Years of the Maritime Continent

K. Yoneyama[1] and C. Zhang[2]

[1] Japan Agency for Marine-Earth Science and Technology, Yokosuka, Japan
[2] NOAA Pacific Marine Environmental Laboratory, Seattle, WA, US

Corresponding author: Kunio Yoneyama (yoneyamak@jamstec.go.jp)

Key Points:

- The Indo-Pacific Maritime Continent (MC) plays a pivotal role in global weather-climate.
- Years of the Maritime Continent (YMC) is an international program for improving understanding and prediction of local variability of the MC and its global impact.
- Preliminary results from YMC reveal new information of physical processes key to multi-scale variability in the MC.

Abstract

Years of the Maritime Continent (YMC) is a multi-year international program with participants from over 15 countries. Its overarching goal is to expedite the progress of improving understanding and prediction of local oceanic and atmospheric multi-scale variability of the Indo-Pacific Maritime Continent (MC) and its global impact through observations and modeling exercises. YMC is motivated by the unique role of the MC in the local and global weather-climate system, our lack of understanding of the key processes governing this role, and persistent systematic regional biases and errors in numerical models. YMC builds a comprehensive database of the MC weather-climate system and educates the next generation of scientists who will be the core workforce and leaders to further advance the study of the MC.

1. Introduction

The Indo-Pacific Maritime Continent (MC) is a unique mixture of over 22,000 islands in the mid 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 continuum. 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, 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 wavetrains that emanate out of the tropics and influence weather at higher latitudes. MJO teleconnections sensitively depend on the location of its convection center relative to the MC. The MC is, however, a known barrier for MJO propagation. Because of atmospheric deep convection penetrating the tropopause and generating gravity waves, the MC is a primary spot for vigorous stratosphere-troposphere interactions. The Indonesian Throughflow (ITF), the artery connecting the tropical Pacific and Indian Oceans, is a crucial branch of the global ocean circulation that affects climate in the region and afar. With many sources of natural and anthropogenic aerosol, the MC is an ideal natural laboratory to study their interactions with the rest of the weather-climate system.

Current global climate models and weather prediction models suffer from persistent systematic biases in precipitation and limited predictions skills in the MC region. They cannot reproduce the observed diurnal cycle and they exaggerate the MJO barrier effect of the MC.

Years of the Maritime Continent (YMC), a multi-year international project, is organized to expedite the progress of improving understanding and prediction of local multi-scale variability of the MC weather-climate system and its global impact 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

2.1 Diurnal Cycle

The diurnal cycle can be considered the heart beat of the weather-climate system in the MC. Rainfall starts near coasts in the local afternoon and reaches its peak in early night. Around midnight, rainfall moves from the land to water, where it reaches its maximum in the early morning, with extensive anvils and stratiform rain that gradually dissipate around local noon. 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; Mori et al., 2004). The convective diurnal cycle is determined by factors such as land-sea breezes, topography, meso-scale convective systems (MCSs), gravity waves, etc. (Houze et al., 1981; Hadi et al., 2002; Mapes et al., 2003; Sakurai et al., 2005). Numerical models cannot correctly represent these factors and thus produce common systematic errors in the timing and amplitude of the diurnal cycle (Takayabu & Kimoto, 2008; Sato et al., 2009; Love et al., 2011; Folkins et al., 2014). 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; Tian et al., 2006; Ichikawa & Yasunari, 2007; Rauniyar & Walsh, 2011; Peatman et al., 2014). Relative contributions to the diurnal cycle in rainfall from land surface conditions, island geometry, air-sea interaction, and background flows, and feedbacks from the diurnal cycle to the large-scale variability need to be quantified.

2.2 Synoptic Systems

Cold surges and Borneo vortices are common in boreal winter. 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). The intensity of Borneo vortices is often modulated by cold surges. They both affect convection, MCS and even tropical depression (Chang et al., 2005, 2016). The exact nature of the interaction among these synoptic perturbations and with the diurnal cycle, MJO, monsoons have yet to be fully understood.

