMWF also operates the Global Flood Awareness System (GloFAS), which provides access to large-scale flood forecasts, and the Copernicus Climate Change Services, which provide access to information for monitoring and predicting climate change.

Within the framework of the Severe Weather Forecasting Demonstration Project for Southeast Asia, the **WMCs in Beijing and Tokyo**, the ECMWF, and the **National Meteorological Centre (NMC)** in Seoul (hosted by the Korea Meteorological Administration [KMA]) make available additional global numerical forecast products (in graphical format) required for severe weather forecasting (mostly under password-protected websites). They also provide related training support, as described in the SWFDP–Southeast Asia Implementation Plan. **WMCs in Beijing and Tokyo** and the **NMC in Seoul** also provide satellite data and product imageries through these websites. These websites and related products are consolidated by the **Regional Forecast Support Centre (RFSC) Hanoi** (hosted by the NHMS of Vietnam), along with regional numerical forecast products (also in graphical format) prepared by the NHMS and available in a password-protected SWFDP web portal. Additional developments include establishing synergies between SWFDP and the **Flash Flood Guidance System (FFGS)** in SEA and having RFSC Hanoi also serve as the Regional FFGS Centre (building upon and expanding from the Mekong FFGS).

The **Regional Specialized Meteorological Centre Tokyo**, also called the **Typhoon Center**, is hosted by JMA and monitors typhoons—from their early stages of formation and throughout their lifetime. It provides forecasts on the behavior of the typhoons, including their movement and changes in intensity, and on associated phenomena, including storm surges and flash floods; these are disseminated to National Meteorological Centres in the agreed formats for operational processing, as described in the Typhoon Committee Operational Manual (**TC 2018; see Chapter 4**). The RSMC Tokyo–Typhoon Center also supports training, including attachments.

The WMO Global Data-processing and Forecasting System infrastructure has been extended to strengthen NMHS capabilities in operationally generating and delivering up-to-date climate information and prediction products for climate services, especially in support of climate adaptation and risk management. Accordingly, 13 WMO-designated **Global Producing Centres for Long-range Forecasts (GPC-LRF)** (Beijing, Centro de Previsão do Tempo e Estudos Climáticos, Exeter, Melbourne, Montreal, Moscow, Offenbach, Pretoria, Seoul, Tokyo, Toulouse, Washington, and the ECMWF)

provide a range of global long-range forecasting products. A **Lead Centre for Long-range Forecast Multi-model Ensemble (LC-LRFMME)**, jointly hosted by the KMA and **National Oceanic and Atmospheric Administration/ National Centers for Environmental Prediction (NOAA/NCEP)**, consolidates all information from the GPC-LRF and prepares and verifies multi-model ensemble products, which are available at the password-protected LC-LRFMME website. In addition, WMO-designated Regional Climate Centres are being implemented to generate and deliver more regionally focused high-resolution data and products as well as to provide training and capacity building. In particular, for the SEA region, the Southeast Asia RCC-Network has been established to create regional products that support climate services at regional and national levels; these products include climate monitoring products (led by the **Philippines Atmospheric Geophysical and Astronomical Services Administration**) and long-range forecasts (led by the **Meteorological Service of Singapore [MSS]**). In the Southeast Asia RCC-Network, the operational data services are supported by the Indonesian Agency for Meteorology, Climatology and Geophysics, and training support is shared among the three organizations.

Some other centers are not officially part of the WMO Global Data-processing and Forecasting System infrastructure, but they provide relevant information and services to SEA. These include the following:

- (1) The ASEAN Specialized Meteorological Center. Hosted in Singapore, this center monitors and assesses land fires, forest fires, and the occurrence of transboundary smoke haze for the ASEAN region. It also conducts seasonal and climate predictions for the ASEAN region.
- (2) The Asia-Pacific Economic Cooperation Climate Center. Hosted by the Republic of Korea, this center produces climate prediction information, leads the development of interdisciplinary research and application of climate prediction techniques at the climate-environment-society nexus, and guides developing countries from the Asia-Pacific Economic Cooperation region in building their capacity to produce climate prediction information.
- (3) The International Research Institute for Climate and Society (IRI). Housed at Columbia University in the United States, IRI focuses on strategic and applied research, education, and other capacity building. It also provides climate prediction and information products with an emphasis on practical and verifiable utility and partnership.



Public weather services

The **WMO World Weather Information Service (WWIS)** is a centralized source on the Internet that allows media to efficiently and effectively access official weather information issued by NMHSs. The WWIS website is developed and maintained by the Hong Kong Observatory (HKO). This global website presents official weather observations, weather forecasts, and climatological information for selected cities, as supplied by NMHSs worldwide. The NMHSs make official weather observations in their respective countries. Links to their official weather service websites and tourism boards/organizations are also provided whenever available. Weather icons are shown alongside written forecasts to facilitate interpretation.



Training

There are 26 WMO Regional Training Centres, which provide a diverse portfolio of education and training opportunities through in-residence classes, distance-learning, and blended learning. In SEA, there are two RTCs:

- (1) The RTC Korea, which provides short-term training courses in specialized subjects in meteorology, climatology, and hydrology.
- (2) The RTC China, which has two branches: (a) the Nanjing University of Information, Science and Technology (NUIST) Nanjing and the China Meteorological Administration Training Center Beijing. NUIST offers BSc, MSc, and PhD degrees as well as post-doctoral studies in atmospheric sciences, applied meteorology, hydrometeorology, ecology, environmental sciences, and management. It also provides short courses (three months or less) on radar meteorology, agricultural meteorology, tropical cyclone, meteorological forecasts, meteorological disaster warning, prevention and mitigation, meteorological instrument use and maintenance, meteorological management, international cooperation on climate change, and climate information service. The China Meteorological Administration Training Center Beijing offers meteorological training at graduate and technician levels. Courses address meteorological theory and technology, including meteorological observing techniques, weather forecasting, satellite and radar meteorology, Numerical Weather Prediction, and graphic software applications in meteorology.

TABLE 2: SUMMARY OF ACTIVITIES BY GLOBAL AND REGIONAL CENTERS THAT BENEFIT NMHSS IN SEA

Regional center	Activities Within The Context Of The Regional Initiative	Activities That Can Be Strengthened By Nmhss Within The Context Of The Regional Initiative
Regional WIGOS Centre	Metadata management; performance monitoring and incident management; regional and national observing network management; capacity building	Improved data quality and availability; capacity building
WIS Centres	Observational and numerical model data sharing	Improved monitoring and forecasting through data sharing
GDPFS Centres	High-quality NWP/EPS forecast data and products; climate predictions; flood forecasts; monitoring and forecasting of typhoons and associated phenomena; capacity building	Improved forecasting; impact-based forecasting and risk-based warnings; capacity building
WWIS	Centralized source of hydromet information worldwide	NMHS visibility; authoritative source of hydromet information
RTCs	Education and training	Capacity building

Notes: EPS = Ensemble Prediction System.

KEY TAKEAWAYS

There is an international system in place for monitoring and forecasting that cascades across global, regional, and national hydrometeorological service providers. Many initiatives focus on the different stages of the process—data collection, forecasting, dissemination of impact-based forecasts and early warnings, delivery of weather and climate services, etc.—that can be utilized by subregional and national hydromet service providers, including in the SEA region.



Photo: Getty Images. Location: Thailand.

INTERNATIONAL INITIATIVES ON REGIONAL COOPERATION AND REGIONAL FRAMEWORKS IN SOUTHEAST ASIA

This chapter focuses on the trends in SEA regional initiatives and challenges in scaling them up. It also discusses regional functions that have a potential to strengthen national capacities, and the extent to which Cambodia, Lao PDR, and Vietnam are utilizing existing projects and initiatives to close national capacity gaps.

