YEARS OF THE MARITIME CONTINENT
(July 2017 – July 2019)

– *Observing the weather-climate system of the Earth's largest archipelago to improve understanding and prediction of its local variability and global impact*

SCIENCE PLAN
(draft)

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EXECUTIVE SUMMARY

The Maritime Continent (MC), a unique mixture of land and ocean straddling the equator between the Indian and Pacific Oceans, is the largest archipelago on Earth. It is known for its complex geophysical setting, its marine and land biodiversity, and its rich human history and culture. Sitting in the middle of the warmest body of water known as the Indian and western Pacific warm pool, the MC plays a pivotal role in the global weather-climate continuum. The complex land-sea distribution and topography make prediction of high-impact events in this region extremely challenging.

The intricacy of land, sea and terrain of the MC cultivates intriguing multi-scale variability in rainfall and in the circulation, which breeds high-impact events such as flood and drought. Predicting extreme events associated with the diurnal cycle, synoptic weather systems, the Madden-Julian Oscillation (MJO), and the monsoons is of paramount socioeconomic benefit to the region.

The MC hosts one of the major equatorial atmospheric convection centers. The tremendous energy released by convective condensation over the MC fuels the global atmospheric circulation. Rossby wavetrains excited by MC convection emanate toward higher latitudes. The atmospheric large-scale upward motion associated with MC convection constitutes the ascending branch of the Walker Circulation, the interannual zonal migration of which is a key ingredient of the El Niño – Southern Oscillation (ENSO) variability. Teleconnections related to the MJO are strongest when its convection is centered over the MC. But the MC is a known barrier for the eastward propagation of the MJO. Atmospheric deep convection penetrating the tropopause over the MC makes it a primary spot for vigorous stratosphere-troposphere interaction. The Indonesian Throughflow (ITF), the artery connecting the tropical Pacific and Indian Oceans, is a crucial link of the ocean general circulation that affects not only properties of these two oceans but also global climate. Coastal upwelling near Sumatra is a key ingredient of the Indian Ocean Dipole (IOD), an essential element of the regional climate.

Unfortunately, current state-of-the-art global climate models (GCMs) and numerical weather prediction (NWP) models suffer from persistent systematic errors and limited predictions skill in the MC region. They cannot reproduce the observed diurnal cycle of precipitation over the MC. They exaggerate the MJO barrier effect of the MC. They suffer from systematic dry and wet biases in precipitation in the MC region. Even models with the highest resolutions cannot reproduce observed rainfall variability and associated dynamical features in the MC region. Prediction skill of rainfall, especially its extreme events, in the MC is very limited.

"Years of the Maritime Continent (YMC)" is a two-year (July 2017 – July 2019) project. Its overarching goal is 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 modeling exercises.

YMC includes five science themes:

Theme 1: Atmospheric Convection. To advance understanding of physical processes governing diurnal, synoptic, intraseasonal and seasonal variability of atmospheric convection and their interaction under the influence of the complex land-sea distribution and topography.

Theme 2: Upper-Ocean Processes and Air-Sea Interaction. To advance understanding of controlling processes for the multi-scale diurnal, intraseasonal and seasonal variability of the ocean and air-sea interaction in the MC region under the influence of extremely complex bathymetry and islands.

Theme 3: Stratosphere-Troposphere Interaction. To advance understanding of processes governing the dynamical coupling of the stratosphere and troposphere and their mass exchanges over the MC.

Theme 4: Aerosol. To advance understanding of key processes by which the multi-scale variability and interaction of convection and circulation affect the production, transport, and disposition of aerosol and their interaction with clouds in the MC.

Theme 5: Prediction improvement. To improve representations of key processes in weather and climate models through use of field observations and improved understanding.

YMC will engage five main activities:

Data Sharing: Through collecting, archiving, and sharing data from observing networks in the MC region, satellites, and NWP products, build a two-year (July 2017 – July 2019) comprehensive database for detailed documentation of multi-scale variability and interaction of the MC weather-climate system.

Field Campaign: Collect special observation through a two-year (July 2017 – July 2019) field campaign to advance our understanding of physical processes key to the multi-scale variability and interaction of the MC weather-climate system.

Modeling: Quantify biases/errors of numerical models and the potential for improvement of prediction and simulation skill, and improve physical understanding through coordinated numerical experiments.

Prediction and Applications: Demonstrate prediction improvement through model improvement and assimilating supplementary data from activities 1 and 2; Study optimizations of targeted prediction products for users, information disassembling through modern media, and support to emergency management.

Outreach and Capacity Building: Educate the general public about the MC weather-climate system, its local variability and global impacts; Train the next generation of scientists, forecasters, and technicians for future research, operations, and applications of prediction and simulation tools.

In summary, through international collaboration and coordination, integrating observations and modeling, bridging research and operations, and outreach and capacity building, YMC strives to advance at an unprecedented pace our understanding and prediction of the MC weather-climate systems for socioeconomic benefit both locally and globally.

1. INTRODUCTION

The Maritime Continent (MC) of the Indian and Pacific Ocean is a unique mixture of land and ocean. This largest archipelago on Earth consists of more than 17,000 islands, including the world's second and third largest (see the cover page). The MC is known for its marine and land biodiversity, and its rich human history and cultures. Sitting in the middle of the warmest body of water known as the Indian and western Pacific warm pool, the MC plays an unmatched role in the weather-climate continuum of the region and the world (Ramage 1966). The complex land-sea distribution and topography make prediction of high-impact events in this region extremely challenging.