2.3 Intraseasonal Oscillations

The MC exerts a barrier effect on the MJO by weakening it or completely stopping it from propagating through (Rui & Wang, 1990; Zhang & Ling, 2017). This barrier effect is often exaggerated in numerical models (Kim et al., 2009; Seo et al., 2009), creating a "Maritime Continent prediction barrier" for the MJO (Weaver et al., 2011; Fu et al., 2013). Global impact of the MJO (Fig. 1) depends on longitudinal locations of its convection center. Possible reasons for the barrier effect include: a reduced surface moisture source because of the land coverage (Sobel et al., 2010), topographic interference with the low-level flow (Hsu & Lee, 2005; Inness & Slingo, 2006; Wu & Hsu, 2009), and an energy drain by the perpetual diurnal cycle in precipitation over land (Neale & Slingo, 2003). Studies on the barrier effect must cover mechanisms for both its causes and overcoming.

Air-sea interaction has been proposed as a mechanism for the northward propagation of the boreal summer intraseasonal oscillations (BSISOs) (Hsu & Weng, 2001; Fu et al., 2003; Bellon et al., 2008). It has yet to be confirmed that this mechanism is at work over the MC, given the presence of the islands as well as other processes such as the MJO and synoptic perturbations (Chen & Murakami, 1988; Lawrence & Webster, 2002; Wang et al., 2009).

