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TOWARD A MESOSCALE OBSERVATION NETWORK IN SOUTHEAST ASIA

BY TIEH-YONG KOH AND CHEE-KIAT TEO

A coordinated network of in situ instruments, remote sensors, and satellite receiving stations could accelerate research and forecasting progress in a region where observations are currently inadequate.

EMERGING INTEREST IN SOUTHEAST ASIA. The 550 million people living in Southeast Asia account for 7% of the world's population (ASEAN 2006). Although the region has undergone significant economic development in the past few decades, the benefits have not permeated all strata of the society: about 20% of the region's population are still living in poverty (ASEAN 2006), with their lives and livelihood vulnerable to natural hazards. The Philippine Islands and Indochinese coasts are affected by typhoons, while many parts of Indonesia, the Malay Peninsula, and the Mekong River basin

suffer from massive floods often following torrential monsoon rains. Rapid industrialization and urbanization also gave rise to new problems like air pollution and increased pressure on freshwater resources.

Environmental issues in Southeast Asia were traditionally considered domestic woes of each nation, often overshadowed by the more immediate socioeconomic problems. However, over the last decade, collective concern for the environment has been rising in the region. Environmental issues are now related to the sustainable development in the Association of Southeast Asian Nations (ASEAN) and they play a significant role in international diplomacy, as witnessed in the controversies surrounding the Kyoto Protocol. The problems are recognized as being transnational; for example, the smoke-haze emitted by forest fires in Sumatra and Borneo during the 1997/98 El Niño event affected several Southeast Asian countries. The urgency of solving certain issues is evident from the initiatives taken by ASEAN, such as the agreement on transboundary haze pollution (ASEAN 2002) and the long-term strategic plan for freshwater management (ASEAN 2006). Environmental monitoring and prediction in Southeast Asia became the focus of international attention in the aftermath of the 2004 Asian tsunami.

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In tandem with mounting interest in environmental issues in Southeast Asia, international scientific interest in this region's meteorology has also been increasing. Latent heat released over the maritime continent is a major driving force for the world's circulation, and yet GCMs are unable to capture the strength of diurnal convection in this region (Neale and Slingo 2003). The onset of the Asian summer monsoon over Indochina is hotly researched, and the findings from South China Sea Monsoon Experiment (SCSMEX; Ding et al. 2004) suggest that warm SST in South China Sea may be the key to the onset. Other international research programs in Asia, such as the Global Energy and Water Cycle Experiment (GEWEX) Asian Monsoon Experiment (GAME; Yasunari et al. 2003) and the Monsoon Asian Hydro-Atmosphere Scientific Research and Prediction Initiative (MAHASRI), have included Southeast Asia as a key component in the scientific questions addressed (MAHASRI 2006).

Concurrent with modeling efforts and field campaigns, since the late 1990s, atmospheric remote sensing facilities have been established in Southeast Asia, for example, through Japanese–Indonesian collaborations to investigate interactions between intraseasonal variation (ISV) and the local diurnal convection. Recent plans to add X- and C-band Doppler radars along the equator under the Hydro-meteorological Array for ISV–Monsoon Automonitoring (HARIMAU) program (Yamanaka et al. 2008) attests further to the emerging interest in Southeast Asia weather and climate.

LACK OF REGIONAL OBSERVATIONS.

From the regional and international interest in

weather monitoring, prediction, and research in Southeast Asia, the opportunity has arisen for the community to address the lack of spatiotemporally dense meteorological observations in this region. This is a pressing problem both for research in Southeast Asian weather and for operational forecast. Short-term weather prediction (up to 48 h in advance), especially quantitative precipitation forecast, is a crucial first step to mitigate weather-related hazards such as floods, landslides, droughts, forest fires, and smoke–haze. Advancing the capability in weather observation and forecasting and the underlying understanding of Southeast Asian weather systems should also be part of the region's mitigation strategy for plausible weather hazards induced by climate change.