The MC is at the center of global multi-scale interactions involving the global mean circulation and variability on a wide range of timescales including convective, diurnal, synoptic, intraseasonal, seasonal, interannual, decadal, and longer periods (McBride 1998; Chang et al. 2004a). It hosts one of the major equatorial atmospheric convection centers. The tremendous energy released by convective condensation fuels the global atmospheric circulation (Chang and Lau 1982; Lau et al. 1983; Sardeshmukh and Hoskins 1988). The atmospheric large-scale upward motion associated with the MC convective center constitutes the ascending branch of the Walker Circulation (Bjerknes 1969), with its interannual zonal migration being a key manifestation of the ENSO variability (Philander 1985).

Both the summer and winter East Asian/Australian monsoons have their footprints over the MC (Meehl 1987; Wang 1994). With its complex coastal lines and terrain, the MC causes asymmetry in both latitudinal extension and temporal transition of the two monsoons (Chang et al 2005). The seasonal cycle of rainfall in the MC, known as the Maritime Continent monsoon (Chang et al 2005; Robertson et al. 2011), exhibits substantially different characteristics among different islands. Some islands undergo distinct wet vs. dry seasons with opposing phases; others receive almost perennial rainfall. The seasonal march of the monsoon onset and withdrawal appears from both the west (Indochina) and east (Australia) as seen in cloud activity (Matsumoto 1992; Matsumoto and Murakami 1994).

The Madden-Julian Oscillation (MJO) often brings the onset of the austral summer monsoon and the rainy season (Hashiguchi et al. 1995) and induces intraseasonal rainfall variability in the MC (Hidayat and Kizu 2010). Probabilities of many global hazards (e.g., tropical cyclones, cold surges, extreme rainfall, lightning, and flood) depend on whether an MJO convection center is stalled over the eastern Indian Ocean, passes over the MC, or moves into the western Pacific (Zhang 2013). MJO-related teleconnections are strongest when MJO convection is over the MC (Adames and Wallace 2014). The MC is, however, a known barrier for the eastward propagation of the MJO (Nitta et al. 1992). Nearly 40% of MJO events over the Indian Ocean fail to propagate through the MC.

Unique synoptic perturbations (e.g., Borneo vortices) help organize and sustain convective systems beyond their individual lifespans and create distinct local weather patterns (Johnson and Houze 1987; Chang et al. 2003). The mean and variability of rainfall over the MC are also influenced by many other synoptic perturbations, such as equatorial waves, cold surges, and tropical cyclones. They can cause sequential flooding events over a broad region of Southeast Asia (Wu et al. 2007; Yokoi et al. 2008).

The intricacy of land, sea and terrain in the MC region cultivates atmospheric convective systems with an intriguing diurnal cycle (Houze et al. 1981; Johnson and Priegnitz 1981; Williams and Houze 1987; Yang and Slingo 2001; Keenan and Carbone 2008; Kanamori et al 2013). The diurnal cycle is modulated by the large-scale variability, such as the MJO, monsoon, IOD, and ENSO (Murata et al. 2002; Sakurai et al. 2005; Rauniyar and Walsh 2011; Peatman et al. 2014). The multi-scale (diurnal, synoptic, intraseasonal, seasonal, and interannual) variability of rainfall nourishes the agriculture but also breeds damaging extremes in the MC region, such as severe storms, floods and droughts (Aldrian and Djamil 2008; Tangang et al. 2008; Wu et al. 2007 and 2013; Tabata et al., 2011b). The complex geographical setting, multi-scale variability, and models' difficulty at simulating convection in this region at all time and space scales make prediction of rainfall, especially its extreme events, in the MC region daunting challenges.

Frequent deep atmospheric convection penetrating through the tropopause over the MC makes it a primary spot for vigorous stratosphere- troposphere interaction. Approximately 83% of the global tropospheric air mass that enters into the tropical tropopause layer and 71% that enters the stratosphere does so over the MC and western Pacific (Fueglistaler et al. 2004). This marks the importance of the MC in large-scale stratospheric variations, such as stratospheric sudden warming, polar vortex intensification , the quasi-biennial oscillation, the semi-annual oscillation (SAO), etc., all having great global impacts.

The Indonesian Throughflow (ITF) is the only artery connecting two tropical oceans: the Pacific and Indian Oceans. Through air-sea interaction in the Indonesian Seas and active vertical mixing, the ITF cools and freshens the Indian Ocean thermocline (Gordon 2005). By carrying mass, heat, and freshwater, the ITF transfers climate signals in the global thermohaline circulation and influences the regional air-sea exchange and precipitation patterns over many time scales (Sprintall et al. 2014). In consequence, the ITF plays a vital role in the global climate system (Schneider 1998; Wajsowicz and Schneider 2001; Le Bars et al. 2013). The Pacific-Indian Ocean warm pool that embeds the MC is the main driving force of the global atmospheric circulation. Any modulation of the upper ocean heat content by oceanic processes and air-sea interaction could have a large impact on local and tropical climate (Koch-Larrouy et al. 2010). The archipelago is one of the regions in the world with the largest internal tides generation (10% of the global value), which produce intense vertical mixing, that upwells cool waters at the surface that reduce precipitation and thus modify tropical mean state and variability (Koch-Larrouy et al. 2010). The impact on sea temperature and salinity of the internal tidal Indonesian mixing over the Indian and Pacific tropical oceans is as strong as when closing the ITF, emphasizing the key role of the Indonesian archipelago on the Indo-Pacific climate.