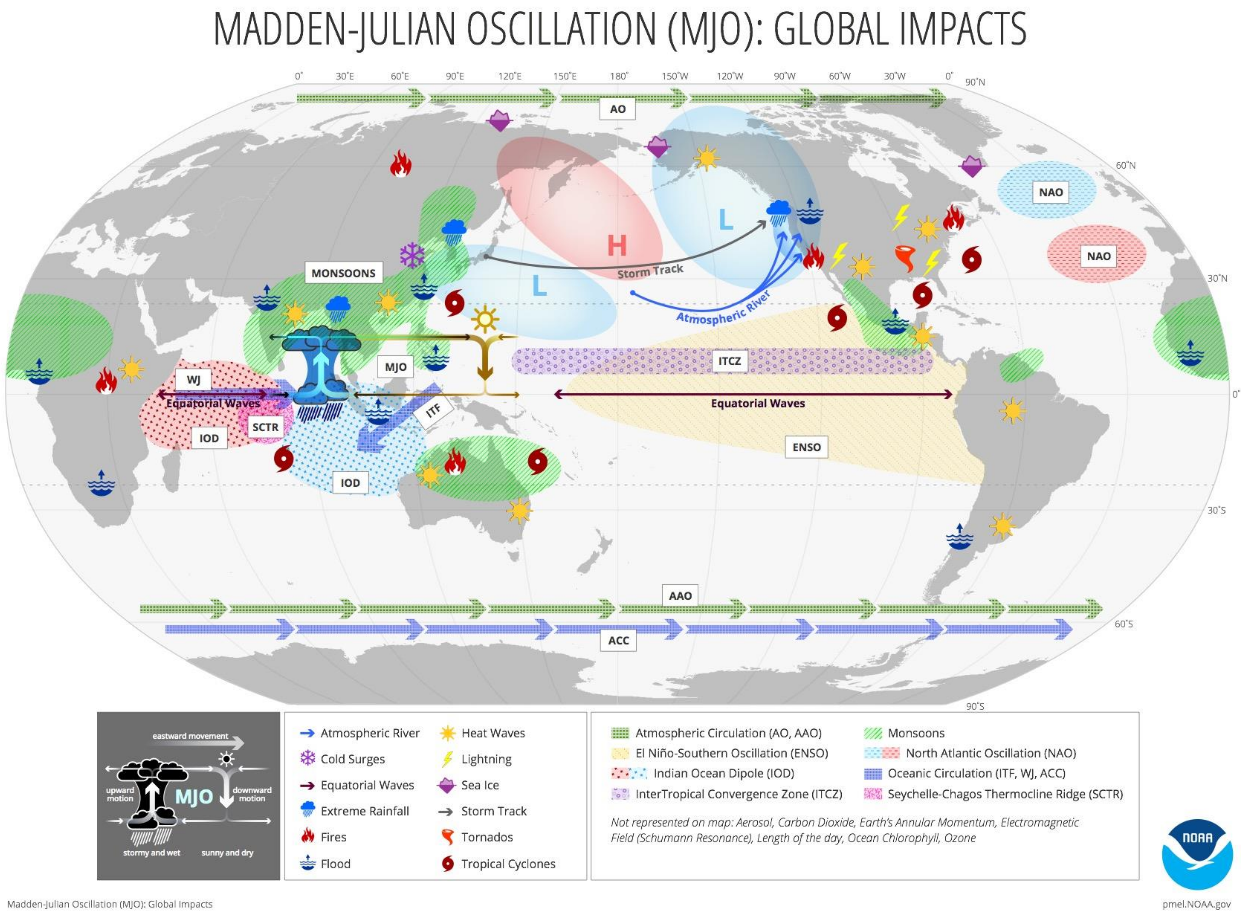

Figure 1. Schematic illustration of global impact of the MJO. The locations of the symbols are not meant to be precise. Included MJO-affected phenomena are incomplete.

2.4 Monsoons

The MC is a crossroad of the East Asian monsoons. There, the seasonal cross-equatorial flows switch between northerlies in boreal winter to southerlies in boreal summer. They 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, and the Indo-Australian monsoon onset often coincides with the arrival of the first MJO event (Hendon & Liebmann, 1990). During boreal summer, the mean monsoon flow is a major moisture supply to the rainfall over the South China Sea and the Philippine Sea (Murakami & Matsumoto, 1994; Wang, 2006; Kubota et al., 2011) and may provide mechanisms for the northward propagation of BSISO when interacting with small-scale convective systems (Jiang et al., 2004; Bellon & Sobel, 2008; 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 plays an essential role in the regional climate (Lee et al., 2002) as well as the MC Sea heat and salt budgets (Kida & Wijffels, 2012). 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 (Wang et al., 2006; Gordon et al., 2012). The complex array of shallow and deep marginal seas in the MC forms an integral component of the larger-scale ocean and climate, responding to and in turn influencing those systems. 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 layers and a warm mixed layer that trap surface fluxes (Sprintall et al., 2014). The upper ocean is influenced by many factors on various time scales. These factors include the monsoonal winds (Gordon & Susanto, 2001; Qu et al., 2005), ocean Kelvin waves (Drushka et al., 2010; Pujiana et al., 2013), the MJO (Napitu et al., 2015), inertial mixing (Alford & Gregg, 2001), tidal mixing (Ffield & Gordon, 1996; Koch-Larrouy et al., 2010), and lateral advection (Kida & Richards, 2009).

2.6 Air-Sea Interactions

Through TOGA COARE (Webster & Lukas, 1993), 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 timescales (Chen and Houze, 1997; Moum et al., 2014; DeMott et al., 2015; de Szoeke et al., 2015). It is, however, unclear to what extent such knowledge and understanding can be applied to the MC, given its intricate geographic setting. Many features of the MC are absent from open oceans but 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 low-level wind, blocking of surface fluxes by land, tidal mixing, strong ocean advection, and coastally trapped oceanic waves and upwelling. Making in situ surface observations in the region remains a challenge due to heavy marine traffic. A key unresolved issue is the role of land-related processes in air-sea interactions of the MC.