A REGIONAL DIMENSION

Weather, climate, and water know no national borders. Transboundary issues related to political history, socioeconomic conditions, geography, laws, and institutions may exist in the region, but there is coordination and cooperation among countries on hydrometeorological services. Typhoon Ketsana, which hit the Philippines, Vietnam, Lao PDR, and Cambodia in 2009, and the powerful 2015/2016 El Niño, which caused widespread drought in the Indochina Peninsula ([see Technical Insight 1](#)), have shown that regional hydromet collaboration can strengthen national early warning systems. Some of the major regional initiatives and cooperative international efforts in the region, including regional policies, strategic and planning documents, and institutional arrangements and partnerships, are described below.

INTERNATIONAL INITIATIVES ON REGIONAL COOPERATION

WMO Regional Association II (RA II, Asia)

The 16th session of the WMO Regional Association II (RA II, Asia) (WMO 2017c) adopted the RA II Operating Plan (OP) for 2016–2019. This Operating Plan provides the direction and defines priorities for the region, in an effort to contribute to the implementation of a regional hydromet strategy. It aims to pull together ongoing and future activities to contribute to and support weather-, climate- and water-related disciplines as well as their applications. It also provides guidance for RA II members (33 member states and two member territories), including Cambodia, Lao PDR, and Vietnam, in formulating their national strategic plans and in developing, carrying out, and enhancing their national programs in meteorology, hydrology, and related disciplines; the goal is to help countries respond to the demand for a widening range of services to meet their sustainable development goals. The OP seeks to strengthen RA II members' capabilities to deepen their contribution and regional role in climate science, aeronautical meteorology, and multi-hazard early warning of transboundary hazards. Meteorological and hydrological information must be more precise and accurate to tackle these three main challenges effectively. This is why investing heavily in cutting-edge climate research and building up regional expertise to improve the understanding of the dynamic tropical weather patterns are critical to greatly enhance the precision of weather and climate predictions over the region.

A key beneficiary of these efforts is the aviation sector, one of the most weather-sensitive of all economic sectors. The sector is undergoing a transformation driven by rapid growth. Global air traffic is doubling every 15 years (ICAO 2014) with the strongest growth centered on the Asia region. There is an increasing need within the sector for more effective and efficient operations that also preserve safety. This in turn drives demand for cutting-edge aeronautical meteorological services, which need to be seamless and coordinated at the regional level. Natural and environmental hazards and climate change have been identified as priority areas for RA II; they are especially challenging factors for interoperable and harmonized data management systems. The WMO Regional Office continues to work with its members to foster greater cooperation in end-to-end multi-hazard early warning systems (from observations to the

delivery of warning/alert services at various time scales) for the region. Such efforts are complemented by capacity-building programs. All RA II activities and projects are coordinated by various working and expert groups aligned with the priorities identified for the region (aeronautical meteorology, climate services, and disaster risk reduction); at the same time, keeps RA II monitoring and expanding the basic systems, including the observing and information systems for weather, climate, and hydrology. The Asian Consortium for NWP Forecast has been supporting two WMO/RA II pilot projects, one on city-specific NWP forecasts and one that seeks to support NMHSs in NWP by providing access to model source codes and tools. For many years, RA II has also been implementing the Pilot Project to Develop Support for NMHSs in Satellite Data, Products and Training, which addresses RA II region-oriented requirements for satellite data access and exchange.

Economic and Social Commission for Asia and the Pacific (ESCAP)

The United Nations Economic and Social Commission for Asia and the Pacific is the regional development arm of the United Nations for the Asia-Pacific region, with 53 member states and nine associate members. ESCAP works to overcome some of the region's greatest challenges by developing policy dialogues and recommendations and by providing members with results-oriented projects, technical assistance, and capacity building in various areas, including (among others) (a) environment and development; (b) information and communications technology and disaster risk reduction; and (c) subregional activities for development. Through regional cooperation, ESCAP brings countries together to address issues that (a) are faced by all or a group of countries in the region, to allow countries to learn from each other; (b) benefit from regional or multicountry involvement; (c) are transboundary in nature, or would benefit from collaborative intercountry approaches; or (d) are sensitive or emerging and hence require further advocacy and negotiation.

In 2015, ESCAP adopted a resolution to strengthen regional mechanisms, cooperation, and collective action for implementing the Sendai Framework for Disaster Risk Reduction 2015–2030, which will also contribute to achieving some objectives of the 2030 Agenda for Sustainable Development and the Sustainable Development Goals. With the support of the ESCAP Secretariat based in Bangkok, a regional road map for implementing the 2030 Agenda (ESCAP 2017) was also developed. This road map identifies priority areas, describes their current status, and discusses opportunities for and means of implementing regional cooperation in thematic areas. Examples include the following:

- (1) Disaster risk reduction and resilience. Work in this area promotes effective regional and subregional efforts to strengthen monitoring and multi-hazard early warning systems of common and transboundary disasters, through (for example) sharing data and maximizing the efficiency of existing regional cooperation mechanisms, including the WMO/ESCAP Typhoon Committee and the Regional Cooperative Drought Mechanism for Drought Monitoring and Early Warning (see details in sections below).
- (2) Climate change. Work in this area promotes capacity building for climate action through policy dialogue and the sharing of experiences and information using existing institutions, forums, and platforms.

In this context, ESCAP has been supporting the Monsoon Forum in Myanmar, Lao PDR, and Cambodia, with the goal of helping stakeholders in high-risk, low-capacity countries better understand climate outlooks (i.e., seasonal forecasts). Through South-South cooperation, ESCAP has been tapping into member state NHMSs' experience and knowledge of short- and medium-range forecasts and early warning communication systems. In partnership with the WMO, it will also continue to support the integration of innovative tools and techniques for forecasting and monitoring tropical cyclones through the Typhoon Committee (see section below). A tool kit for flood forecasting and early warning in transboundary river basins (ESCAP and RIMES 2016) was prepared in collaboration with the Regional Integrated Multi-hazard Early Warning System for Africa and Asia (RIMES) and in coordination with the International Centre for Water Hazard and Risk Management (ICHARM) of Japan, the European Centre for Medium-range Weather Forecasts (ECMWF), and the Mekong River Commission. The product supports the capacity building process in the region and introduces recent advances in tool- and technique-based innovative space applications.

ESCAP/WMO Typhoon Committee

The ESCAP/WMO Typhoon Committee is an intergovernmental body established in 1968 under the auspices of the United Nations Economic Commission for Asia and the Far East (UNECAFE) and the WMO. Its purpose is to promote and coordinate the planning and implementation of measures required for minimizing the loss of life and material damage caused by typhoons in the SEA region. The Typhoon Committee is currently composed of 14 members: Cambodia;

China; Democratic People's Republic of Korea; Hong Kong SAR, China; Japan; Lao PDR; Macao SAR, China; Malaysia; the Philippines; Republic of Korea; Singapore; Thailand; Vietnam; and the United States. The Typhoon Committee Secretariat, its executive arm, is mandated to assist the committee in its day-to-day work. Its main function is to advise members on the technical and administrative coordination of plans for implementing improved meteorological, hydrological, disaster prevention, preparedness, and other facilities to mitigate typhoon damage. Specifically, it offers advice and assistance to Typhoon Committee members in (a) the international exchange of meteorological and hydrological data and distribution of typhoon forecasts and warnings; (b) the operation and improvement of meteorological and hydrological observing networks, telecommunication systems, and facilities as required for typhoon, flood, and storm surge forecasting and warning; (c) review of progress achieved and promotion of research studies relating to typhoons, storm surge, and flood forecasting; and (d) efforts to seek assistance from external sources.