Air-sea interaction is also active and important in the Indonesian Seas and surrounding waters, such as the South China Sea (SCS) and Philippine Sea. The SCS throughflow feeds fresh water to the ITF. Air-sea interaction in the Philippine Sea provides moisture not only for the MC monsoon but also for the Asian summer monsoon (Wang 2006).

The west coast of the MC blocks eastward propagation of oceanic equatorial Kelvin waves excited in the Indian Ocean, generating coastal waves that move toward higher latitudes and carry equatorial ocean dynamical signals to the extratropics. Coastal upwelling near Sumatra is a key ingredient of the Indian Ocean Dipole (IOD, Saji et al. 1999; Webster et al. 1999), which is an essential feature of the regional climate.

Given the pivotal role of the MC in the regional and global weather-climate continuum, it is imperative that key processes of the ocean, atmosphere, land and their coupling, and the multi-scale variability and interaction in the MC region are well represented in numerical models. Unfortunately, current state-of-the-art global climate models (GCMs) and numerical weather prediction (NWP) models suffer from persistent systematic errors over the MC. Critical upper-ocean mixing processes are often missing in the models. Models cannot reproduce the observed diurnal cycle of precipitation over the MC. They suffer from large systematic biases in mean rainfall in the MC region, often with distinct contrasts between the ocean and land. They exaggerate MC barrier effect on the MJO. In NWP models, this leads to an MC prediction barrier for the MJO. Even models with the highest resolutions fail to reproduce observed dynamical features such as realistic vertical velocity profiles in atmospheric deep convection in the MC region.

Many countries in the MC region and Southeast Asia are highly susceptible to hydrological perturbations on a wide range of timescales. Severe tropical cyclones, the MJO, and intense monsoonal activity frequently bring dramatic flooding to the region. Periods of drought also have significant adverse effects on people and agriculture of the region. In order to facilitate water planning and emergency response strategies, it is critical to understand how weather extremes will be affected by changing climate and how their societal impact will become more severe in the face of increasing populations.

Given the global importance of the MC, it is no double that improving our ability to simulate and predict the regional and global weather-climate continuum critically depends on advancing our understanding of key processes of the ocean, atmosphere, and their coupling in the MC. Detailed observations in the MC are irreplaceable elements for this. The intricate distributions of the ocean, land, and their topography make it a daunting challenge to attain observational data that unravel connections among different components of the MC system as well as specific information for each component. Collecting such data is beyond any single institute or even single country. Concentrated and coordinated international efforts are needed.

“Years of the Maritime Continent” (YMC) is conceived in this spirit. The main goal of YMC is to *observe the weather-climate system of Earth’s largest archipelago to improve understanding and prediction of its local variability and global impact.*

YMC will cover a two-year period including both winter and summer East Asian/Australian monsoons: July 2017 – July 2019. It includes five science themes: Atmospheric Convection, Ocean and Air-Sea Interaction, Stratosphere-Troposphere Interaction, Aerosol, and Prediction Improvement. YMC will engage five main activities: Data Sharing, Field Campaigns, Modeling, Prediction Improvement, and Outreach/Capacity Building. The main anticipated outcomes of YMC would be: (a) a two-year (July 2017- July 2019) comprehensive data archive from regional observing networks, satellite observations, and field campaigns. This data archive will include diverse observations needed to document the detailed multi-scale variability in the MC; (b) advanced understanding of physical processes of the weather-climate system of the MC that are key to its local multi-scale variability and global impact; (c) improved model capability of simulating and predicting the weather-climate system of the MC and demonstration of its benefit to the society; and (d) a new generation of scientists and technicians who will be the intellectual core of operation and research in the MC for years to come.

The YMC science themes are introduced and discussed in section 2. The scientific objectives of YMC are summarized in section 3. The YMC activities are briefly described in section 4. Leverage and synergy with relevant programs are discussed in section 5. Contributors to this document are listed in section 6. References are in section 7. Appendix A lists potential participation in YMC. Appendix B introduces regional observing networks in the MC. Appendix C lists and briefly discusses previous field campaign in the MC.

2. SCIENCE THEMES

2.1 Atmospheric Convection

Atmospheric convection in the MC region undergoes substantial multi-scale variability on the mesoscale, diurnal, synoptic, intraseasonal, and seasonal scales. Mechanisms for the multi-scale variability and their cross-scale interaction are not well understood and are at the center of this theme.

2.1.1 Dominant processes controlling the diurnal cycle

The diurnal cycle can be considered the heart beat of the multi-scale variability in the MC region. Observations from the surface (Houze et al. 1981; Johnson and Priegnitz 1981; Kamimera et al. 2012; Kanamori et al 2013) and from satellites (Williams and Houze 1987; Yang and Slingo 2001; Nesbitt and Zipser 2003; Ichikawa and Yasunari 2006; Keenan and Carbone 2008) have documented diurnal cycle in the MC region. The climatological diurnal cycle in rainfall manifests as a systematic phase shift between land and water (Fig. 2.1). Over land (island) rainfall starts near coasts in the local afternoon, and quickly reaches its peak in early night. Around midnight, rainfall signals move from the land to the adjacent water. Offshore rainfall reaches its maximum in the early morning, with extensive anvils and stratiform rain that gradually dissipate around local noon. The largest amplitude of the diurnal cycle occurs along the coast of major islands and near mountain ranges, with weaker amplitude over the open ocean away from the coast (Nitta and Sekine 1994; Ohsawa et al. 2001; Mori et al. 2004), correlated and migrated with sea-land breeze circulations (Hashiguchi et al. 1995; Hadi et al. 2002; Sakurai et al. 2005; Araki et al. 2006; Tabata et al. 2011b). The diurnal cycle over the MC is particularly strong in rainy days and in the rainy season (Wu et al. 2003, 2009).

