

# Geophysical Research Letters



## INTRODUCTION TO A SPECIAL SECTION

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### Special Section:

Years of the Maritime  
Continent

### Key Points:

- The Indo-Pacific Maritime Continent (MC) plays a pivotal role in the global weather climate system
- Years of the Maritime Continent (YMC) is an international program to improve understanding and prediction of local variability of the MC and its global impacts
- Preliminary results from YMC reveal new information on physical processes key to multiscale variability in the MC

### Supporting Information:

- Supporting Information S1

### Correspondence to:

K. Yoneyama,  
yoneyamak@jamstec.go.jp

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## Years of the Maritime Continent

K. Yoneyama<sup>1</sup> and C. Zhang<sup>2</sup>

<sup>1</sup>Japan Agency for Marine-Earth Science and Technology, Yokosuka, Japan, <sup>2</sup>NOAA Pacific Marine Environmental Laboratory, Seattle, WA, USA

**Abstract** Years of the Maritime Continent (YMC) is a multiyear international program with participants from over 15 countries. Its overarching goal is to expedite the progress toward improving understanding and prediction of the local oceanic and atmospheric multiscale variability of the Indo-Pacific Maritime Continent (MC) and its global impacts. YMC is motivated by the unique role of the MC in both the local and global weather climate systems, our lack of understanding of the key processes governing this role, and persistent systematic biases and errors in numerical model output for the region. YMC builds a comprehensive observational data set of the MC weather climate system, encourages observation-modeling integration, and educates the next generation of scientists who will be the core workforce and leaders to further advance the study of the MC.

**Plain Language Summary** Years of the Maritime Continent is a multiyear international program to study the weather climate system of the Indo-Pacific Maritime Continent and its global impacts. Systematic biases in regional rainfall produced by numerical forecast and climate models and incomplete knowledge of the regional weather climate system motivated this program. This program conducts field campaigns to collect atmospheric and oceanic observations. Its preliminary results reveal new information that encourage further researches by combining observations with numerical models. This article also serves as a solicitation for contributions to a cross-organization special collection of publications in journals of seven professional organizations. This special collection is intended to promote further studies on the diverse nature of the weather climate system of the Maritime Continent.

## 1. Introduction

The Indo-Pacific Maritime Continent (MC) is a unique mixture of over 22,000 islands in the middle of Earth's warmest body of water, the Indo-Pacific warm pool. This largest archipelago on Earth is known for its complex geophysical setting, its marine and land biodiversity, and its rich human history and culture. The MC plays a pivotal role in the global weather climate system (Ramage, 1968). The intricate distributions of land, sea, and terrain of the MC cultivate intriguing scale interactions, which breed high-impact local events such as floods. Predicting extreme events associated with the diurnal cycle, synoptic weather systems, the Madden-Julian Oscillation (MJO), and monsoons is of paramount socioeconomic benefit to the region. The MC hosts the world's strongest atmospheric convection center. Its tremendous energy release fuels the global atmospheric circulation, including Rossby wave trains that emanate out of the tropics and influence weather at higher latitudes (Jin & Hoskins, 1995). MJO teleconnections sensitively depend on the location of its convection center relative to the MC (Adames & Wallace, 2014). The MC is, however, a known barrier to MJO propagation (Zhang & Ling, 2017). Because of its atmospheric deep convection that penetrates the tropopause and generates strong gravity waves, the MC is a primary spot for vigorous stratosphere-troposphere interactions (Fueglistaler et al., 2004). The Indonesian Throughflow (ITF), the artery connecting the tropical Pacific and Indian Oceans, is a crucial branch of the global ocean circulation that affects the climate of the region and afar (Gordon, 2005). There are many natural and anthropogenic sources of aerosol in the MC, making it a complex and highly interdisciplinary natural laboratory to study interactions between aerosol and other elements of the regional and global atmosphere (Reid et al., 2013).

Global climate models and weather prediction models suffer from persistent systematic biases in precipitation and limited predictions skills in the MC region (Wang et al., 2019). They cannot reproduce the observed diurnal cycle (Love et al., 2011), and they exaggerate the MJO barrier effect of the MC (Kim et al., 2016).

Years of the Maritime Continent (YMC), a multiyear (2017–2021) international endeavor, is organized to expedite the progress toward improving understanding and prediction of local multiscale variability of the

MC weather climate system and its global impacts through observations and numerical modeling. This article briefly summarizes the background, motivation, objectives, scientific themes, main activities, preliminary results, and forthcoming plans of YMC.