2.7 Troposphere-Stratosphere Interactions

Above the warm pool embedding the MC lies an extremely cold tropical tropopause layer (TTL). Where high altitude cirrus preferentially forms and sediments (Massie et al., 2007), and extremely dry air enters the tropical stratosphere before being transported globally through the global equator-to-pole Brewer-Dobson transport circulation (Butchart, 2014), and thus influencing global radiative forcing (Solomon et al., 2010) and 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 semi-annual oscillation. The transport of gas and particles in the TTL and more generally, in the upper troposphere and lower stratosphere, and dehydration/hydration processes are influenced and controlled by deep convection (Liu and Zipser, 2005; Iwasaki et al., 2012), diurnal variability including atmospheric tides (Fujiwara et al., 2009), and equatorial waves (Suzuki et al., 2013), all of which are common and vigorous in the MC region. Tropospheric-lower stratospheric winds exhibit geographical differences in the MC (Widiyatmi et al., 2001; Okamoto et al., 2003). In situ observations of these processes are needed for validation of satellite observations and numerical simulations.

2.8 Aerosol

The MC is a major source of different types of aerosol from biomass burning of agriculture practice and deforestation (Reid et al., 2012), industrial pollution due to economic development (Salinas et al., 2013), and sea spray from surrounding oceans with frequent high-wind events (Shpund et al., 2019). The monsoon circulation and cold surges may bring aerosol from remote sources to the MC. The response of local convective clouds to fluctuations in aerosol is unclear for several reasons. It is challenging to separate dynamical effects under various meteorological conditions (ENSO, monsoons, MJO, synoptic perturbations, diurnal cycle) from those of the embedded aerosol themselves (Campbell et al., 2016). Very little is known about 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 make the region an almost ideal natural laboratory for experimental studies on interactions between tropical clouds and aerosol.

2.8 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 rainfall events that can result in flash floods, landslides and large-scale inundation. Experience tells that they are usually associated with large-scale phenomena such as ENSO, Indian Ocean dipole, monsoon surges, the MJO, and synoptic perturbations such as Sumatra squall lines, Borneo vortices, and equatorial waves. Model errors in the MC spread quickly around the globe (Ferranti et al., 1990; Hendon et al., 2000). Improving prediction for the MC depends on better representations of sub-grid 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 impact.* To help reach this goal, YMC strives to achieve the objectives of (i) Building a comprehensive database 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 the previous section. YMC engages five main activities: Data Sharing, Field Campaigns, Modeling, Prediction and Applications, and Outreach and Capacity Building. By considering complexity of multi-scale interactions among dominant various temporal-spatial modes, YMC encourages field campaigns at different locations and time using all possible platforms of observations. YMC sets the field campaign period from July 2017 through February 2021 as Phase-1 with intensive observations on specific topics shorter than 1-2 months in addition to long-term observations by the MC local operational agencies and by special land-based or mooring systems. During Phase-2, the participants will evaluate the improvements of our knowledge on processes, modeling simulation and prediction skills, and capacity building under the YMC framework with tighter relations between science, operations, and applications.

Table 1. IOPs conducted and planned by multi-national participation.