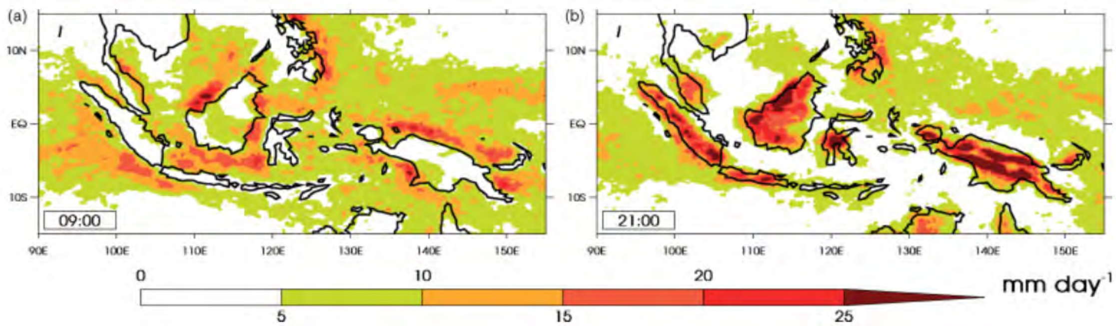

Figure 2.1 Mean precipitation rate (mm day^{-1}) derived from TRMM for 11 Oct 2008 – 8 April 2009 at (a) 0900 LST and (b) 2100 LST. From Love et al. (2011).

The solar cycle ultimately controls the triggering of new convection over land, with sea breezes and upslope flows playing an important role. The time of maximum coverage by rain and high cloud depends on the lifecycle of mesoscale convective systems (MCSs) that evolve from the triggered convection (Houze et al. 1981), suggesting the importance of the convective scale, growth, and organization.

The processes controlling the offshore migration of precipitating systems are not well understood. They may be related to: land breezes (Wapler and Lane 2012; Houze et al. 1981), propagating gravity waves generated by the diurnal heating (e.g., Mapes et al. 2003) or by moist convection over land (Love et al. 2011), outflow associated with the land convection that took place overnight (Fujita et al. 2010), or a combination of the three. These suggested mechanisms are different from those proposed to explain the diurnal cycle over the tropical open ocean that involve interaction between convection, radiation, and surface fluxes (Chen and Houze 1997; Randall et al. 1991). As the offshore propagating systems are organized on the mesoscale (Houze et al. 1981), the up-scale growth of the convection is of critical importance over the entire diurnal lifecycle.

There are spatial variations in the characteristics of the diurnal cycle in the MC region (Fig. 2.1) related to the timing of the peak in convection over land and the existence and extent of the offshore propagating convective systems. These differences are likely related to aspects of the island size and orientation, and terrain height. Moreover, differences in island geometry should help determine how the diurnal cycle responds to changes in large-scale conditions (see next section).

The diurnal cycle over the islands and coastal regions is closely related to the land-sea heating contrast and the soil moisture condition, which depends on both precipitation frequency and the timescale of soil moisture retention (Wei et al., 2008). During the past decade, the deforestation rate over the MC region has been among the highest in the world (Margono et al. 2014). Changes to land surface characteristics, including soil moisture and runoff, may have significantly modify aspects of the diurnal cycle.

Many of these characteristics of the diurnal cycle can be seen from cloud cluster distributions shown in Fig. 2.2. This figure also reveals other features of the diurnal cycle that have not been sufficiently emphasized in the existing literature. It appears that along some coastlines the inland-propagating and offshore-propagating convective systems are not initiated at the same time. While convection inland tends to disappear completely near mid-morning, convection over water away from land is perpetual. As convection initiated near the coast propagates offshore, it must interact with convection initiated over water. The distance from the shore at which oceanic convection is affected by land-initiated convection is not well known.