Observations from the traditional network of surface weather and radiosonde stations, sampling at an interval of 6 or 12 h, are inadequate for monitoring tropical convective weather, which operates on the subhour time scale. Furthermore, these observing stations are unevenly distributed in Southeast Asia because of the maritime nature of the region, and the islands and peninsula are uninhabited either because of their mountainous and forest terrain or because they are economically underdeveloped. Observing stations in Southeast Asia tend to be located along coasts and at sparse densities¹ (Fig. 1). Even with aircrafts and ships collecting data routinely, observations remain inadequate. Although national meteorological centers (NMCs) in the region also operate weather radars (Fig. 2), the total area covered is limited especially

¹ The only exception is in Thailand, where surface stations are distributed at a higher density inland.

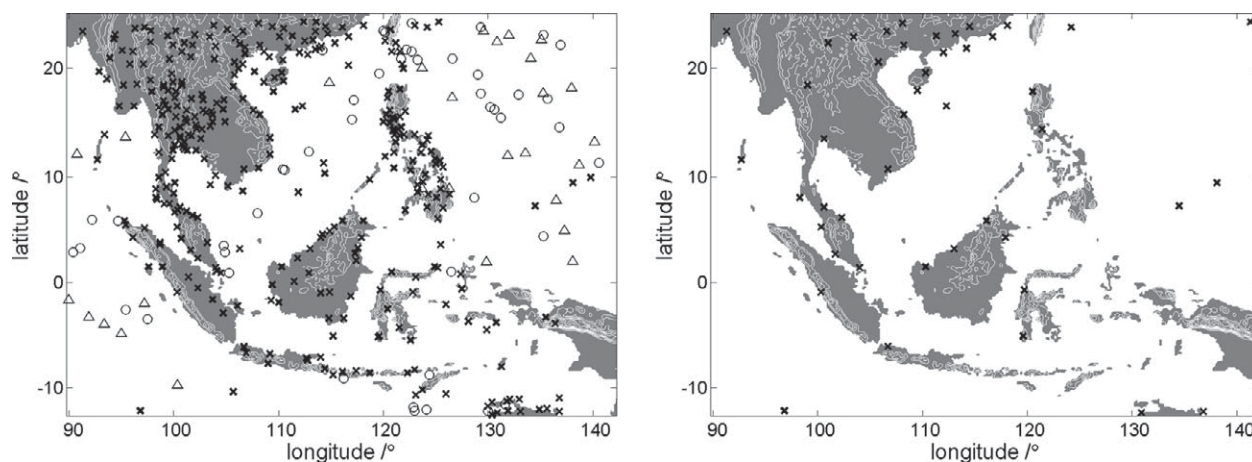


FIG. 1. The locations of (left) surface and (right) radiosonde measurements in Southeast Asia available at 0000 UTC 10 Dec 2001, by way of illustration. For the left panel, the crosses, circles, and triangles represent synoptic stations, ships, and automated buoys, respectively.

over the sea and access to the data is limited for users outside the owner NMC. Additional atmospheric sensors deployed in ongoing research projects (cf. MAHASRI 2006 and Yamanaka et al. 2008) are also sparsely distributed, for example, the four HARIMAU wind profiler radars cover a distance equal to the width of Indian Ocean at the equator.

Mesoscale NWP models are increasingly deployed for weather forecasts within the region. For example, Nanyang Technological University in Singapore uses the Coupled Ocean–Atmosphere Mesoscale Prediction System (COAMPS²; Hodur 1997) to generate twice-a-day predictions for Singapore’s environs at 9-km resolution, while the Thai Meteorological Department runs the Unified Model (Davies et al. 2005) at 17-km resolution for daily national forecasts. Although the stochastic nature of small-scale convection and the model uncertainties associated with subgrid parameterizations impose an upper limit on the predictability of mesoscale weather, this in-principle limit is presently far from being reached in Southeast Asia because of the lack of observational data.