The Typhoon Committee's Strategic Plan 2017–2021 (TC 2017) identified two regional targets, five key results areas (KRAs), and various priorities to save lives, mitigate damage, and decrease social and economic effects from typhoon-related events, through regional cooperation and collaboration. The impact of climate change is considered to influence all the KRAs, targets, and priorities and is a cross-cutting theme for this strategic plan. The two targets are to (a) substantially reduce total mortality caused by typhoon-related disasters in member states in the decade 2020–2030 compared to the period 2005–2015; and (2) reduce direct economic loss caused by typhoon-related disasters relative to the total gross domestic product of members by 2030. KRAs include the following: (a) enhance capacity to monitor mortality and direct economic loss caused by typhoon-related disasters; (b) enhance capacity to generate and provide accurate, timely, and understandable information using multi-hazard impact-based forecasts and risk-based warnings; (c) improve typhoon-related flood control measures and integrated water resource management; (d) strengthen typhoon-related disaster risk reduction activities in various sectors, including increased community-based resiliency with better response, communication, and information-sharing capability; and (e) enhance Typhoon Committee's regional and international collaboration mechanisms.

A major Typhoon Committee milestone and output is the Typhoon Committee Operational Manual (TC 2018), which specifies the activities of the Regional Specialized Meteorological Centre (RSMC) Tokyo–Typhoon Center (roles and responsibilities are summarized in Chapter 3) and states regional cooperation procedures and agreements among Typhoon Committee members. It also describes national practices and procedures. Training is supported by RSMC Tokyo and the Regional Training Centre in Nanjing, China. The Typhoon Committee Operational Manual is annually revised and refined through experience gained in its use.

The Typhoon Committee and the Panel on Tropical Cyclones (PTC) jointly implemented the Synergized Standard Operating Procedures (SSOPs) for the Coastal Multi-Hazards Early Warning System project, with funding from the ESCAP Multi-Donor Trust Fund for Tsunami, Disaster and Climate Preparedness in Indian Ocean and Southeast Asian Countries. As an output of this project, a manual (TC 2015) was developed to promote community resilience to coastal multi-hazards and to improve the policies and institutional arrangements at national, subnational, and community levels. This manual was designed to provide flexible approaches, operational guidance, and recommendations based upon best practices and available resources in order to prepare SSOPs for coastal multi-hazards early warning systems. It includes key concepts, basic principles, and basic standards for SSOPs. It also provides useful information, examples, and references on the role of NMHSs in preparing and implementing effective SSOPs.

Regional Integrated Multi-Hazard Early Warning System (RIMES)

RIMES is a regional intergovernment organization with the mandate to build capacity in end-to-end early warning systems among member and collaborating states. RIMES was established in 2009 and comprises the NMHSs of 32 member and collaborating states. It operates from its regional early warning center located at the campus of the Asian Institute of Technology in Pathumthani, Thailand.

During the second RIMES ministerial conference, held in July 2015, ministers (and representatives of ministers) of RIMES member and collaborating states adopted the RIMES Master Plan 2016–2020 (RIMES 2015). The Master Plan details country-specific capacity-building priorities and projects for user-centered multi-hazard risk-based early warning; it also suggests how countries can maximize opportunities associated with climate change. In keeping with the RIMES Master Plan for 2016–2020, RIMES provides technical assistance to member and collaborating states in

(a) hazard monitoring, detection, analysis, prediction, and forecasting; (b) risk assessment; (c) potential impact analysis; (d) generation of tailored risk information at different time scales; (e) risk communication; and (f) application of tailored risk information in decision making.

ASEAN Subcommittee on Meteorology and Geophysics

The Association of Southeast Asian Nations (ASEAN) was founded in 1967 with the goal of accelerating economic growth, social progress, and cultural development and promoting peace and stability in the region. It has been working since then to deepen regional cooperation in economic issues and free trade, environmental concerns, and human rights. As a result of these efforts, in December 2008 the ASEAN Charter came into force, giving the organization a new legal framework and a number of new organs. ASEAN's main institution is the secretariat (located in Jakarta, Indonesia), which is responsible for coordinating and implementing ASEAN projects and activities.

Following the adoption of the ASEAN Plan of Action on Science, Technology and Innovation (APASTI) 2016–2025 (ASEAN 2015a) at the 16th ASEAN Ministerial Meeting on Science and Technology (AMMST-16) in 2015, an implementation plan (ASEAN 2015b) was developed that identified priorities, targets/deliverables, specific actions, timelines, and indicators for the various subcommittees, including the Subcommittee on Meteorology and Geophysics (SCMG).

The SCMG seeks (a) to enhance the capabilities of national services in meteorology and geophysics for protection of lives and properties in the ASEAN region and for application sectors (such as aviation, agriculture, maritime, and tourism); (b) to improve forecasting services and early warning systems related to the mitigation of natural disasters caused by meteorological and geophysical phenomena; and (c) to establish or enhance appropriate centers to support the requirements of ASEAN member countries in the fields of meteorology, satellite meteorology, climatology, seismology, volcanology, and meteorological and geophysical environmental issues. In support of these requirements, the subcommittee coordinates a network of meteorological, seismological, and volcanological systems, including standardization of meteorological and seismological measurements. In addition, it undertakes research on areas of meteorology and geophysics, including climate prediction, monsoon meteorology, transboundary marine and air pollution, paleoseismology and earthquake prediction, and hazard zonation and assessments. Training and exchange programs support these activities.

Mekong River Commission

The Mekong, one of the world's greatest rivers and the largest river basin in SEA, crosses six countries: Cambodia, China, Lao PDR, Myanmar, Thailand, and Vietnam. It is an exceptionally complex system with high intra-annual and interannual flow variability caused by the southwest monsoon. It creates both great risks and great opportunities for the region. The Mekong River Commission is a regional initiative established in 1995 by the signing of the Mekong Agreement (MRC 1995). It is the only intergovernmental organization that works directly with the governments of Cambodia, Lao PDR, Thailand, and Vietnam to jointly manage the shared water resources and the sustainable development of the Mekong River. The MRC is a platform for regional cooperation in which member states share the benefits of common water resources despite different national interests. Under the MRC Strategic Plan 2016–2020 (MRC 2016), it also acts as a regional knowledge hub on water resources management and helps to ensure that decision making is based on scientific evidence. MRC activities cut across all sectors, including fisheries sustainability, identification of opportunities for agriculture, freedom of navigation, sustainable hydropower, flood management, preservation and conservation of important ecosystems. It develops rules, regulations, and procedures, including for data and information exchange, and related technical guidelines for their implementation (MRC 2005). MekongInfo, hosted by MRC, is an interactive web portal for sharing information and experiences in natural resources management in the Mekong River basin, including flood reports from the MRC's Flood Management and Mitigation Programme (see more details in the section below).

The Mekong Adaptation Strategy and Action Plan (MASAP) (MRC 2017) for the Lower Mekong basin, developed by MRC, identifies strategic priorities and actions/projects for MRC that support climate change adaptation and strengthen basin-wide resilience. Priorities for MRC include assessment of climate change impact on hydrology and water resources along with flood forecasting of extreme transboundary events. MRC therefore helps member states develop their national strategies so they can better face the future effects of more extreme floods, prolonged droughts, and sea-level rise associated with climate change.

REGIONAL INITIATIVES IN SOUTHEAST ASIA, FOCUSING ON CAMBODIA, LAO PDR, AND VIETNAM

Initiatives related to weather and climate

Since its inception in 2010, the WMO Severe Weather Forecasting Demonstration Project (SWFDP) in SEA has been strengthening the capacity of NMHSs in Cambodia, Lao PDR, Philippines, Thailand, and Vietnam to deliver improved forecasts and warnings of severe weather and hence to save lives, safeguard livelihoods, and protect property and infrastructure. The project has improved the lead time and reliability for alerts and warnings about high-impact events such as heavy precipitation and strong winds. It has strengthened the engagement of NMHSs with users, including media, disaster management and civil protection agencies, and local communities, for improved disaster risk reduction efforts and better decision making. The project is also establishing synergies with the Southeast Asia Flash Flood Guidance System (FFGS) (see below).