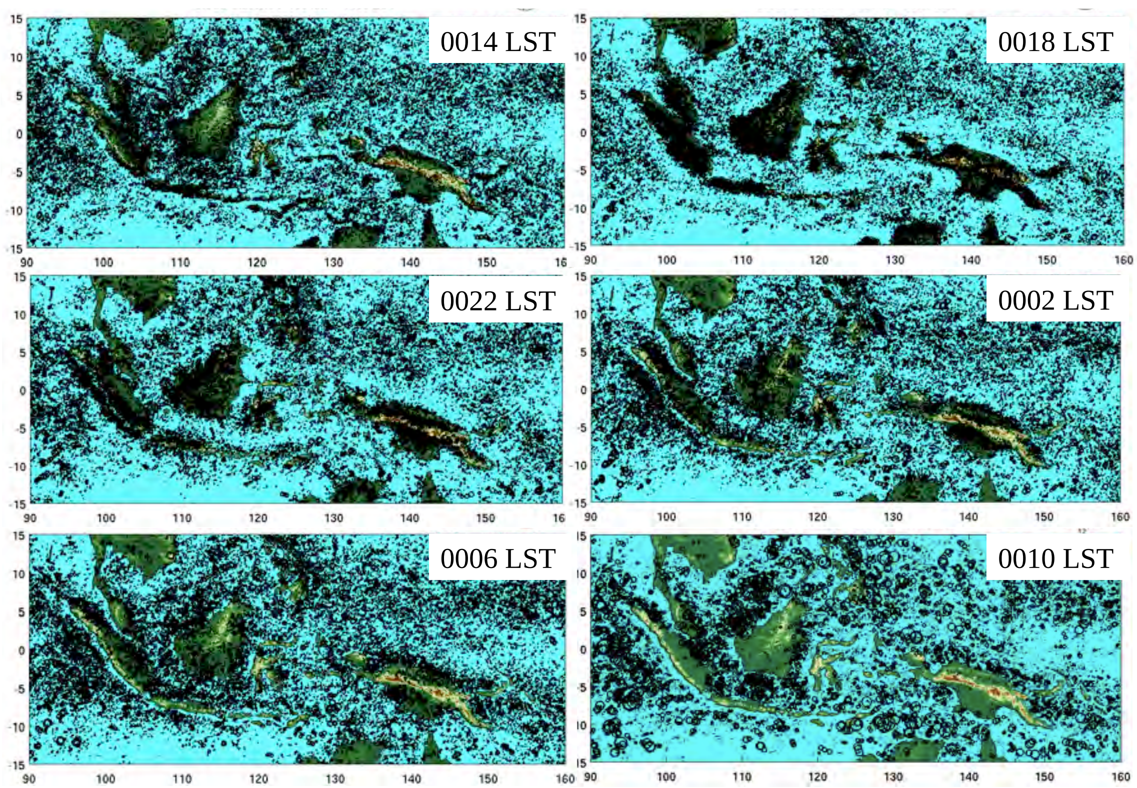

Figure 2.2 Diurnal cycle of cloud clusters defined as cloud top brightness temperature < 208 K. Sizes of each circle is proportional to the cluster sizes (> 100 km^2). Courtesy of Shuyi Chen and Brandon Kerns.

One common systematic error of climate models is their incorrect diurnal cycle in the timing and amplitude of the convective peak (Takayabu and Kimoto 2008; Love et al. 2011). This error depends sensitively on cumulus parameterization (Sato et al. 2009; Stratton and Stirling 2011; Folkins et al. 2014). Models in which convection is explicitly resolved can produce an improved representation of the diurnal cycle in the MC region (e.g. Pritchard and Somerville 2009), although do not alleviate all deficiencies. Better resolved distributions of land, sea, and topography, their related circulations (land-sea breezes, mountain–valley flows), and the associated patterns and motions of convergence and convective systems are very important to reduce the biases not only in the diurnal cycle but also in overall magnitudes of precipitation in the MC region (Qian 2008; Ploshay and Lau 2010, Hagos et al. 2013).

Specific outstanding questions pertaining to the diurnal cycle include:

- What is the relative role of sea breezes in initiating convection in comparison to local thermally forced convergence over land?

- How does the local orography affect the diurnal evolution of convection in comparison to that over a flat island?
- What is the relative role of land breezes, storm outflows, and gravity waves in controlling the offshore propagation of convective systems?
- How do the dominant processes controlling initiation and offshore propagation vary with island geometry and orientation, and land surface characteristics including vegetation and soil moisture?
- How far may the land effect extend into the ocean through the diurnal cycle and how does convection propagating from land interact with convection initiated over water?
- How do MCSs modulate upper ocean properties and what is the role of the ocean in their development on the diurnal timescale?
- To what degree is the inability of models cumulus parameterization to reproduce the observed diurnal cycle rooted in their deficiencies in accurately presenting convective triggering, propagation, and growth?
- What are the relative contributions from deficiencies in cumulus parameterization, unresolved details of the sea-land-topography distribution, and other factors (e.g., large-scale conditions) to the inability of climate models to reproduce the observed diurnal cycle in the MC region?

The following hypotheses have been developed relating to the diurnal cycle of MC convection:

Hypothesis 1.1: The diurnal cycle of convection in the MC region involves three steps: (i) Triggering, which occurs over both land near coasts due primarily to sea-breeze convergence and land heating destabilization, and open water due to interactions of convective clouds, surface fluxes, and radiation; (ii) Propagation, which takes place from the coastal region to inland mountains as well as to open water due to gravity waves, sea/land breezes, and/or convective outflows; (iii) Upscale growth through aggregation and organization, which leads to the formation of MCSs with lifespans beyond a single diurnal cycle.

Hypothesis 1.2 The contrasts between convection over land and water and between convection around different islands come mainly from the relative roles the above three steps of the diurnal cycle play.

2.1.2 Diurnal and large-scale variability

Understanding the diurnal behavior of precipitation over the MC is essential to understanding convective coupling with larger-scale circulations in the tropics. Several studies have documented the relationship between the diurnal cycle in the MC with the monsoons (Houze et al. 1981; Johnson and Priegnitz 1981; Churchill and Houze 1984a,b), the MJO (Chen et al. 1996; Houze et al. 2000; Tian et al. 2006; Ichikawa and Yasunary 2007; Rauniyar and Walsh 2011; Oh et al. 2012; Peatman et al. 2014), and synoptic-scale perturbations (Houze et al. 1981). The MJO modulates the amplitude of the diurnal cycle (by up to 10 mm day^{-1}). This amplitude modulation by the MJO occurs over both land and ocean in the MC region, but the effect is stronger over the sea than land, and is particularly strong near coasts (Rauniyar and Walsh 2011). In regions where there is a strong diurnal cycle, about 80% of the MJO precipitation signal is accounted for by changes in the diurnal amplitude (Peatman et al. 2014).