## 2. Scientific Issues

In this section, we briefly discuss the main scientific issues related to several key phenomena in the MC (variability on diurnal, synoptic, intraseasonal, and monsoon time scales; the upper-oceanic processes; air-sea interaction; troposphere-stratosphere interactions; and aerosol) and their prediction. These phenomena are illustrated in Figure 1. Each of them individually may occur in many places. But their collective strong presence in the MC can hardly be found elsewhere on Earth. They are all connected to each other. Moist convection is central to atmospheric variability on all time scales and to troposphere-stratosphere interactions. Aerosol transport depends on circulations on all time scales, and aerosol-cloud interaction affects convective development as well as aerosol removal. Air-sea interaction critically depends on conditions of the upper ocean and atmospheric boundary layer that vary on all time scales and feed back to each other. The active and complex system of the MC makes this region one of the most difficult places to accurately predict.

### 2.1. Diurnal Cycle

The diurnal cycle can be considered the heartbeat of the regional weather climate system. Rainfall generally starts near the coast in the afternoon and reaches its peak in the evening. Around midnight, rainfall tends to move from the land to offshore (Figure 1b), reaching its maximum in the early morning, with extensive anvils and stratiform rain that gradually dissipate around noon (Houze et al., 1981; Mori et al., 2004). The amplitude of the diurnal cycle in precipitation is the largest near the coast of major islands and near mountain ranges, where it is 2–3 times larger than anywhere else in the tropics (Nitta & Sekine, 1994; Yang & Slingo, 2001). The diurnal cycle is connected to synoptic-scale perturbations (Houze et al., 1981), the monsoons (Johnson & Priegnitz, 1981), and the MJO (Chen et al., 1996; Ichikawa & Yasunari, 2007; Peatman et al., 2014; Rauniyar & Walsh, 2011; Tian et al., 2006). The convective diurnal cycle is determined by several factors such as land-sea breezes, mesoscale convective systems (MCSs), land surface conditions, island geometry and topography, air-sea interaction, background flows, and gravity waves (Hadi et al., 2002; Mapes et al., 2003; Sakurai et al., 2005). Numerical models do not correctly represent these factors and thus produce common systematic errors in the timing and amplitude of the diurnal cycle (Folkins et al., 2014; Love et al., 2011; Sato et al., 2009; Takayabu & Kimoto, 2008). These effects and feedbacks from the diurnal cycle to the large-scale variability need to be quantified by new observations and improved numerical models.