Countries participating in the project are able to benefit from advances in the science of weather forecasting, especially the dramatic development in NWP, including Ensemble Prediction Systems (EPS) that guide weather forecasters in advance of potential hazardous weather conditions for issuance of alerts and warnings. SWFDP uses a “cascading forecasting process” (global to regional to national), following the regional implementation plan (WMO 2015), as follows:

- **Global centers** (CMA, ECMWF, JMA, and KMA) provide available satellite imagery, NWP, and EPS products, including in the form of probabilities for a specific time frame.
- **Regional centers** interpret information received from global and other regional centers, prepare daily guidance products for distribution to National Meteorological Centres, and maintain the regional center web portal, where all products are available in graphical form. In SEA, the Regional Forecast Support Centre in Hanoi (see Chapter 3) takes this role, with the support of RSMC Tokyo and RSMC New Delhi, which forecast tropical cyclones forming respectively in the western North Pacific Ocean and South China Sea, and in the Bay of Bengal and the Arabian Sea; and the Hong Kong Observatory, which offers technical training support.
- **National Meteorological Centres** (NMHSs of Cambodia, Lao PDR, Philippines, Thailand, and Vietnam) issue alerts, advisories, and severe weather warnings to the public via the media and other dissemination channels; they also liaise with disaster management officials and certain economic sectors and contribute feedback and project evaluation.

Climate Risk and Early Warning Systems (CREWS) Building Resilience to High Impact Weather through Strengthening Multi-hazard EWS in SEA was launched in 2017 and runs until March 2021. With new funds provided by the Government of Canada to support the CREWS initiative, WMO and its partners are stepping up efforts to support disaster risk reduction in SEA. The project would strengthen weather-, climate-, and water-related impact-based decision support services and so help protect lives and property. The beneficiary countries in SEA are Cambodia, Lao PDR, the Philippines, Thailand, and Vietnam. The project will meet goals by sponsoring WMO flagship activities such as the SWFDP and the Southeast Asia Flash Flood Guidance System (see below) in support of wider WMO strategic objectives on disaster risk reduction and service delivery, and by ensuring that these activities are streamlined. These activities are expected to empower participating NMHSs to maintain effective multi-hazard early warning systems that are more accurate, give more advance notice, and are more responsive to the needs of users, including disaster management and civil protection agencies, the media, and the general public. Specifically, the project aims to (a) review capabilities, gaps, and needs in relation to risk analysis and forecasting tools for severe weather, flash/riverine floods, and droughts, including a stocktaking of actors involved and of relevant ongoing projects; (b) strengthen governance arrangements and coordination/communication mechanisms within and among the participating NMHSs and stakeholders in all sectors; (c) upgrade the forecasting capabilities of the Regional Forecast Support Centre in Hanoi to access and use global and regional data, products, and tools; and (d) provide regional and in-country technical assistance to the NMHSs to develop and deliver impact-based warnings, products, and services.

ASEAN Climate Outlook Forums (ASEANCOFs) produce consensus-based, user-relevant climate outlook products (generally probabilistic predictions of seasonal mean rainfall, surface air temperature, and other weather parameters, as well as the likely evolution of key drivers of seasonal climate variability relevant to the region, such as ENSO) in real time in order to reduce climate-related risks and support sustainable development for the coming season in sectors of critical socioeconomic significance for the ASEAN region. These forums bring together national, regional, and international climate experts, on an operational basis, to produce regional climate outlooks based on climate predictions from all participants.

By bringing together countries with common climatological characteristics, the forums ensure consistency in the access to, and interpretation of, climate information. Through interaction with users in the key economic sectors of each region and with extension agencies and policy makers, the forums assess how the outlooks will likely affect the most pertinent socioeconomic sectors in the given region and explore how these outlooks could be used.

These ASEANCOFs are usually followed by national forums, where the information is downscaled and tailored to national climate outlooks and risk information, including warnings to decision makers and the public. The forums have facilitated regional cooperation and networking, and have demonstrated the benefits of sharing climate information and experience. Close interaction between both the providers and the users of climate information and predictions has enhanced feedback from the users to climate scientists, and has catalyzed the development of many user-specific products. Typically, the users who will benefit from the forum contribute to its organization and to the breadth of the sessions, thus ensuring the applicability to user needs. User sector participants include (a) agriculture and food security; (b) water resources; (c) energy production and distribution; (d) public health; (e) disaster risk reduction and response; and (f) outreach and communication. Other sectors such as tourism, transportation, urban planning, etc. are increasingly involved.

The Regional Cooperative Drought Mechanism for Drought Monitoring and Early Warning (ESCAP 2014) was established by ESCAP in collaboration with other UN agencies and regional entities to enhance the capacity of its member states to use space-based data and geographic information system applications for effective drought monitoring and early warning. It has four main components:

- (1) **Regional service nodes.** Satellite imagery and services as well as capacity development are promptly and freely provided to pilot countries by national remote sensing centers in other countries in the region—at present, China and India.
- (2) **Thematic and scientific communities.** Diverse groups are networked together under common thematic areas to advise on drought monitoring and early warning, preparedness, and appropriate action.
- (3) **Pilot countries.** Drought-prone countries are selected upon request to participate as beneficiaries of cutting-edge science and technology to better prepare for drought. Current pilot countries are Cambodia, Mongolia, Myanmar, Nepal, and Sri Lanka.
- (4) **Government authorities and the agricultural community.** Direct beneficiaries on the ground can proactively reduce the impacts of drought based on sound knowledge and timely warning information from the government.

The Southeast Asia Radar Network/Composite project consists of (a) capacity building on radar observation and its utilization, and (b) development of a regional radar network/composite in the region. This project has been discussed for many years within the framework of the ASEAN Subcommittee on Meteorology and Geophysics and the Typhoon Committee, and it has recently been recognized as an activity under the WMO/RA II WIGOS project for observing-system integration in support of disaster risk reduction. Although the project is important, there are technical challenges associated with its implementation, and efforts need to be made to assist NMHSs in SEA to first be able to manipulate and use the relevant radar data. This step requires the support of the WMO Regional WIGOS Centre Tokyo before national radar data are integrated into a regional network.

Initiatives related to hydrology

The **MRC's Regional Flood Management and Mitigation Programme** supports governmental agencies in flood management by monitoring river levels throughout the flood season and generating early warning forecasts at different time scales based on the upstream data. The cooperation for data sharing at the MRC Regional Flood Management and Mitigation Centre began in the 1950s; since then the data are collected at the center, including the upstream data from China. The staff from the MRC member states are seconded to the regional center to participate in flood forecasting and early warning services, so that they are exposed to the mitigation measures countries can take to reduce flood impacts. Training workshops and study visits are organized to support information sharing and first-hand learning experiences. These exchanges allow decision makers to share the lessons they have learned and support the development of region-specific solutions. During the June-November flood season, the Regional Flood Management and Mitigation Centre issues daily flood forecasts and warnings up to 10 days in advance, based on the Flood Early Warning System (FEWS). Data from hydromet stations are used to predict water levels at 23 forecast points on the Mekong River system. The MRC shares

these daily bulletins—by fax, by email, and on the MRC home page and its dedicated flood forecasting website—with national Mekong committees, nongovernmental organizations, the media, and the public. These bulletins supplement the national operational flood forecasting information and are also conveyed to the European Flood Awareness System (EFAS) partner network twice a day.