	Project	Main Targets	Locations	Time	Main Participation
1	YMC Pilot Study	Diurnal cycle, MJO	Sumatra Is.	Nov. - Dec. 2015	Japan, Indonesia
2	Sea-Air-Land Interaction in the Context of Archipelago (SALICA)	Air-sea interaction	Western Pacific	Aug. 2017, Aug. - Oct. 2018	Philippines, US
3	YMC-Sumatra	Diurnal cycle, MJO	Sumatra Is.	Nov 2017 - Jan. 2018	Japan, Indonesia, US
4	South China Sea Two-Island Monsoon Experiment (SCSTIMX)	Monsoon	South China Sea (SCS)	Dec. 2017, May - Jun. 2018, Aug. - Oct. 2018	Taiwan, US
5	YMC- Boreal Summer Monsoon (BSM)	BSISO, Troposphere-Stratosphere interaction	Western Pacific, Vietnam, Sumatra Is.	Jun. - Aug. 2018	Japan, Palau, Philippines, Vietnam, Indonesia
6	Propagation of Intra-Seasonal Tropical Oscillations (PISTON)	BSISO, Diurnal Cycle	Western Pacific	Aug. - Oct. 2018, Sept. 2019	US, Taiwan, Philippines
7	MJO and Australian Monsoon Onset Study (MAMOS) & Coupled Warm Pool Dynamics in the Indo-Pacific	MJO, Monsoon, Air-sea interaction	Eastern Indian Ocean (EIO)	Nov. 2018 - Oct. 2019	China, Australia
8	Ocean Mixing & Coastal Acoustic Tomography (CAT)	Tidal mixing	Indonesian Seas	Feb. - Mar. 2019	Japan, Indonesia, China, US
9	Cloud, Aerosol and Monsoon Processes Philippines Experiment (CAMP2Ex)	Aerosol-cloud interaction	SCS, Western Pacific	Aug. - Oct. 2019	US, Philippines
10	Tropical observations of atmospheric convection, biogenic emissions, ocean mixing, and processes generating intraseasonal SST variability	Diurnal cycle, MJO, Ocean mixing	EIO, Timor Sea	Oct. - Dec. 2019	Australia, Indonesia, UK, Taiwan
11	Equatorial Line Observations (ELO)	Equatorial waves	EIO, Indonesian Seas, Sumatra Is.	Jan. - Apr. 2019, Jan. - Feb. 2020	US, UK, Poland, Indonesia
12	TerraMaris	Diurnal cycle, MJO	South of Java Is.	Jan. - Feb. 2021	UK, Indonesia, Australia
13	YMC-Banda Sea	Air-sea interaction	Banda Sea	Jan. - Feb. 2021	US, Indonesia
14	Modeling Indonesian Throughflow International Experiment (MINTIE)	Indonesian Throughflow	Indonesian Seas	Jan. - Feb. 2021 Jan. - Feb. 2022	US, Indonesia, Australia, China
15	Diurnal Cycle Interactions with MJO Propagation (DIMOP)	Diurnal cycle, MJO	Borneo Is.	Pending	US, Indonesia