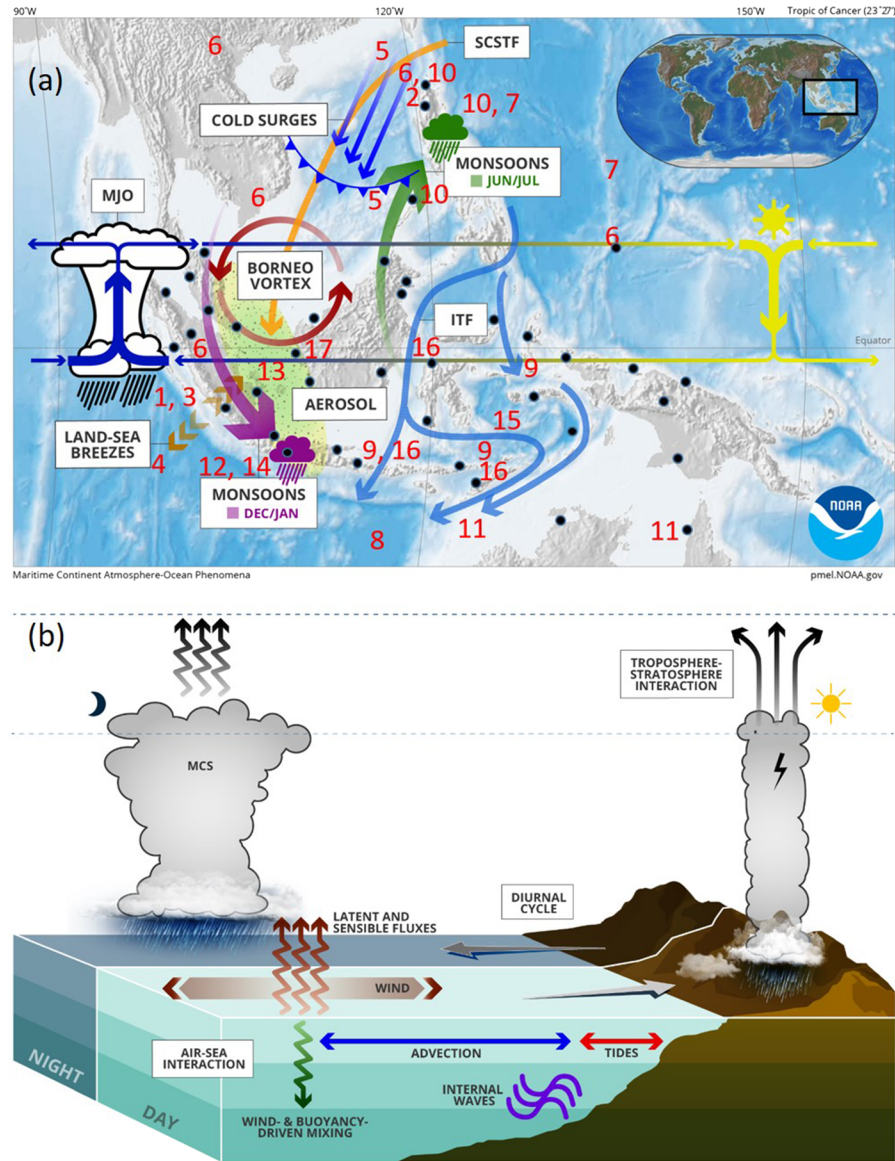
### 2.2. Synoptic Systems

Cold surges and Borneo vortices are common in boreal winter (Figure 1a). Equatorial waves are present all year round. Triggered by southward and eastward movements of the Siberian High, cold surges pass through the South China Sea and reach/cross the equator (Chang et al., 2016). Their associated enhancement of the upper tropospheric outflow over the MC and the East Asian meridional overturning circulation may strengthen the East Asian jet and lead to further interactions with midlatitude systems (Chang & Lau, 1982; Lau & Chang, 1987). A meso- $\alpha$ -scale cyclonic circulation, which is observed in the boreal winter off west coast of Borneo Island, is known as the Borneo vortex (Cheang, 1977). The intensity of the Borneo vortex is often modulated by cold surges. They both affect convection, MCS, and even the formation of tropical depressions (Chang et al., 2005, 2016). The exact nature of the interaction among these synoptic perturbations and their connections with the diurnal cycle, MJO, and monsoons are not yet fully understood.

### 2.3. Intraseasonal Oscillations

On the intraseasonal time scale, two major issues pertain to the MC: (i) the barrier effect of the MC on the MJO propagation (Figure 1a) and (ii) its role in the northward propagation of the BSISO. The MC barrier effect weakens the MJO and in many cases brings it to a complete halt. Nearly 40% of MJO events in boreal winter fail to propagate from the Indian Ocean across the MC (Kerns & Chen, 2016; Zhang & Ling, 2017). The barrier effect is often exaggerated in numerical models (Kim et al., 2009; Seo et al., 2009). This creates a “Maritime Continent prediction barrier” for the MJO (Fu et al., 2013; Weaver et al., 2011) because global impacts of the MJO (Figure 2) depend on the longitude of its convection center. Possible reasons for the

MARITIME CONTINENT ATMOSPHERE-OCEAN PHENOMENA



**Figure 1.** Schematic diagrams of major phenomena under study by YMC. (a) Approximate locations of the Indonesian Throughflow (ITF), South China Sea Throughflow (SCSTF), and Borneo vortex. The monsoons, cold surges, land-sea breezes, aerosol, and the MJO can cover much broader areas than indicated. The upper-right inset shows the MC in a global context. Numbers, which correspond to those in Table 1, mark approximate locations of intensive observations. Dots indicate radiosonde stations operated by the participating MC meteorological agencies. (b) Illustration of the diurnal cycle in rainfall; land-sea breezes; troposphere-stratosphere interaction; upper-oceanic processes including advection, tidal mixing, and internal gravity waves; and air-sea interaction including surface heat fluxes induced by surface wind and upper-ocean mixing driven by wind and buoyancy. The two horizontal blue dashed lines represent the tropical tropopause layer (TTL). Phenomena not included are the boreal summer intraseasonal oscillation (BSISO), atmospheric equatorial waves, coastal Kelvin waves and upwelling, and freshwater runoff.

barrier effect include blocking of surface evaporation by the islands (Sobel et al., 2010), topographic interference with the low-level flow (Hsu & Lee, 2005; Inness & Slingo, 2006; Wu & Hsu, 2009), and the perpetual diurnal cycle in precipitation over land that drains energy (Neale & Slingo, 2003) and inhibits MCS from fully developing over water to carry the main convective signals of MJO propagation through the MC (Zhang & Ling, 2017). Future studies on the barrier effect need to address what causes it and how it can be overcome for some MJO events to propagate through.