The strength and organization of diurnally varying MC convection can have significant impacts on precipitation organization at daily and longer timescales. For example, improving model representation of the diurnal cycle in the MC region led to reduced biases in mean precipitation (Love et al. 2011). A particularly salient example is the modulation of the diurnal cycle in the MC region by the MJO (Fig. 2.3). The diurnal cycle of convection in land regions of the western MC peaks in advance of the arrival of the broader oceanic convective envelope in this region. Daily mean precipitation over land and coastal regions peaks during the period of the strongest diurnal cycle amplitude, in advance of the daily mean precipitation maximum over water. As a result, the propagation of the MJO appears faster over the MC than over the Indian and Pacific oceans (Peatman et al. 2014)

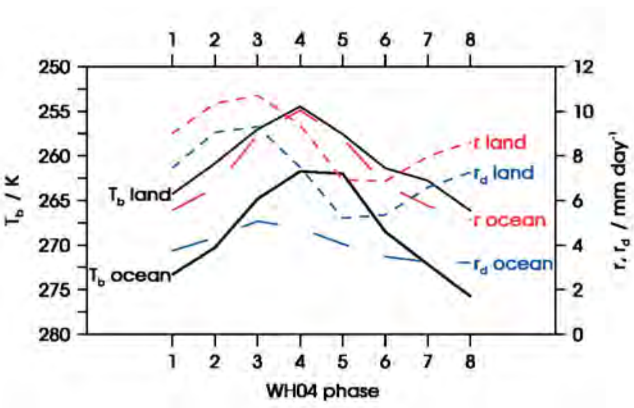

Figure 2.3 Means of brightness temperature (**T_b**), daily mean rainfall (**r**), and the diurnal cycle amplitude (**r_d**), all averaged separately over land and ocean, for the region 7˚S–10˚N, 100–120˚E (most of Sumatra and Borneo), plotted against MJO phases. Solid black lines show **T_b** (bold for ocean, thin for land); dashed lines show **r** and **r_d** (long- dashed for ocean, short-dashed for land). From Peatman et al. (2014).

Key research questions regarding the modulation of the diurnal cycle by large-scale variability include:

- What are the mechanisms through which the diurnal cycle in the MC region is modulated by large-scale atmospheric and oceanic conditions and land surface characteristics on the intraseasonal and seasonal timescales?
- How do variations in the amplitude and organization of diurnally varying convection feed back to intraseasonal and seasonal variability?

Two hypotheses on multi-scale interaction related to the diurnal cycle are proposed:

Hypothesis 1.3 Large-scale conditions related to the MJO and monsoon modulate the diurnal cycle through affecting the timing, location, and/or vigor of convective triggering, propagation, and/or growth.

Hypothesis 1.4 Responses of the diurnal cycle to large-scale forcing over land and water and over different islands are not the same because convective triggering, propagation and growth mechanisms are modulated differently by large-scale variability.

2.1.3 MJO propagation barrier

In the MC region, the MJO significally modulates many processes in the region, including the diurnal cycle of atmospheric convection, aerosol transport, and air-sea interaction. The behavior of the MJO over the MC is very different from that over the open waters of the Indian and western Pacific Oceans. In observations, when the MJO propagates over the MC it often weakens, its propagation speed becomes uneven, and it may completely break down and fail to reemerge on the Pacific side (about 40% of MJO events formed over the Indian Ocean do so). This is known as the "MJO propagation barrier". The natural MC barrier effect is commonly exaggerated in numerical weather prediction models and climate models (Inness et al. 2003; Inness and Slingo 2006; Vintzileos and Pan 2007), creating a "Maritime Continent prediction barrier" for the MJO. The strongest teleconnection pattern from the tropics to extratropics generated by the MJO occurs when an MJO convection center is located over the MC and close to the exit of the northern hemispheric westerly jet (Adames and Wallace 2014). Failing to propagate MJO convection through the MC in prediction models would inevitably undermine the model capability of forecasting global influences of the MJO.

Three factors have been considered as possible reasons for MJO propagation to be interrupted by the MC in nature: a reduced surface moisture source (Sobel et al. 2008) because of the land coverage, interference with low-level flow by the topography (Inness and Slingo 2006; Wu and Hsu 2009), and an energy drain through the strong diurnal cycle in precipitation over land (Neale and Slingo 2003). The MC prediction barrier of the MJO is likely due to deficiencies in model physics (Neena et al. 2014) that are manifested in the poorly simulated convection in the MC region, in addition to coarse model resolutions that do not resolve the necessary details of the sea-land-topography distribution crucial for convective variability.

The modulation of the diurnal cycle by the MJO is uneven over land and water not only in the timing and amplitude of rainfall (section 2.1.2), but also in sizes of MCSs. Figure 2.4 indicates that the modulation on the diurnal cycle of convection by the MJO is much larger over water than over land. The strongest contrast between MJO active and suppressed phases is the number of large MCSs over water. This may have two implications. One is the mechanism by which the MJO modulates the diurnal cycle. The other is possible feedback of the diurnal cycle to the MJO.