Considerable research has been done on Southeast Asian rainfall from intraseasonal to interannual time scales (e.g., Hamada et al. 2002; Hendon 2003; Chang et al. 2005; Juneng and Tangang 2005). In contrast, investigation into the precipitating systems in this region is still largely overlooked (with a few exceptions; e.g., Desa and Niemczynowicz 1997; Okumara et al. 2003). The lack of a good observation network has arguably hampered the understanding of the regional weather. Conversely, a well-developed observation network would stimulate research in Southeast Asian weather systems. For instance, the use of wind profilers had contributed to the understanding of the convective systems associated with ISV over Indonesia (e.g., Seto et al. 2004; Shibagaki et al. 2006).

A MESOSCALE OBSERVATION NETWORK.

A mesoscale observation network for Southeast Asia may begin with monitoring the meteorologically important and densely populated regions of

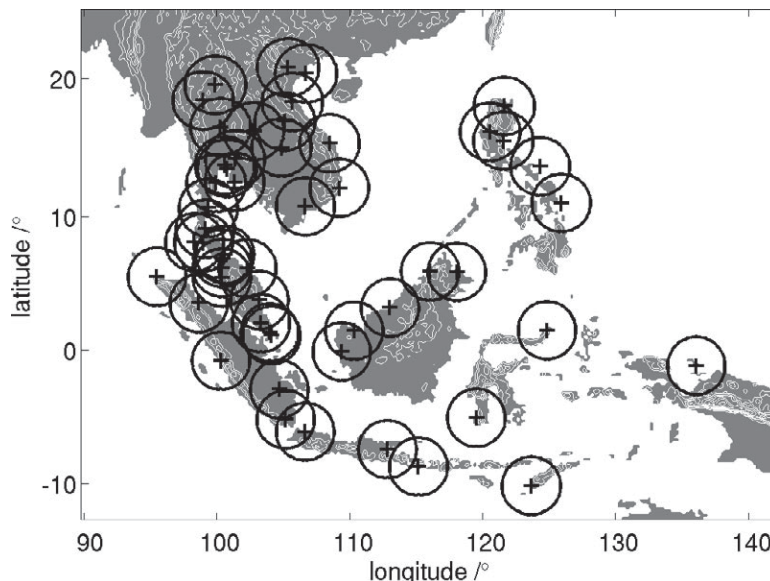


FIG. 2. Location and estimated operating range of existing weather radars in Indonesia, Malaysia, the Philippines, Singapore, Thailand, and Vietnam.

the western maritime continent (Java, Sumatra, and Borneo Islands, Malay Peninsula, and Isthmus of Kra). Data collected will be analyzed and used to test and tune model parameterizations. Assimilation into numerical models will improve the forecast and help elucidate the roles of land–sea contrast, orography, and boundary layer stability in i) thunderstorm initiation and evolution into organized systems, for example, squalls; ii) monsoon synoptic weather, for example, South China Sea cold surge and Borneo depression; and iii) modulation of convection by eastward-propagating intraseasonal oscillations from the Indian Ocean.

The proposed network complements the excellent infrastructural developments in research programs like the HARIMAU and MAHASRI-Tropics. Meanwhile, the process of regional network integration addresses a common weakness of the above programs: they are primarily bilateral collaborations (Japan–Indonesia, Japan–Thailand, or Japan–Vietnam), focusing on one Southeast Asian country at a time, and so they do little to foster transnational cooperation within Southeast Asia itself. One way to build platforms for intraregional coordination is through sustained and focused community-based workshops like those conducted annually in the “International Research for Prevention and Mitigation of Meteorological Disasters in Southeast Asia” project (information online at www.mete.kugi.kyoto-u.ac.jp/project/MEXT/).