The **Mekong Hydrological Cycle Observing System (Mekong-HYCOS)** resulted from a Memorandum of Understanding on cooperation between the MRC and the WMO signed in 2001. It recognized the importance of flood management and mitigation in the Mekong River basin and defined the joint development of the Mekong-HYCOS project as a regional component of WMO's WHYCOS program. The objective of Mekong-HYCOS (funded by the Agence Française de Développement) is to establish and operate a real-time flood information system in the Mekong basin, with Cambodia, Lao PDR, Thailand, and Vietnam as participating countries. The telemetric hydrometeorological monitoring network established within the project's framework consists of 49 stations installed in the four riparian countries and China from 2008 to 2010. Thirty-two new stations were installed within the Mekong-HYCOS project, and 17 former Hydrological Network Improvement Project stations were upgraded to the HYCOS standard. The upgraded stations now contribute to a database management system utilizing quality control methods (mainly funded outside the Mekong-HYCOS project); partners share data online via the MRC data portal. Data are transmitted frequently (every 15 minutes), which is useful for flash flood, tidal, or rainfall applications, and through these data the project contributes to the Flood Management and Mitigation Programme for flood forecasting and early warning systems. Local technicians have been trained to maintain and operate the associated equipment.

The **Southeast Asia Flash Flood Guidance System (SEAFFGS)** has been developed by the WMO Commission for Hydrology jointly with the WMO Commission for Basic Systems and in collaboration with the U.S. National Weather Service, the U.S. Hydrologic Research Center (HRC), and United States Agency for International Development/ Office of U.S. Foreign Disaster Assistance. This system is an important tool necessary to provide operational forecasters and disaster management agencies with real-time informational guidance products pertaining to the threat of small-scale flash flooding. It is a robust system designed to provide the regional guidance products to support the development of warnings (at national level) for flash floods from rainfall events through the use of remote sensed precipitation (e.g., radar and satellite-based rainfall estimates) and hydrological models. To assess the threat of a local flash flood, the FFGS is designed to allow product adjustments based on forecaster experience with local conditions, incorporation of other information (e.g., NWP output), and any last-minute local observations (e.g., nontraditional rain gauge data) or local observer reports. For forecasters to use FFGS products effectively in daily operations, training is crucial. A Mekong FFGS has been implemented by MRC, where the Regional Flood Management and Mitigation Centre has been functioning as the FFGS regional center; however, in light of the synergies between the SWFDP and the FFGS, plans have been initiated to have the SWFDP Regional Forecast Support Centre serve as the SEAFFGS regional center.

Other projects

The **SERVIR-Mekong Project** (2014–2019) has been implemented by the Asian Disaster Preparedness Center and financed by the United States Agency for International Development, in partnership with the U.S. National Aeronautics and Space Administration (NASA). This project supports governments, regional institutions, and other key stakeholders in the Lower Mekong countries in using publicly available satellite imagery and geospatial technologies, such as mapping and related analyses, to prepare for and respond to disasters, manage natural resources, and improve food security. SERVIR-Mekong is part of a network of SERVIR hubs currently in operation across the developing world. This project develops tools based on the needs of the region. Some ongoing tools include (a) the Regional Drought and Crop Yield Information System, which helps provide drought-related information to support short- and long-term mitigation measures; (b) the Satellite Radar-derived Virtual Rain and Stream Gauge Data Service, which provides satellite-based rainfall and stream height data from publicly available satellite measurements; (c) the Historical Flood Analysis Tool, which analyzes the locations and temporal distribution of surface water from 1984 to 2015 based on satellite images; and (d) the Land Cover Monitoring System, which developed a series of annual (2000–2016) land cover maps with a multi-purpose typology for land resource planning, and which offers decision-support tools, geospatial data sets, resources, and publications, as well as—most importantly—a technical assistance service.

OPPORTUNITIES FOR SEA REGIONAL DIMENSION

Technical Insight 3 discusses the trends in SEA regional initiatives and challenges in scaling them up. Based on the descriptions of the international initiatives on regional cooperation and regional frameworks in SEA, Table 3 identifies the activities by regional initiatives that can benefit the NMHSs in SEA, highlighting the functions that have a potential to strengthen the NMHSs' capacities within the context of a regional initiative.

Technical Insight 3: Trends in SEA regional initiatives and challenges in scaling them up

International initiatives focusing on regional cooperation among hydromet services have identified several priorities, including the establishment of end-to-end multi-hazard early warning systems (focused on typhoons, floods, and droughts) in support of disaster risk reduction, and the development of climate-related mechanisms to cope with climate variability, change, and adaptation. Some of these international initiatives define operating procedures and protocols for data sharing, such as those established within the context of the WMO/ESCAP Typhoon Committee and the Mekong River Commission. Strategic documents acknowledge the importance of capacity building, and identify regional activities and projects for donor funding.

Most regional initiatives/projects being implemented in SEA focus on the access, use, and interpretation of satellite-based imagery, and numerical products and tools via web-based platforms. Some of these projects also consider user engagement. Most of these regional activities are time-bounded pilot projects, which rely on in-kind contributions from advanced NMHSs or donor funding. Regional centers still struggle to include their regional commitments within their routine operations, while at the global level, most of the systems are fully automated, and therefore fully operational. Scaling up these initiatives from demonstrations into operations requires innovative finance approaches for the sustainability of the investments, and for operation and maintenance at both regional and national levels.

TABLE 2: SUMMARY OF THE ACTIVITIES UNDER REGIONAL INITIATIVES THAT BENEFIT NMHSS IN SEA

Regional Initiative	Activities Within The Context Of The Regional Initiative	Activities that can be strengthened by the NMHSS within the context of the regional initiative
SWFDP-Sea	Weather forecasting; Numerical Weather Prediction; Ensemble Prediction Systems	Improved weather forecasting and warnings; capacity building; forecast verification; post-processing and calibration; downscaling; probabilistic forecasting; data sharing
CREWS	Integration of SWFDP-Sea and SEAFFGS	QPE/QPF; capacity building
ASEANCOF	Seasonal outlooks	Improved seasonal forecasting; capacity building
Regional cooperative drought mechanism	Drought monitoring and early warning	Acquisition and use of space-based data and GIS applications for drought monitoring and early warning; capacity building
SEA Radar Network/ Composite	Monitoring of hazardous hydromet conditions, nowcasting, and warnings	Capacity building; radar observation and its utilization; QPE; improved monitoring of hazardous hydromet conditions, nowcasting and warnings
FMMP	River level monitoring; flood forecasting and early warnings; data sharing	Improved flood forecasting and warnings; capacity building
Mekong-HYCOS	Real-time flood information system in the Mekong basin; telemetric hydromet monitoring; data sharing	Improved hydrological monitoring and flood forecasting; capacity building
SEAFFGS	Flash flood guidance	Improved flash flood forecasting; capacity building
SERVIR-Mekong	Regional drought and crop yield information system; satellite radar-derived virtual rain and stream gauge data service; historical flood analysis tool; land cover monitoring system	Satellite imagery and geospatial technologies; decision-making tools for surface water distribution; capacity building

Notes: QPE = Quantitative Precipitation Estimates;
QPF = Quantitative Precipitation Forecast.

MAXIMIZING THE BENEFITS OF EXISTING PROJECTS AND INITIATIVES IN SEA

Regional initiatives offer many opportunities to support capacities of national hydromet service providers in the SEA region, although there are challenges in fully benefiting from regional opportunities. There are also regional gaps that need to be addressed. **Table 4** identifies the current strengths that support, as well as challenges and gaps that hinder, NMHSs' ability to benefit from existing global and regional initiatives that are relevant for SEA. It also discusses possible solutions to address these challenges and gaps.