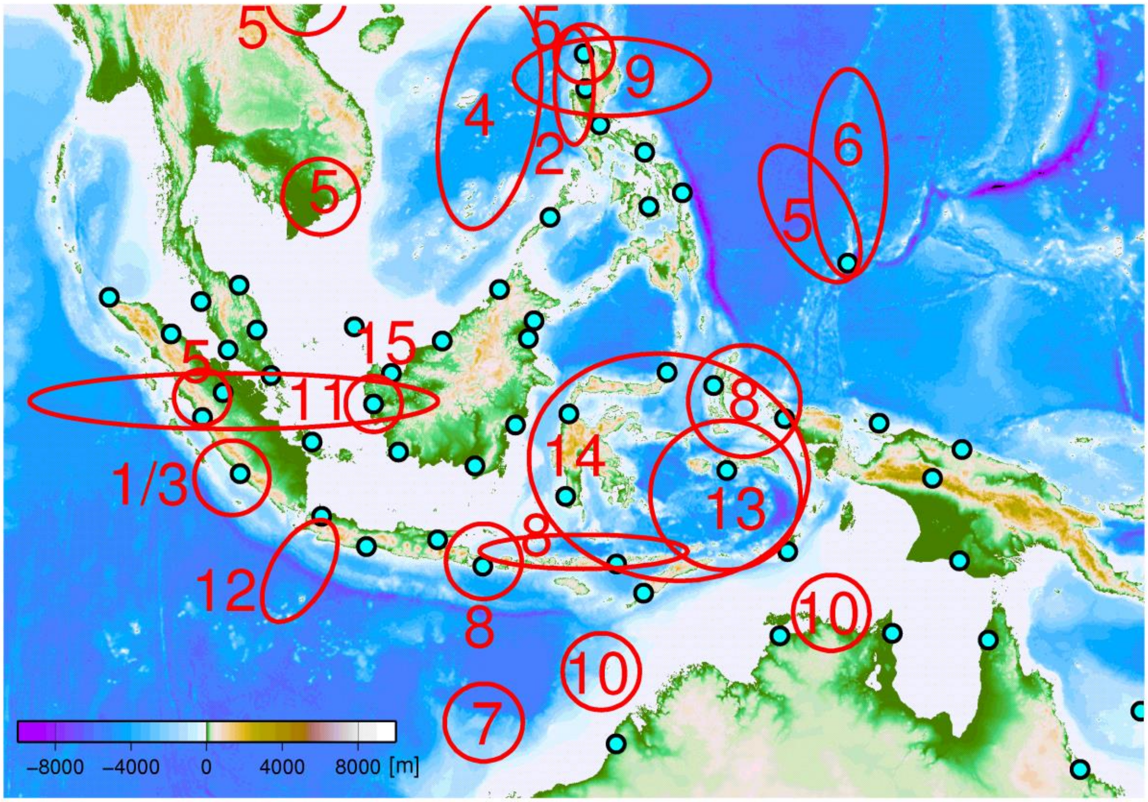

Figure 2. Areas of IOPs (red circle). Numbers correspond to ones indicated in Table 1. Blue dots indicate radiosonde sounding stations operated by the participating MC meteorological agencies.

Table 1 and Fig. 2 summarize major Intensive Observation Periods (IOPs) conducted or planned during YMC as of December 2019. They cover the campaigns with multi-national participations under the framework of or in coordination with YMC. Various types of coordination have been accomplished among those projects. For example, while US projects PISTON and CAMP^{2}Ex conducted their observations as their own international efforts, they also collaborated with SALICA and SCSTIMX projects. Japan-Indonesia joint project Ocean Mixing was coordinated with another Japan-Indonesia-China-US project CAT to study ITF 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 observation data obtained from different periods and/or areas for further analyses. Figure 2 also shows the radiosonde sounding network by the MC local agencies. They have agreed to provide the scientific community with their original high-resolution data during YMC Phase-1. Such high-resolution soundings are usually not available for operational or scientific use. It is highly expected that they help capture large-scale atmospheric features not available from satellite and other routine observing systems. In addition, other routine data sets such as those from surface meteorology stations and scanning weather radars will also be available at some sites (not shown here). Data available from the YMC IOPs as well as the regional observing networks form the base for the action of "Data Sharing" as a key YMC activity. Data archive as well as information on the campaigns are available from YMC website at http://www.jamstec.go.jp/ymc/.

4. Preliminary Results

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

A YMC pilot study was conducted in November - December 2015 with R/V Mirai deployed offshore of 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 setting 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 might cause ascending motions in the lower troposphere ahead of cumulus convection (Yokoi et al., 2017). Westward moving diurnal convection over the western coast of Sumatra may converge with mesoscale convective systems of the eastward propagating MJO and immediately cause torrential rain along the coast (Wu et al., 2017). These behaviors can be modulated by large-scale wind patterns during the El Niño in 2015 or La Niña in 2017, respectively (Nasuno, 2019; Yokoi et al., 2019). Also observed is an effect of MJO convection on a sudden deepening of an oceanic barrier layer from 5-10 m to 85 m in 5 days (Moteki et al., 2018). This widened the temperature difference in the lower troposphere between the ocean and land, which may influence the behavior of offshore propagation of the diurnal convection (Wu et al., 2018). Videosonde observations near a coastal region of Sumatra Island revealed large numbers of ice crystals in the upper layer of the thick stratiform clouds and spherical graupel immediately above the freezing level (Suzuki et al., 2018). All results above mentioned are based on in-situ measurements. Such unique high-resolution data offer the opportunity to evaluate previous numerical modeling studies such as the role of gravity waves in rainfall offshore migration (Hassim et al., 2016), the impact of the MJO on the ocean (Shinoda et al., 2016), etc. It is also possible to expand previous studies, which were done from large-scale viewpoints. For example, Kubokawa et al. (2016) showed that temperature perturbations in the TTL over the mountainous regions of the MC are 1-2 K larger than those measured in regions of lower elevation, which they attributed as topography effect. YMC data obtained around the coastline may fill the gap of details in such topography differences. Besides, microphysics obtained by videosondes may provide a clue to study lightning activity over the MC, where diurnal lightning variability is strongly modulated by the passage of the MJO (Virts et al., 2013). Preliminary results obtained so far suggest possible usage of campaign data to verify various hypotheses for convective processes over the MC.