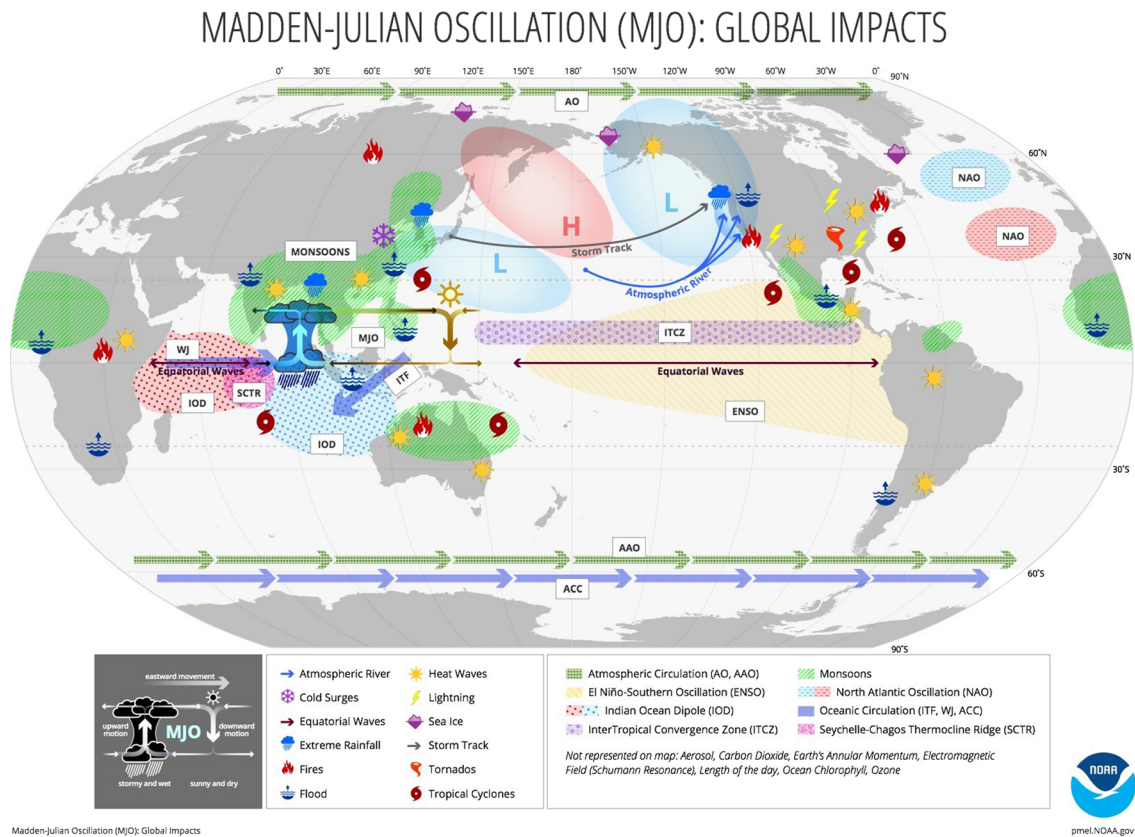


Figure 2. Schematic illustration of global impacts of the MJO. The locations of MJO-affected phenomena are not meant to be precise and complete.

For the northward propagation of the BSISO, several mechanisms have been proposed. They include air-sea interaction, synoptic perturbations, and moisture transport (Bellon et al., 2008; Fu et al., 2003; Hsu & Weng, 2001; Lawrence & Webster, 2002; Wang et al., 2009). It remains unknown how these mechanisms are at work over the MC, given the complication of the additional processes (e.g., coastal upwelling and the diurnal cycle in rain and wind) introduced by the islands.

#### 2.4. Monsoons

The MC is a crossroad of the East Asian monsoons. There, the seasonal cross-equatorial flow switches between northerlies in boreal winter to southerlies in boreal summer (Figure 1a). These winds determine the locations of coastal upwelling (Susanto et al., 2001). During boreal winter, the northeasterly monsoon flow in the Northern Hemisphere provides a favorable mean condition for the equatorial penetration of cold surges. The Indo-Australian monsoon onset often coincides with the arrival of the first MJO event of the season (Hendon & Liebmann, 1990). During boreal summer, the mean monsoon flow is a major moisture supply to rainfall over the South China Sea and the Philippine Sea (Kubota et al., 2011; Murakami & Matsumoto, 1994) and may provide mechanisms for the northward propagation of the BSISO through its interaction with small-scale convective systems (Bellon & Sobel, 2008; Jiang et al., 2004; Kang et al., 2010).