TABLE 4: CURRENT STRENGTHS, CHALLENGES, AND GAPS IN FULLY BENEFITING FROM REGIONAL OPPORTUNITIES

Current strengths that support NHMSs' ability to benefit from regional initiatives	Challenges/gaps that hinder NHMSs' ability to benefit from initiatives	Possible solutions to address challenges and gaps
<p>Many regional policies highlighting the need for regional cooperation</p>	<p>Introducing specific and detailed actions in regional operating plans; establishing a relationship between regional and national strategic and operating plans; establishing ongoing programs for observations, forecasting, etc.</p>	<p>International hydromet initiatives, including regional policies and strategic plans, highlight the need for regional cooperation; however, in general, regional operating plans do not identify or require many specific actions, in part due to the lack of associated financial mechanisms. In addition, regional cooperation measures have not been well articulated in national strategic plans. The establishment of ongoing programs for observations, forecasting, etc. would facilitate the optimum design of the systems, ensuring interoperability, integration, and complementarity within the region, which contribute positively to efficiencies and optimization of infrastructure costs.</p>
<p>Access to most advanced data, products, and techniques; quick improvements in medium- to long-range forecasts</p>	<p>Integration of web-based graphical products and tools into NMHSs' operational systems and processes; getting access to digital data and products; aligning data-sharing policies with modernization of NMHSs; lack of nowcasting tools</p>	<p>Most of the global and regional activities focus on web-based access and use of graphical data and products from advanced services, which ensure that NMHSs get access to the most advanced products and techniques. This has contributed to improving medium- to long-range forecasting in many NMHSs; however, it also brings additional systems into the NMHSs, which are not integrated in their operational monitoring and forecasting processes. This lack of integration creates bottlenecks and inefficiencies in operations. Availability of global and regional digital data and products is critical for integration, so regional data-sharing/exchange policies will need to be aligned with the modernization of NMHSs. Recent World Bank projects have sought systems' integration, but these have been nationally driven and primarily focused on observing systems. It could be beneficial to take this approach at regional and/or subregional levels.</p>

Many training and other capacity-building activities in Southeast Asia

Insufficient technical, budgetary, and human resources to add capacity at national level; lack of coordination in capacity building activities and training; lack of targeting to address specific country needs

Training and other capacity-building initiatives have been regularly provided as part of regional projects and activities, as well as by major global and regional service providers. But there are technical, budgetary, and human resource challenges at the national level that hinder the uptake and integration of the data, products, and tools in national systems, and that constrain sustainable national participation in regional initiatives. The limited understanding of the benefits offered by the new data, products, and tools also contributes to the process, as does the lack of ownership.

Development partners' investment in the modernization of NMHSs aligned with the national strategic plans

Integrating international cooperation in national strategic plans; shifting focus from infrastructure to a service-based approach in national strategic plans; ensuring information and communications technology assets and infrastructure are available; lack of compatibility, harmonization, and integration of monitoring systems

The modernization of the NMHSs tends to be aligned with their national strategic plans, which currently provide limited room for addressing, contributing to, or realizing any benefit from international initiatives. In addition, national strategic plans traditionally focus on infrastructure developments. Development partners will continue to support separate elements of the hydromet infrastructure without making necessary systemic changes to the entire national system due to incompatibility/ interoperability. Information and communications technology required to fully harmonize and integrate the systems is typically neglected. In particular, limited attention has been given to strengthening and expanding the NMHSs' communication systems to the "outside world." Better communications would allow NMHSs to benefit from data and products being made available through the Global Telecommunication System. It would also allow them to make their own data available for improved monitoring and numerical forecasting, which would be beneficial to the worldwide meteorological community and a step toward full compliance with data-sharing policies. Rethinking the national strategic planning processes—including redesigning a modernized NMHS to meet user requirements (i.e., shifting the focus to a service-based approach) and considering new business models and related investments required—could make it easier for NMHSs to contribute to international activities and improve the quality of the support provided by global and regional service providers. It could also encourage private sector engagement in sustainable investments.

KEY TAKEAWAYS

There are numerous initiatives and regional frameworks in the SEA region that could help address some of the major challenges faced by national hydromet service providers. At the same time, there are challenges involved in fully benefiting from regional opportunities, scaling up specific initiatives from demonstrations into operations, ensuring relevance to national and regional systems, and sustaining national participation. These are linked to existing constraints in human and financial resources, as well as to a lack of awareness at the national level of the benefits offered by regional approaches.



Photo: Istockphoto.com. Location: Thailand

REGIONAL HYDROMET COOPERATION: THE WAY FORWARD IN SOUTHEAST ASIA

This chapter provides a list of recommended actions that Cambodia, Lao PDR, and Vietnam could take to address some of the main challenges their hydromet service providers face. Taking the steps suggested below could support the NMHSs in coping with common hydromet hazards and help them meet the increasing demand for improved products and better services, while allowing them to fully benefit from regional initiatives.

The services provided by NMHSs rely on a complex and dynamic system of subsystems—monitoring and observing, modeling, forecasting, service delivery, information and communication technology, research, and quality management—all of which are supported by institutional capacity building, technical training, and outreach to stakeholders and recipients of information. A common desire is to direct investments toward the modernization of all subsystems at the national level, for example by installing comprehensive observing networks and developing the ability to run sophisticated local limited area models (LAMs). However, these are technological goals rather than activities designed to achieve the expected socioeconomic outcomes that drive the hydromet investment in the first place. In any case, technological constraints are not the only limitations SEA countries face; they also have limited human and financial resources for carrying out the operation and maintenance of the subsystems.

Existing regional frameworks and initiatives in the SEA region could help address some of the major challenges that national hydrometeorological service providers face. For example, very costly functions could be handled at the regional level. However, there are also challenges in making use of these initiatives. The list below recommends actions that Cambodia, Lao PDR, and Vietnam could take to address some of these challenges.



SHORT-TERM ACTIONS (ONE TO THREE YEARS)

1. Develop a regional Concept of Operations for the Lower Mekong region.

International good practice suggests that a regional approach applied to countries facing common hydromet conditions (like Cambodia, Lao PDR, and Vietnam) has advantages: it enables enhanced networking; ensures robust interoperability, efficiencies, and optimization of infrastructure costs; and results in greater harmonization, integration, and complementarity within the region. An example of a well-established regional cooperative program is the European Meteorological Services Network (EUMETNET), through which members develop and share capabilities related to various subsystems to strengthen individual and joint capacities.

Effective regional collaboration can contribute to improved forecast accuracy, boosting the capabilities of lower-capacity NMHSs; over the longer term, it can increase savings and sustainability of the investments. In the SEA context, the first required step could be the development of a Concept of Operations (CONOPS) for the Lower Mekong region, which would guide the design and development of an optimum regional composite for hydromet observational networks, modeling, forecasting, and service delivery that meet societies' existing and future needs. A well-defined regional CONOPS is intended as a living document that guides the implementation and ongoing operation of the system of systems; it should be clearly aligned with national CONOPS documents that address user needs. The national CONOPS document should also evolve with the system.

Actions:

- (i) Task the Management Team of the Severe Weather Forecasting Demonstration Project–Regional Subproject in Southeast Asia (SWFDP-SeA) to develop the regional CONOPS.
- (ii) Encourage donors and development partners to participate in and support the development of the regional CONOPS.