In Europe and the United States, multisensor mesoscale observation networks, or “mesonets,” are

² COAMPS is a registered trademark of Naval Research Laboratory.

fast becoming a reality (e.g., Dabberdt et al. 2005a,b; Ralph et al. 2005; Schroeder et al. 2005). The fact that present-day Southeast Asia lacks the needed infrastructure and financial capacity should not detract it from working toward such a goal. A good starting point may be to deploy a research test bed in an Indonesia–Singapore–Malaysia collaboration to better understand and forecast Sumatra squalls (Yi and Lim 2007). Despite being a common weather pattern in the southern Straits of Malacca, the initiation, structure, and propagation of these squalls are not well understood and modeled. The straits is a major economic artery because it carries half of the oil and one-third of the sea-borne trade of the world every year. Establishing a “Straits Testbed” will ultimately benefit weather monitoring and forecasting and hence safeguard commercial shipping against weather-related losses and enhance international security deployments there. Incidentally, the current political–diplomatic climate seems to favor such an initiative; take, for example, the various bilateral and multilateral defense cooperation among the three littoral nations and Thailand against piracy in the straits (Ho 2006).

The test bed is envisioned to cover a 500 km × 500 km area, spanning from Bukit Barisan (“Line Mountain”) in West Sumatra, and eastward across the straits to the Johor–Singapore–Riau Islands complex at

the tip of the Malay Peninsula. Existing infrastructure from the NMCs would be utilized—surface stations and automatic rain gauges in the test bed domain, the radiosonde and wind profiler at Singapore Changi International Airport, and Doppler weather radars at Kuala Lumpur, Kuantan, and Singapore. Additional ground-based remote sensors like the multispectral radiometer, wind profiler radar with a ratio acoustic sounding system (RASS), X-band radar, and atmospheric lidar (cf. Table 1) should be tested and deployed either permanently or during field observation campaigns. These sensors are needed to clarify the thermodynamics and cloud microphysics of Sumatra squalls.

Surface and upper air will be sampled at subhourly intervals where possible and analyzed using the latest variational (e.g., Guo et al. 2000; Wulfmeyer et al. 2006; Kawataba et al. 2007) and Kalman filter (Meng and Zhang 2008) techniques. Mesoscale models employed in Southeast Asia, for example, COAMPS, Weather Research and Forecast (WRF) model (Skamarock et al. 2005), the fifth-generation Pennsylvania State University (PSU)–National Center for Atmospheric Research (NCAR) Mesoscale Model (MM5; Grell et al. 1994), and the Non-Hydrostatic Model (NHM) of the Japan Meteorological Agency (Saito et al. 2006), will assimilate the data for research and experimental forecasts, in tandem with

TABLE 1. Various remote-sensing instruments and their typical characteristics with potential for use in Southeast Asia.

	Instrument	Variables measured	Typical range*	Sampling rate and/or resolution
A	Microwave radiometers	Temperature, water vapor, integrated water vapor	~10 km, under clear and cloudy but not rainy conditions	Sampling rate: ~10 min
B	Wind Profiler Radar with RASS	Horizontal wind speed and direction, vertical wind speed, virtual temperature	50 MHz: 2–12 km (wind); 2–4 km (virtual temperature), 915 MHz: 0.1–5 km (wind)	Resolution: 50 MHz: 300/900 m (low/high resolution mode); 915 MHz: 100–200 m
C	X-band weather radar	Reflectivity, precipitation rate, radial wind, hydrometeor concentration	~50–75 km (radial range)	Resolution: ~150 m
D	Lidar: (a) Raman lidar; (b) differential absorption lidar	Water vapor, liquid water	Clear-sky conditions required; Raman: ~8.5 km (night), ~5 km (day, solar blind); DIAL: ~7 km	Sampling rate: 1 min (<2 km AGL); ~10 min (mid-/upper troposphere); Resolution: 75–150 m (<2 km AGL); 300–900 m (mid-/upper troposphere)
E	GPS COSMIC GPS Radio Occultation	GPS: integrated water vapor; COMSIC: water vapor and temperature profile	Troposphere, all weather	GPS: Sampling rate and resolution depend on several factors, e.g., network configuration; COMSIC: resolution ~100 m in vertical; ~200 km in horizontal

* Vertical range for zenith-pointing instruments unless otherwise mentioned.

observation campaigns wherever possible. Multi-model intercomparison and multimodel ensemble predictions will be conducted for each observation and modeling campaign to evaluate the verity of the simulation. High-resolution research computations will aid in answering scientific questions raised at the beginning of this section. Finally, a review of the experience gained from the Straits Testbed will provide directions for the development of other test beds in Southeast Asia, such as in the heavily populated and flood-prone Java Island and the lower reaches of the Mekong River.