Pressing issues related to the role of the MC in the MJO can be discussed from two aspects: processes in reality and their reproduction in numerical models.

- What processes determine the strength, propagation speed, and rainfall distribution of the MJO over the MC? Specifically, what are the roles of the diurnal cycle, air-sea interaction, land-sea distribution, and topographically modified flow in regulating MC influences on the MJO?
- To what extent the evolution of the cloud population over the MC through a life cycle of the MJO is different from that over the open oceans and to what extent such

difference results in the unique behavior of the MJO over the MC?

- How is an incorrect diurnal cycle in a numerical model related to its erroneous simulation of the MJO in the MC?

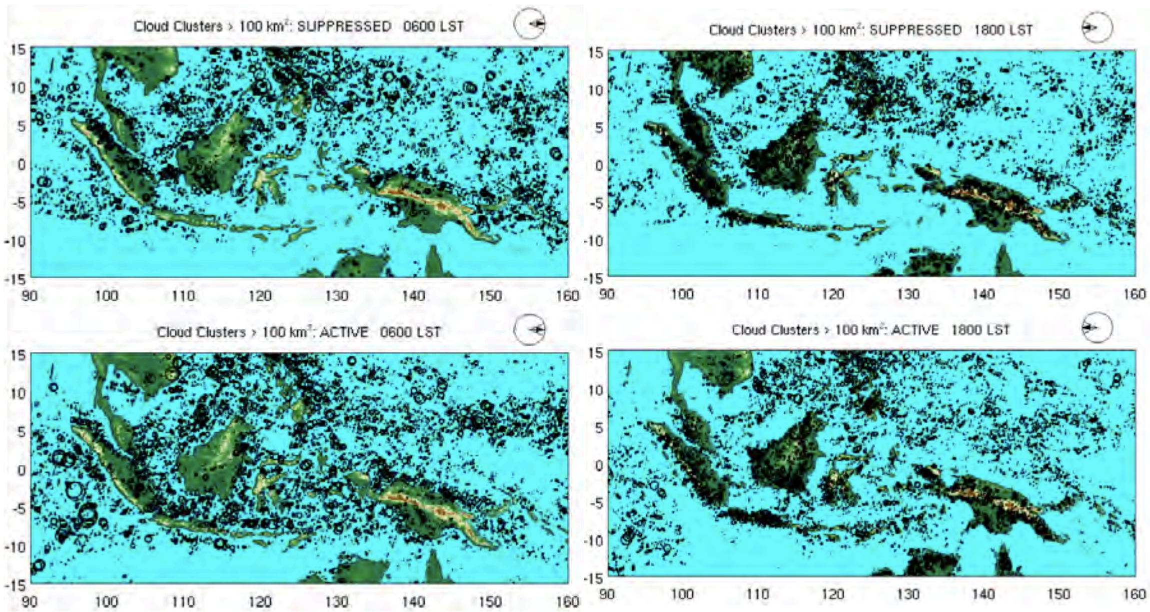

Figure 2.4 Comparison of the diurnal contrast of cloud clusters (defined as cloud top brightness temperature < 208 K) during MJO active and suppressed phases. Sizes of each circle are proportional to the cluster sizes (> 100 km^2). Courtesy of Shuyi Chen and Brandon Kerns.

Possible interactions between the diurnal cycle and MJO lead to the following hypotheses:

Hypothesis 1.5 Modulation of the diurnal cycle, especially that over water in the MC, by large-scale variability associated with the MJO is instrumental to the propagation of MJO convective signals through the MC. Oceanic convective growth and organization into MCSs are the major convective signal of the MJO propagating through the MC.

Hypothesis 1.6 The inability of global models to properly represent the salient processes for the triggering, propagation, and growth of diurnal convection and the formation of MCSs over he MC water limits their ability to propagate the MJO though the MC.

2.1.4 Boreal winter interactions between East and Southeast Asia and MC

The southward and eastward movement of the Siberian High, which is strongly influenced by the East Asian Major Trough and jet stream, is an important part of tropical-midlatitude interaction. These movements often trigger cold surges that pass through the South China Sea (SCS) and reach and cross the equator (Chang et al. 2006, 2015). Cold surges are associated with enhanced upper-tropospheric outflow over the MC and an enhanced East Asian meridional overturning circulation that may strengthen the East Asian jet and lead to further interactions with the midlatitude systems (Chang and Lau 1982; Lau and Chang 1987; Neal and Slingo 2003). Cold surge air is moistened along trajectories over water (Johnson and Houze 1987). It can considerably reduce SST of the SCS (Li et al. 2006). This midlatitude-tropical feedback makes the Asian winter monsoon one of the most energetic planetary-scale circulation systems on Earth (Chang et al. 2006).

In addition to the synoptic-scale cold surges, tropical convection in the SCS and the western MC region is also affected by local sea surface temperature (Hendon 2003; Yang et al. 2012; Koseki et al. 2013) and other disturbances including the Borneo vortex (Chang et al. 2005, 2006, 2015) and the MJO (Yang et al. 2015). Borneo vortices are most active during boreal winter when its intensity is often modulated by the cold surges. Their associated convection, MCS and even tropical depression formation associated may interact with the local diurnal cycle.