#### 2.5. Oceans

The ITF is the most prominent signature in the ocean circulation of the region (Godfrey, 1996; Gordon, 2005). It is the main means of water mass exchange between the tropical Pacific and Indian Oceans (Figure 1a). It plays an essential role in the regional climate through affecting heat and salt budgets of the MC seas (Kida & Wijffels, 2012) and thereby air-sea interaction (Lee et al., 2002). The South China Sea Throughflow (Qu et al., 2006) also affects the heat distribution in the MC, the water properties of the ITF, and the tropical Indian and western Pacific Oceans (Gordon et al., 2012; Wang et al., 2006). The complex array of shallow and deep marginal seas in the MC is an integral component of the larger-scale ocean and

climate (Sprintall et al., 2014): The MC seas share a common trait of warm, relatively low salinity surface layers of <50 m thick; in the deeper seas the surface layer is underlain by a strong thermocline, resulting in a salinity-stratified barrier layer and a warm mixed layer that trap surface fluxes. The upper ocean is influenced by many factors on various time scales (Figure 1b). These factors include the monsoonal winds (Gordon & Susanto, 2001; Qu et al., 2005), coastally trapped oceanic Kelvin waves (Drushka et al., 2010; Pujiana et al., 2013; Syamsudin et al., 2004), the MJO (Napitu et al., 2015), inertial mixing (Alford & Gregg, 2001), tidal mixing (Field & Gordon, 1996; Koch-Larrouy et al., 2010), and lateral advection (Kida & Richards, 2009). Interactions among these processes and their fractional contribution to the upper-ocean properties need to be quantitatively determined.

### 2.6. Air-Sea Interactions

Through TOGA COARE (Webster & Lukas, 1992), CINDY/DYNAMO/AMIE/LASP (Yoneyama et al., 2013), and many other field campaigns, we have gained tremendous knowledge and understanding of air-sea interactions over open oceans on diurnal to intraseasonal time scales (Chen et al., 2016; Chen & Houze, 1997; DeMott et al., 2015; de Szoeke et al., 2015; Moum et al., 2014). It is unclear to what extent such knowledge and understanding can be applied to the MC, given the presence of its islands. Many features of the MC, absent in open ocean regions, may play essential roles in local air-sea interactions. They include freshwater input from river runoff, strong diurnal cycles in land convection and wind (land-sea breezes), topographic interference with the low-level wind, blocking of surface fluxes by land, tidal mixing, strong ocean advection, and coastally trapped oceanic waves and upwelling (Figure 1b). All these land-related processes would alter the properties of the upper ocean and atmospheric boundary layer. But how they may affect air-sea exchanges remains an unresolved issue. This issue pertains to both the MJO and BSISO. The active fisheries of the region complicate the collection of in situ observations at the air-sea interface.

### 2.7. Troposphere-Stratosphere Interactions

Above the warm pool surrounding the MC lies an extremely cold TTL. High-altitude cirrus preferentially forms and sediments there (Massie et al., 2007). The extremely dry air produced through this process enters the tropical stratosphere before being transported globally through the Brewer-Dobson circulation (Butchart, 2014), thereby influencing global radiative forcing (Solomon et al., 2010) and the polar ozone loss (Shindell, 2001). Gravity waves generated by MC deep convection (Tsuda et al., 2000) propagate upward, interact with the mean zonal flow in the stratosphere, and help produce the quasi-biennial oscillation and the semiannual oscillation. The vertical transport of gas and particles and dehydration/hydration processes in the TTL and, more generally, in the upper troposphere and lower stratosphere are influenced and controlled by deep convection (Iwasaki et al., 2012; Liu & Zipser, 2005), monsoon flows (Pan et al., 2016), diurnal variability including atmospheric tides (Fujiwara et al., 2009), and equatorial waves (Suzuki et al., 2013). These phenomena are common and vigorous in the MC region (Figure 1b), but their effects are heterogeneous as evidenced by the spatial patterns of upper tropospheric and lower stratospheric winds over the MC (Okamoto et al., 2003; Widiyatmi et al., 2001). In situ observations are needed to validate satellite observations and numerical simulations of these processes.

### 2.8. Aerosol

The MC is a major source of different types of aerosol from biomass burning of agriculture practices and deforestation (Reid et al., 2012), industrial pollution (Salinas et al., 2013), and sea spray from surrounding oceans (Shpund et al., 2019). The monsoon circulation and cold surges may bring aerosol from remote locations to the MC. Aerosol sources and effects are confounded by the tropical meteorology related to emissions, transport, and deposition (Reid et al., 2012). Although aerosol may affect fair weather clouds (Ross et al., 2018) and severe storms (Thornton et al., 2017), knowledge about their relation is limited. It is challenging to separate dynamical effects under various meteorological conditions (sections 2.1–2.4) from those of the embedded aerosol themselves (Campbell et al., 2016). It is difficult to obtain information on the abundance and characteristics of “background” aerosol in the MC to contrast with polluted scenarios. We also know little about the characteristics of the local aerosol in terms of their roles as cloud condensation or ice nuclei. These difficulties complicate experimental studies on the interactions between clouds and aerosol. But the MC could be an ideal natural laboratory for such studies because of the rich information to be harvested.