Because test beds act as nuclei to grow larger mesonets in Southeast Asia, the important role played by existing Doppler weather radars operated by NMCs must be emphasized. A transnational cooperative network of weather radars should be set up to facilitate real-time sharing of radar reflectivity and radial wind measurements and be made available to regional forecast and research groups. From the density of coverage shown in Fig. 2, this relatively low-cost initiative will benefit the countries in western Maritime Continent tremendously. The following main obstacles are nonscientific and must be overcome by radar instrument vendors and NMCs: 1) datasets from radars are proprietary and not freely distributed outside the owner agency, and 2) radar data formats are not standardized, preventing the portability of retrieval codes.

Land-based mesonets and national weather radars leave gaps in maritime atmospheric observation. Without comparably dense and frequent monitoring over the sea, the improvements to NWP gained at land locations will be lost over 24–48 h, particularly during the monsoon seasons (when synoptic-scale organization strongly couples mesoscale weather both on land and at sea). For Southeast Asia, utilizing data from spaceborne sounders remains the most cost-effective option for good maritime data coverage. Research efforts in the region should be directed toward assimilating satellite data either directly (radiance) or indirectly (temperature and humidity retrievals) from microwave sounders, for example, the Advanced Microwave Sounding Unit (AMSU), and hyperspectral infrared sounders, for example, the Atmospheric Infrared Sounder (AIRS) and Infrared Atmospheric Sounding Interferometer (IASI). Because the superiority of one assimilation technique over another depends on factors including operational settings, instruments, and usage (Errico et al. 2000), the two techniques should be critically assessed for the various instruments to elucidate their relative strength and weakness in a regional context.

From the dearth of conventional data, a positive impact on weather prediction over the sea and in coastal regions when satellite data are optimally assimilated in NWP is foreseeable.

Looking further ahead, the region should research beyond using only clear-sky radiance and tackle the problem of cloudy and precipitating radiance, because clouds are the norm here. New weather satellites may yet provide other opportunities; for example, in the era of the Global Precipitation Mission (Smith et al. 2007), it is probable that satellite rainfall data would be available every 3 h and at a resolution of about 100 km². Thus, research in assimilating the rainfall rates retrieved in the Tropical Rainfall Measuring Mission (Huffman et al. 2007) may eventually lead to greater yield for regional NWP than is demonstrated for global NWP (Marécal and Mahfouf 2000, 2002; Benedetti et al. 2005). Likewise, GPS radio occultation data [e.g., the Constellation Observing System for Meteorology, Ionosphere & Climate (COSMIC) dataset; Anthes et al. 2008] might be exploited to complement the radiosonde soundings (especially over the sea), given its high vertical resolution.

REGIONAL PARTNERSHIPS. Because the suggested mesoscale observation network for Southeast Asia would be transnational, with stakeholders and users in NMCs and other public agencies, universities, research institutions, and private companies, careful consideration of the type of partnership is vital in making the network a sustainable reality. While there is no precedent in the region to serve as a reference in defining suitable organizational models for partnership, much can be learned from elsewhere. In particular, Dabberdt et al. (2005b) suggested one model based on a “confederation of independent entities,” which could be adapted to Southeast Asia because of ASEAN’s history of mutual respect and relative independence in technological advancement.

In the “confederation” model, the network will not be owned and operated solely by one organization; rather, it will be a coordinated amalgamation of several observing subnets led by various organizations. From the last section, the proposed subnets would be as follows (cf. Fig. 3):

- 1) several clusters of test beds (and emergent mesonets) for in situ measurements and remote sensing,
- 2) one regional network for sharing numerical data from weather radars, and
- 3) a group of satellite receiving and processing stations within a coordinated program.