Data from those field campaigns also have been used to evaluate numerical models. Dipankar et al. (2019) used in situ observations from R/V Mirai during the 2015 YMC pilot study to assess numerical model skills. They found that a low-SST bias in initial conditions caused a delay of simulated diurnal cycle of rain over land. Meanwhile, observed cases during YMC have been targeted for numerical modeling. In a case study focusing on heavy rainfall events observed in October 2017, Porson et al. (2019) examined prediction skills of convective rainfall over Singapore using convection-permitting regional model ensembles nested within two global ensembles. They found no clear advantage of using one global ensemble over the other, but their combination gives better results. It is expected that more modeling studies will use YMC data that are of high resolution in time, even though they may not be available for operational use. When other parameters observed by specially deployed instruments such as C-band polarized weather radar are assimilated into regional high-resolution data products, more detailed evaluation of numerical models will be possible. Thus, more cases can be studied by combining in-situ field campaign data with operational numerical models.

There are many other studies motivated by YMC and/or addressing YMC issues using data from satellites, global reanalysis products, and numerical models. These studies cover a wide range of topics; 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), prediction and predictability (Wang et al., 2019), and others.

5. A Cross-Organization Special Collection

YMC has motivated a surge of research activities on various topics related to the MC. Publications on these topics have been and will be published in a wide range of international journals. Particularly, each YMC field campaign will be followed by a number of publications dedicated to it. To better serve readers who are interested in YMC and the MC in general, it is desirable to establish a cross-organization special collection of journal articles on the YMC topics, so that readers can see a list of the entire collection at a single stop instead of going through each journal of these organizations. This collection on YMC has been arranged by the YMC Science Steering Committee and seven professional organizations in the fields of atmospheric and oceanic sciences. These professional organizations are *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*. Table 2 lists the journals of these organizations that participate in the special collection.

Authors who are interested in publishing in this cross-organization special collection on YMC 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). 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.

Table 2. List of journals that participate in the cross-organization special collection on YMC

Journal	Organization
Atmospheric Chemistry and Physics	*The European Geosciences Union*
Atmospheric Science Letters	*The Royal Meteorological Society*
Bulletin of the American Meteorological Society	*The American Meteorological Society*
Earth and Space Science	*The American Geophysical Union*
Geophysical Research Letters	*The American Geophysical Union*
International Journal of Climatology	*The Royal Meteorological Society*
Journal of Advances in Modeling Earth Systems	*The American Geophysical Union*
Journal of Climate	*The American Meteorological Society*
Journal of Geophysical Research – Atmospheres	*The American Geophysical Union*
Journal of Geophysical Research – Oceans	*The American Geophysical Union*
Journal of Physical Oceanography	*The American Meteorological Society*
Journal of Southern Hemisphere Earth Systems Science	*The Australian Meteorological and Oceanographic Society*
Journal of the Atmospheric Sciences	*The American Meteorological Society*
Journal of the Meteorological Society of Japan	*The Meteorological Society of Japan*
Monthly Weather Review	*The American Meteorological Society*
Nonlinear Processes in Geophysics	*The European Geosciences Union*
Ocean Science	*The European Geosciences Union*
Quarterly Journal of the Royal Meteorological Society	*The Royal Meteorological Society*
Scientific Online Letters on the Atmosphere	*The Meteorological Society of Japan*
Terrestrial, Atmospheric and Oceanic Sciences	*The Chinese Geoscience Union*
Weather and Forecasting	*The American Meteorological Society*

6. Concluding Remarks

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

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