### 2.9. Prediction Improvement

As for many other parts of the world, the major forecast concerns for the MC are extreme or high-impact events, particularly very heavy rain events that can result in floods and landslides. Previous studies have demonstrated that these high-impact events are usually associated with large-scale phenomena such as El Niño–Southern Oscillation (ENSO), Indian Ocean dipole, monsoon surges, the MJO, and synoptic perturbations such as Sumatra squall lines, Borneo vortices, and equatorial waves (Haylock & McBridge, 2001; Lestari et al., 2019). Model errors in the MC spread quickly and degrade predictions in remote regions (Ferranti et al., 1990; Hendon et al., 2000). Improving prediction for the MC depends on better representations of subgrid-scale processes that are critical to scale interactions, particularly related to the diurnal cycle (Love et al., 2011), and systematic biases in mean precipitation (Martin et al., 2006).

## 3. YMC Goal, Objectives, Themes, and Activities

The overarching goal of YMC is *observing the weather-climate system of the Earth's largest archipelago to improve understanding and prediction of its local variability and global impacts*. To help reach this goal, YMC strives to achieve the following objectives: (i) building a comprehensive and accessible data set of the MC weather climate system, (ii) advancing modeling and prediction capability, and (iii) educating the next generation of scientists in the region. YMC targets five science themes: Atmospheric Convection, Upper-Ocean Processes and Air-Sea Interactions, Stratosphere-Troposphere Interactions, Aerosol, and Prediction Improvement. These themes are motivated by scientific needs described in section 2. YMC engages five main activities: data sharing, field campaign coordination, modeling, prediction and its applications, and outreach and capacity building. Considering the complexity of multiscale interactions among the various prominent phenomena discussed in section 2, YMC encourages field campaigns at different locations and time using all possible observing platforms. YMC sets the field campaign period from July 2017 through February 2021 as Phase 1 with intensive observations on specific phenomena on time scales shorter than 1–2 months, supplemented by long-term observations provided by the MC local operational agencies and by special land-based or mooring systems. During Phase 2, YMC will evaluate the progress in our understanding of key processes, modeling capabilities, prediction skills, and capacity building under the YMC framework and develop tighter connections between science, operations, and applications.

YMC is a framework within which relevant projects are coordinated and connected. Table 1 and Figure 1a summarize major observational field campaigns conducted or planned during YMC as of April 2020. They include projects with multinational participations under the framework of or in coordination with YMC and others established outside the auspices of YMC. For example, SCSTIMX (Sui et al., 2020) conducted field campaigns in three intensive observing periods (IOPs) in December 2017, March–April 2018, and May–June 2018 as part of YMC. SCSTIMX also collaborated with PISTON and CAMP<sup>2</sup>Ex, which were established independently of YMC, for a boreal summer monsoon study in 2018 and 2019. Ocean Mixing, a Japan-Indonesia joint project, was coordinated with another Japan-Indonesia-China-United States coastal acoustic tomography experiment to study vertical structures in currents and waves in the Lombok strait, which led to a finding of rapid subsurface temperature changes due to internal solitary waves (Syamsudin et al., 2019). The YMC open data policy allows researchers to combine observational data at different times and locations for further analyses. Figure 1a also shows the radiosonde sounding network operated by the MC regional agencies. They have agreed to provide the scientific community with their original high-resolution data during YMC. Such high-resolution sounding data are usually not available for operational or scientific use. The enhanced soundings (e.g., from twice daily routine operation to 6-hourly soundings) during the IOPs were and will be sent to the Global Telecommunication System (GTS) by the regional agencies to be available for assimilation by prediction centers across the entire world. It is expected that these additional observations help capture atmospheric signals not available in satellite and other operational observations. Other routine data sets, such as those from surface meteorology stations and weather radars, are also being made available at certain sites (not shown). Data available from the YMC IOPs as well as the regional observing networks form the base for the key YMC activity “data sharing.” Links to data archives are provided at YMC data site (<http://www.jamstec.go.jp/ymc/data/>).

**Table 1**
*Intensive Field Campaigns Conducted and Planned by Multinational Participations in the MC Region, Including Projects Under the Framework of or in Coordination With YMC and Those That Have Been Established Outside the Auspices of YMC as of April 2020*