2. Improve harmonization, compatibility, and integration of systems.

Many development partners have supported and will continue to support separate elements of the hydromet infrastructure. Although these efforts have provided significant improvements, staff at NMHSs still struggle with data integration, typically because systems are not compatible or interoperable. This lack of integration creates bottlenecks and inefficiencies in operations. Recent World Bank projects have been focusing on systems' integration at the national level. Noting that harmonization, compatibility, and integration are common challenges among the countries in the Lower Mekong region, the existing World Bank initiative could be scaled up to address this problem at the regional level. In line with international good practice, the design of a ground-based observing system for a region would serve the needs of regional and national weather forecasting (including Numerical Weather Prediction), climate services, and early warning systems. Examples of good practice include the EUMETNET Composite Observing System (EUCOS) in Europe and the Caribbean Meteorological Organization (CMO) in the Caribbean. The harmonization of the various components of the observation networks (including automatic weather stations, radio sounding, radar, etc.) within the Lower Mekong region would help development partners select technical equipment (such as by following similar specifications) and would facilitate system integration. Technical specifications could be developed as part of the regional CONOPS for the Lower Mekong region. Their application would then need to be promoted by the NMHSs in the region any time a development partner or donor expressed a willingness to support the NMHSs' observational infrastructure. This greater degree of harmonization will result in cost saving and will increase systems' efficiency and effectiveness, while also contributing to improved monitoring and more accurate forecasts.

Actions:

- (i) As part of the regional CONOPS for the Lower Mekong region, develop standardized technical specifications for the various components of the observation network (including automatic weather stations, radio sounding, radar, etc.)
- (ii) Establish formal agreements between the NMHS and the development partner or donor on the use of such technical specifications, which should be developed in the context of the regional CONOPS to allow integration.
- (iii) Encourage donors and development partners to comply with the technical specifications developed in the context of the regional CONOPS.

3. Enhance data collecting and sharing.

WMO adopted data-sharing policies with the intent of establishing a system for free and unrestricted exchange of weather, climate, and hydrological data and products at the international level. However, many NMHSs do not comply due to political, technical, and resource issues. Regional policies are more effective, such as those established by MRC for hydrological data sharing among the countries in the Mekong basin. Given that the National Hydro-Meteorological Service of Vietnam is the Regional Forecast Support Centre and acts as a WMO regional hub for forecasting (making graphical forecast products from global and regional service providers available), it could extend its role to coordinate sharing of meteorological observational and forecasting data in the Lower Mekong region.

Actions:

- (i) Assign to the NHMS of Vietnam (as the WMO Regional Forecast Support Centre) the role of coordinator of meteorological observational and forecasting data sharing in the Lower Mekong region.
- (ii) Establish data-sharing protocols and agreements with global and regional service providers in Southeast Asia in order to get access to digital data (not only graphical products).

4. Strengthen ICT assets and infrastructure with the international community.

To ensure that individual NMHSs can quickly access data and products from existing global and regional initiatives, and can also contribute observational data for improving numerical forecast accuracy, a key priority is the acquisition and installation of the WMO Information System/Global Telecommunication System (WIS/GTS) in individual countries. This allows communication with the international community through the WMO's World Weather Watch infrastructure. This step will require strengthening of data management so that data can be easily retrieved and processed to generate sector-specific products. In addition, numerous improvements in infrastructure (such as database servers, routers, switches, forecaster workstations, etc.) and/or cloud computing will also be required to help the NMHSs improve their services.

Actions:

- (i) Acquire and install the WIS/GTS in individual countries, along with related ICT infrastructure and/or cloud computing.
- (ii) Upgrade to reliable high-speed Internet in individual countries.
- (iii) Establish formal agreements with WMO/WIS centers—e.g., the Data Collection or Production Centre (DCPC) in Bangkok and Global Information System Centres (GISCs) in Beijing and Tokyo—for continuous support and capacity building in ICT system operations.

5. Improve monitoring and nowcasting of hazardous hydromet conditions.

Like the EUMETNET Operational Project for the Exchange of Weather Radar Information (OPERA) in Europe, the Southeast Asia Radar Network/Composite project in the ASEAN region aims to enhance expertise in the field of weather radar and build capacity in radar observation and its utilization. This project is important for nowcasting, especially for monitoring transboundary hazardous events; it is also important for determining Quantitative Precipitation Estimates required for hydrological monitoring and forecasting. However, there have been significant technical challenges associated with its implementation, as NMHSs in SEA must first be able to manipulate and use the relevant radar data. This requires the support of the WMO Regional WIGOS Centre in Tokyo and the NMHS of Thailand (which is trained in the use and manipulation of radar data), as well as making data available to the regional radar composite. Software such as the open source SWIRLS (Short-range Warning of Intense Rainstorms in Localized Systems), developed and maintained by the Hong Kong Observatory, could be implemented for nowcasting.

Actions:

- (i) Establish a formal collaboration mechanism with the WMO Regional WIGOS Centre Tokyo and with the NMHS of Thailand, which has recently been trained in the use and manipulation of radar data, and make data available to the regional radar composite.
- (ii) Work with Hong Kong Observatory to implement SWIRLS at the WMO Regional Forecast Support Centre in Vietnam, once the regional radar composite is in place.

6. Run and calibrate a regional numerical model.

Frequently, NMHSs request donor funds to support their local deterministic LAM efforts. However, given that the global NWP models are now reaching the resolutions served by previous-generation local and regional deterministic LAMs, these investments are relevant only if local deterministic LAMs run with optimal parameterizations of the physical processes at very high resolutions (1–2km), with high-quality processing and full data assimilation of local observational data for a rapid refresh/update. Running these models poses significant challenges to NMHSs, especially in developing countries. Both robust and reliable telecommunications infrastructure (to import the required volumes of data) and large supercomputers are required to support models of competitive resolution and to address data assimilation, spin-up, and cycling issues. In addition, large and expert staff with scientists and computer technicians is required to develop and maintain such a system in an operational environment 24 hours per day, 365 days per year. Efficient provision of such NWP services is therefore best concentrated within a limited number of regional centers, with support where appropriate from global centers. This arrangement would allow the NMHSs to focus their limited resources on forecast verification and feedback, model post-processing and calibration, model output interpretation, and delivery of services. In the Lower Mekong region, the forecast capacity of the NHMS of Vietnam has been significantly strengthened both in terms of hydromet infrastructure and technical skills. In the context of the SWFDP-SeA and the Southeast Asia Flash Flood Guidance System (SEAFFGS), the NHMS has been serving as regional center, making available many forecast products to the NMHSs of Cambodia and Lao PDR. Continuous support to NHMS is required to ensure that its regional services respond to the increased demands. Thus far, participation in these developments by staff from NMHSs of Cambodia and Lao PDR has been limited. Similarly, at the national level, Cambodia and Lao PDR have made limited use of the available global and regional forecast products, mainly because these products are not integrated in the NMHSs' forecast process. For purposes of verification and post-processing for calibration of forecast products for the Lower Mekong region countries, the regional role of Vietnam's NHMS should be strengthened even further. At the same time, a formal regional plan should be established for NWP development and for creation of a sustainable mechanism to

engage staff from NMHSs of Cambodia and Lao PDR in NWP-related developments in the region; this approach would ensure joint ownership, which is in line with the international good practice, for example in the Scandinavian region.

Actions:

- (i) Strengthen the capabilities of Vietnam's NHMS as the Regional Forecast Support Centre to ensure that demonstration functions within the context of the SWFDP-SeA and SEAFFGS make the transition to operations.
- (ii) Establish a Lower Mekong Region Consortium for numerical modeling and invite staff from the three NMHSs to participate in the development, testing, and calibration of the regional model.
- (iii) Encourage donors and development partners to support regional functions of the NHMS of Vietnam and the participation of staff from NMHSs of Cambodia and Lao PDR in the consortium.
- (iv) Use model codes and parameterizations being shared within the WMO Regional Association II (Asia), which are supported by World Meteorological Centres (WMCs) in Beijing and Tokyo.
- (v) Establish formal agreements with WMCs in Beijing and Tokyo for continuous support and capacity building.