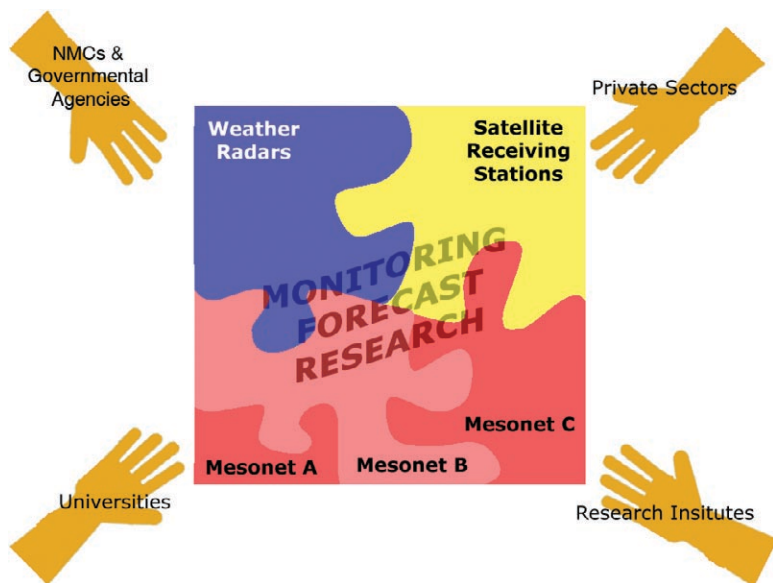


FIG. 3. Schematic diagram of the envisioned mesoscale observation network with its component subnets and various stakeholders.

Leadership in each subnet would come naturally from the largest stakeholders. Thus, the clusters loosely gathered in subnet 1 would each be led by one or a few research or commercial organizations as bottom-up initiatives, giving the greatest versatility to respond to local requirements; subnet 2 could be organized as a close partnership of NMCs under WMO's framework; and subnet 3 could be spearheaded by an international consortium of universities or research institutions. Overall coordination among the subnets and clusters could be achieved by a multinational advisory committee comprising members of various stakeholders and user groups.

Issues such as the type of sensors to be acquired and their deployment sites or the data assimilation strategies to be adopted would be discussed and coordinated in regular meetings among the parties involved and decisions would be taken through consensus. Similarly, the fund-raising and management responsibilities would be distributed among participating organizations that best fit the interests of each initiative. Ad hoc groups would be formed to garner financial and political support where needed. Among the diverse confederates, there must be the following common commitment: the data collected by this network should be available to the members of the confederation. Bilateral and multilateral agreements would be set up to waive charges for the use of data. In this way, flexibility and resilience is ensured in the long-term growth of a truly regional network in the face of the complex physical and human geography across Southeast Asia.

SUMMARY. Current observation platforms cannot adequately capture the convective weather in Southeast Asia. This impedes progress in regional forecasting and understanding mesoscale weather systems in Southeast Asia. A transnational mesoscale test bed, the Straits Testbed, comprising ground-based remote and in situ sensors deployed in the Straits of Malacca for investigating Sumatra squalls, is proposed as a plausible first step in realizing a regional mesoscale observation network. Integrating the existing weather radars is emphasized as a crucial effort in improving the regional observation network. Although the sharing of radar data and the assimilation of more satellite data would be significant first

steps forward, more could be achieved through gradual, sustained, and coordinated regional efforts in deploying in situ and remote-sensing instruments first in test beds, but eventually as multisensor clusters. Because of the maritime nature of this region, concerted effort should also be focused in exploiting satellite data. To fully realize the potential benefits from any data source, concurrent research should be devoted in the related assimilation strategy, numerical modeling, and data validation.

The mature mesoscale observation network in Southeast Asia is envisioned to comprise several coordinating subnets of radar and other remote sensors, in situ instruments, and satellite data receiving stations. A confederation of independent entities is suggested as the organizational model to be sensitive to the region's diversity. Apart from benefiting weather forecasts, the data collected by the network would act as a stimulus for much needed research into Southeast Asian weather systems.

It is hoped that this paper would raise international awareness of the need for a better mesoscale observation network in Southeast Asia for atmospheric monitoring, forecasting, and research, and motivate discussions toward the realization of such a network.

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