	Project	Main targets	Locations	Period	Main participation
1	YMC Pilot Study (Pre-YMC 2015)	Diurnal cycle and MJO	West coast of Sumatra Island	November–December 2015	Japan and Indonesia
2	Regional Scales of Variability in Precipitation (RSVP)	Air-sea interaction	Off northwest Luzon Island	August 2017	Philippines
3	YMC-Sumatra	Diurnal cycle and MJO	West coast of Sumatra Island	November 2017 to January 2018	Japan, Indonesia, and United States
4	Eastern Indian Ocean Upwelling Research Initiative (EIOURI)	Upwelling and ocean surface structure	Eastern Indian Ocean (EIO)	November 2017 to February 2018 and November–December 2019	China, Indonesia, and United States
5	South China Sea Two-Island Monsoon Experiment (SCSTIMX)	Monsoon	South China Sea (SCS)	December 2017, March–April 2018, and May–June 2018	Taiwan
6	YMC- Boreal Summer Monsoon study (BSM)	BSISO and troposphere-stratosphere interaction	Western Pacific, Laoag, Hanoi, Ho Chi Minh, and Sumatra Island	June–August 2018 and July–August 2020	Japan, Palau, Philippines, Vietnam, and Indonesia
7	Propagation of Intra-Seasonal Tropical Oscillations (PISTON)	BSISO and diurnal cycle	Western Pacific (north of Palau, northeast of Luzon)	August–October 2018 and September 2019	United States, Taiwan, and Philippines
8	MJO and Australian Monsoon Onset Study (MAMOS) /Coupled Warm Pool Dynamics in the Indo-Pacific	MJO, monsoon, and air-sea interaction	EIO (northwest of Australia)	November 2018–	China and Australia
9	Ocean Mixing/Coastal Acoustic Tomography experiment	Tidal mixing and ocean surface structure	Lombok Strait, Flores, Seram, and Halmahera Seas	February–March 2019	Japan, Indonesia, China, and United States
10	Cloud, Aerosol and Monsoon Processes Philippines Experiment (CAMP <sup>2</sup> Ex)	Aerosol-cloud interaction	SCS (Luzon Strait to Sulu Sea) and western Pacific (northeast of Luzon)	August–October 2019	United States and Philippines
11	Tropical observations of atmospheric convection, biogenic emissions, ocean mixing, and processes generating intraseasonal SST variability	Diurnal cycle, MJO, and ocean mixing	EIO (northwest of Australia) and Timor Sea	October–December 2019	Australia, Indonesia, United Kingdom, and Taiwan
12	Equatorial Line Observations (ELO)	Equatorial waves	EIO (south of Java Island)	January–April 2019 and December 2020 to March 2021	United States, United Kingdom, Poland, Indonesia, and France
13	ELO-Oceans	Equatorial waves, MJO, and cold surge	Kalimata Strait	October 2020 to February 2021	United States and Indonesia
14	TerraMaris	Diurnal cycle and MJO	Java Island and EIO (south of Java Island)	December 2020 to March 2021	United Kingdom, Indonesia, and Australia
15	YMC-Banda Sea	Air-sea interaction	Banda Sea	January–February 2021	United States and Indonesia
16	Measuring and Modeling the Indonesian Throughflow Throughflow International Experiment (MINTIE)	Indonesian Throughflow	Makassar, Lombok, Ombai, and Timor Straits	January 2021 to January 2024	United States, Indonesia, Australia, and China
17	Diurnal Cycle Interactions with MJO Propagation (DIMOP)	Diurnal cycle and MJO	Borneo Island	Pending	United States and Indonesia

#### 4. Preliminary Results

There are many recent studies on subjects relevant to YMC (see summaries by Yamanaka et al., 2018; Yoden et al., 2017). Here we briefly discuss results based on either YMC data or events during YMC to date.

A YMC pilot study was conducted in November–December 2015 with R/V *Mirai* deployed off the west coast of Sumatra Island near Bengkulu where a land-based observation site is located. This pilot study led to the YMC-Sumatra 2017 field campaign of the same configuration during November 2017 through January 2018. Both field campaigns were designed to study migration processes of diurnally evolving atmospheric convection and its interactions with the MJO. A clear offshore migration of rainfall from evening to early morning was observed during convectively suppressed periods of the MJO. This suggests a possible role of gravity waves, which can cause ascending motions in the lower troposphere ahead of cumulus convection (Yokoi et al., 2017). The role of gravity waves for the offshore migration has been pointed out in previous studies (Hassim et al., 2016; Love et al., 2011) based on numerical modeling. Yokoi et al. (2017) provided the first observational evidence for this mechanism using radiosonde data of high resolutions in time (3-hourly) and space (50 km) taken simultaneously over the adjacent ocean and land. Observations from the two campaigns demonstrate that the offshore migration of rainfall were modulated differently by large-scale wind patterns during the El Niño in 2015 and La Niña in 2017, respectively (Nasuno, 2019; Yokoi et al., 2019). These results encourage future studies to confirm such multiscale interactions from the diurnal to ENSO cycles. The field campaigns also observed that MJO convection caused a sudden deepening of an oceanic barrier layer from 5–10 to 85 m in 5 days (Moteki et al., 2018). This increased the temperature difference in the lower troposphere between the ocean and land, which in turn may have influenced the behavior of offshore propagation of diurnal convection (Wu et al., 2018). Those oceanic and atmospheric data can be further used to evaluate effects of air-sea interaction on the MJO and diurnal cycle. Another unique example is microphysics observed by videosondes near a coastal region of Sumatra Island. They revealed large numbers of ice crystals in the upper layer of thick stratiform clouds and spherical graupel immediately above the freezing level (Suzuki et al., 2018). This new knowledge may provide clues to processes of lightning over the MC being strongly modulated by the passage of the MJO (Virts et al., 2013). Preliminary results obtained so far suggest possible usage of field campaign data to verify various hypotheses on convective processes over the MC.