7. Establish formal collaborations with global and regional centers and universities for capacity building.

Training is an integral and essential part of modernization. Training should be carried out for all staff in their respective areas of expertise and responsibility. Most regional initiatives, as well as most support offered by development partners, have training as one of the key activities for building capacity at national level. International practice suggests that regional training has limited impact for NMHSs' operations, and that the most effective, cost-effective, and sustainable training is conducted on-site (i.e., on-the-job training in specific topics) by experts from global and regional centers (e.g., WMCs Beijing and Tokyo, Southeast Asia RCC-Network) using the systems and equipment available to the staff, as well as introducing new products and tools made available to them through global and regional initiatives. Regional centers or institutions (in charge of regional weather, climate, or hydrological forecast support) play a key role in assessing national requirements. They are also key in coordinating both the development of curricula that introduce new products and tools and the engagement of relevant experts to serve for a specific time period at the national level.

NMHSs should carefully select staff with appropriate skills to become trainers for colleagues and other staff. The selected staff should attend the specialized international training at WMO RTCs in Republic of Korea and China. At the same time, the training curricula supported by these RTCs should be reviewed to ensure that they are fit-for-purpose and address the requirements of the NMHSs in the Lower Mekong region. The so-called South-South training can be particularly effective where staff from different middle- and low- income countries' agencies share their knowledge and experiences.

Protocols with academia and research institutions, including universities, should also be established to ensure that research studies are aligned with the research needs of the NMHSs (e.g., verification of numerical forecasts, post-process and calibration of model outputs, etc.)

Actions:

- (i) Establish a formal agreement with global and regional centers—e.g., WMCs in Beijing and Tokyo, Regional Climate Centre (RCC)-Network ASEAN—to provide in-country training using the systems and equipment available to center staff, and to introduce the new products and tools made available to them through global and regional initiatives.
- (ii) Have Vietnam's NHMS (in its capacity as the Regional Forecast Support Centre) provide in-country training at NMHSs of Cambodia and Lao PDR to boost their operational capacities.
- (iii) Have regional centers or institutions (in charge of regional weather, climate, or hydrological forecast support) assess national requirements, coordinate the development of curricula that include the introduction of new products and tools, and coordinate the engagement of relevant experts who could be deployed for a specific time period at the national level.
- (iv) Identify qualified staff from the three NMHSs to be trained as trainers of other staff at the WMO RTCs in Korea and China.

- (v) Have RTCs in Korea and China review the training curricula to ensure that they are fit-for-purpose and address the requirements of the NMHSs in the Lower Mekong region.
- (vi) Establish protocols with academia and research institutions, including universities, to ensure that research studies are aligned with the research needs of the NMHSs (e.g., verification of numerical forecasts, post-process and calibration of model outputs, etc.)



MEDIUM-TERM ACTIONS (FOUR TO FIVE YEARS)

8. Focus on data quality and availability.

Data quality and availability (which are crucial for hydromet monitoring and forecast verification) are critical issues for NMHSs in developing countries. It is therefore important to establish a strong connection between the NMHSs of Cambodia, Lao PDR, and Vietnam and the Regional WIGOS Centre Tokyo, which could assist and support capacity development in this field. Specifically, the WMO Regional WIGOS Centre carries out performance monitoring and incident management under the WIGOS Data Quality Monitoring System. It addresses (a) real-time monitoring of performance (data availability and data quality) of all WIGOS components, searchable by region, country, station type, period, etc.; (b) delayed mode monitoring of data quality as measured against reference sources of information, for non-real-time observations; and (c) an incident management component for mitigation of performance issues. The system also follows up with data providers (i.e., the NMHSs) in case of data availability or data quality issues.

Actions:

- (i) Establish a good connection between the NMHSs of Cambodia, Lao PDR, and Vietnam and the Regional WIGOS Centre Tokyo, which could assist and support capacity development in this area.
- (ii) Promote the introduction of routine quality assurance/quality control of observations at individual NMHSs, as part of existing and future projects supported by donors and development partners.

9. Improve harmonization of warning criteria and of efforts to share warnings among the three countries in the region.

In line with the development of regional capacity for disaster risk management in SEA, there is a need to harmonize the warning criteria for hydromet hazards within the Lower Mekong region. It is important for individual countries to share and display the alerts and warnings for at least 48 hours, in a manner understandable for professionals and the public, using a dedicated regional web platform. An example of such a platform is Meteoalarm, which was developed under the framework of the European Meteorological Services Network (EUMETNET) (and which recently incorporated hydrological warnings). This move toward greater harmonization of warning criteria requires strong coordination and collaboration among the NMHSs in the Lower Mekong region. Over the longer term, through networking and coordination with the regional and national disaster risk management community, there could be an attempt to harmonize these warnings toward impact-oriented warnings.

Actions:

- (i) Harmonize the warning criteria for hydromet hazards within the Lower Mekong region.
- (ii) Share and display the alerts and warnings from individual countries for at least 48 hours, and do so in a manner that is understandable for professionals and the public using a dedicated regional web platform.
- (iii) Over the longer term, build on strengthened coordination with the regional and national disaster risk management community to harmonize these warnings toward impact-oriented warnings.



LONG-TERM ACTIONS (6 TO 10 YEARS)

10. Improve technical skills, operations and maintenance capacity, and engagement with the private sector.

To contribute to efficiencies and optimization of infrastructure costs and facilitate integration and complementarity within the region, the approach to investing in modernization of NMHSs should be rethought. Efforts to modernize should take into account the national and regional CONOPS, shift the focus from infrastructure to a service-based approach at the national level, support the regional hydromet dimension through the short- to medium-term actions

suggested above, and engage with the private sector. These steps could also contribute to affordable operation and maintenance costs to be supported by governments.

However, there remains another key requirement for enabling and sustaining these activities over the long run: the availability of staff with relevant technical skills to effectively operate the systems and deliver services. A program could be developed for mobilizing staff to fill in the technical capacity gaps among the three countries in the Lower Mekong region, while also building the capacity of newly recruited staff through a comprehensive education and training program.

Actions:

- (i) Develop new business models for the NMHSs by shifting focus from infrastructure to a service-based approach at national level, supporting the regional hydromet dimension through the short- to medium-term actions suggested above, and engaging with the private sector.
- (ii) Develop a program for mobilization of staff to fill in the technical capacity gaps among the three countries in the Lower Mekong region, while building the capacity of new staff through a comprehensive education and training program.

KEY TAKEAWAYS

Taking into account SEA's risk profile, challenges that NMHSs in Cambodia, Lao PDR, and Vietnam face, as well as existing regional projects and international initiatives to promote regional cooperation, and gaps in these efforts, the development of CONOPS for the Lower Mekong region has been identified as a top priority for the region to pursue as it could guide the design and development of optimum regional composites for the various hydromet subsystems (observational networks, modeling, forecasting, and service delivery). These subsystems form part of an overall system that meets the existing and future needs for hydromet information of societies in Cambodia, Lao PDR, and Vietnam.

To address some of their technical, human, and financial resource challenges, Cambodia, Lao PDR, and Vietnam could take the following recommended actions in the short term:

- (i) Improve harmonization, compatibility, and integration of systems;
- (ii) Enhance data collecting and sharing;
- (iii) Strengthen ICT assets and infrastructure with the international community;
- (iv) Improve monitoring and nowcasting of hazardous hydromet conditions;
- (v) Run and calibrate a regional numerical model; and
- (vi) Establish formal collaborations with global and regional centers and universities for capacity building.

Recommended medium-term actions involve improving data quality and availability, improving harmonization of warning criteria, and sharing warnings among the three countries in the region. Improvement of technical skills, operations and maintenance capacity, and engagement with the private sector should be also addressed in the longer term.

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The International Bank for Reconstruction and Development
1818 H Street, NW
Washington, DC 20433, USA

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