Data from those field campaigns have also been used to evaluate numerical models. Dipankar et al. (2019) compared numerical model output against in situ observations from R/V *Mirai* during the 2015 YMC pilot study. They found that a low-sea surface temperature (SST) bias in initial conditions caused a delay of the simulated diurnal cycle of rainfall over land. This result illustrates the importance of accurate initial conditions and suggests that the local circulation can be sensitive to air-sea interaction. Meanwhile, observed cases during YMC have been targeted for numerical modeling. In a study focusing on heavy rainfall events observed in October 2017, Porson et al. (2019) examined predictions of convective rainfall over Singapore using convection-permitting regional model ensembles nested within two global ensembles. They found no clear difference of using one global ensemble versus the other, but their combination yields better results. It is expected that additional modeling studies will incorporate YMC data of high temporal resolution, even though some of them are not available for operational use in real time. There are other parameters observed by specially deployed instruments such as C-band polarized weather radar that can be assimilated into regional high-resolution data products, allowing more detailed evaluations of numerical model performance. We anticipate additional cases studies combining in situ field campaign data with numerical models.

There are many other studies motivated by YMC and addressing YMC issues using data from satellites, global reanalysis products, and numerical models. These studies cover a wide range of topics, such as the diurnal cycle (Baranowski et al., 2019), MJO propagation over the MC (Burleyson et al., 2018; Pang et al., 2018) and its barrier effect (DeMott et al., 2018; Ling et al., 2019), atmospheric waves (Ruppert & Zhang, 2019; Takasuka et al., 2019), aerosol (Bagtasa et al., 2018; Cohen et al., 2018; Koplitz et al., 2018), the monsoon (Diong et al., 2019; Duan et al., 2019), the ITF and the ocean in general (Cao et al., 2019; Gordon et al., 2019; Hu et al., 2019; Liang et al., 2019), and prediction and predictability (Wang et al., 2019).

#### 5. Cross-Organization Special Collection

YMC has motivated a surge of research activities on various topics related to the MC. Research articles on these topics have been and will be published in a wide range of international journals. In particular, a



number of publications will result from each YMC field campaign. To better serve readers who are interested in YMC and the MC in general, a cross-organization special collection of journal articles on the YMC topics has been arranged by the YMC Science Steering Committee and seven professional organizations: the *American Geophysical Union*, the *American Meteorological Society*, the *Australian Meteorological and Oceanographic Society*, the *Chinese Geoscience Union*, the *European Geosciences Union*, the *Meteorological Society of Japan*, and the *Royal Meteorological Society*. This special collection provides a list of all contributing articles at a single site for readers who otherwise would have to search through individual journals. The participating journals are listed in Table S1 in the supporting information.

Authors who are interested in publishing in this special collection are encouraged to submit their manuscripts to their preferred journals. Articles accepted by the participating journals after their regular review processes will be included in a master list hosted at the YMC website ([http://www.jamstec.go.jp/ymc/ymc\\_sp\\_collection.html](http://www.jamstec.go.jp/ymc/ymc_sp_collection.html)). A link to this master list is provided at the special collection webpage of each participating journal/organization. This special collection covers 2020–2025. Authors of articles on the YMC topics published in 2017–2019 in the participating journals may request their papers to be retrospectively included in the special collection. Open access is highly encouraged for articles in this special collection.

## 6. Concluding Remarks

YMC started its first field campaign as a pilot study during 2015. Other field campaigns have been conducted since July 2017, and more are scheduled to take place through 2021 and beyond. This article briefly summarizes the scientific background, needs, objectives, research themes, major activities, and preliminary results of YMC with suggestions of possible research advancement from previous studies. YMC adopts an open data policy, which requires field campaign participants to release quality-controlled data within 1 year after the completion of their field observations. It is anticipated that data from YMC field campaigns and MC operational observing networks will, in combination with other global data (satellite and data assimilation products) and in integration with numerical models, expedite the progress toward understanding and predicting the weather-climate system of the MC and its global impacts.

## Data Availability Statement

Links to YMC data repositories are available online (at <http://www.jamstec.go.jp/ymc/>).

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