The MJO reduces the frequency of weaker surges by interfering with their structure (Fig. 2.5). The MJO has peak amplitude over the MC during the boreal winter, typically when synoptic activity is weak and the diurnal cycle is prominent (Qian et al. 2013; Lim et al. 2013; Peatman et al. 2014). As synoptic-scale convection, intraseasonal convection in the MC region can strengthen the local meridional overturning circulation and the East Asian jet (Jeong et al. 2008; He et al. 2011). The strongest extratropical wave trains emanate from the exit of the northern hemispheric westerly jet when MJO convection is located over the MC (Weickmann 1983; Lau and Phillips 1986, Matthews et al. 2004, Mori and Watanabe 2008, Frederiksen and Lin 2013, Adames and Wallace 2014).

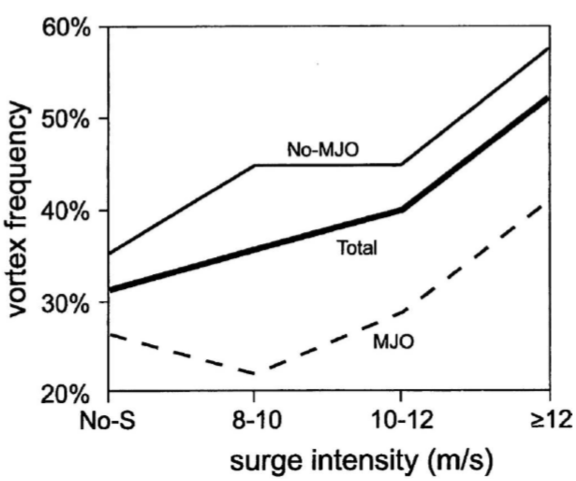

Figure 2.5 The percentage of days containing a Borneo vortex relative to the surge intensity, for all (total) days, no-MJO days, and MJO days. The surge intensity is the average 925 hPa northerly wind along 15°N between 110°E - 117.5°E. (From Chang et al. 2005).

Key research questions to be addressed by YMC include:

- Does the Siberian High affect the variability of convection in the SCS and the MC region on intraseasonal, seasonal, and longer timescales through synoptic-scale cold surges?
- How does convective variability associated with cold surges, Borneo vortex, and MJO feedback to the East Asian Jet and East Asian Major Trough?

Multi-scale convective interactions are the key to the connection between MC convection and high-latitude systems, as stated in the following hypothesis:

Hypothesis 1.7 The influence of the Siberian High (SH) on MC convection varies on intraseasonal, seasonal, and interannual timescales through modulation of synoptic- scale cold surges in the SCS on these timescales.

2.1.5 Northward propagation/migration of MC convection

Boreal summer intraseasonal oscillations (BSISOs) are generally characterized by eastward propagating cloud clusters from the equatorial Indian Ocean to western Pacific with pronounced northward propagation over Indian Ocean, MC and western Pacific (e.g. Lau and Chan 1986; Nitta 1987; Wang and Rui 1990; Kikuchi et al. 2012; Lee et al. 2013). Two types of mechanisms have been proposed to explain northward propagation of the BSISO. The first type of mechanism includes the interaction between the mean seasonal flow and intraseasonal perturbations (Jiang et al. 2004; Drbohlav and Wang 2005, Bellon and Sobel 2008), interaction between the mean flow and small-scale, convective momentum transport (Kang et al. 2010), and the self-advection of a cyclonic perturbation (Boos and Kuang, 2010). The second type mechanism involves air–sea interaction processes (Hsu and Weng 2001; Fu et al. 2003; Fu and Wang 2004; Bellon et al. 2008) through BSISO-induced changes in surface fluxes of latent heat and solar radiation. The latent heat flux is modulated by convection-coupled Kelvin-Rossby components of the MJO flow superimposed on the mean summer monsoon flow that leads to positive (negative) SST anomalies to the north (south) of the convective disturbance. Both increased downward solar radiation and the reduced evaporation contribute to significant warming in the northern Indian Ocean and SCS. The combined changes in latent heat flux and solar radiation in the MC and SCS cause SST fluctuations that feed back to the circulation through convective heating (Wang et al. 2009).

During boreal summer, moist southwesterly to westerly winds into South China Sea (SCS) and Philippine Sea (PhS) bring seasonal rainfall to Indochina peninsula and the Philippines (Wang 2006). Meanwhile, cross-equatorial flows from the southern hemisphere pass between MC inner islands and merge into the SCS and PhS (Chang et al. 2005; Kubota et al. 2011). Over the warm pool of the PhS and SCS, the western North Pacific summer monsoon dominates (Murakami and Matsumoto 1994). Its seasonal and interannual variability influences the intensity of cross-equatorial flows and directly impacts rainfall (Kubota et al. 2011) and air-sea interaction (Kida and Richards 2009) in the MC, and coastal upwelling along Sumatra and Java Seas (Susanto et al. 2001). The convective heating of this monsoon generates Rossby wave response poleward known as the “Pacific-Japan” pattern (Nitta 1987). This teleconnection pattern is a dominant component of interannual variability of the western North Pacific and East Asian summer monsoons and is connected to El Niño Southern Oscillation (ENSO) and tropical cyclone activities in this region (Kubota et al. 2014). Over the SCS and PhS, the negative correlation between SST and rainfall (Lu and Lu 2014) restricts the predictability of he monsoon (Wang et al. 2005).

Although the mechanisms discussed above provide a useful conceptual framework for understanding the northward propagation of BSISO, the observed evolution of BSISO in the MC and SCS region exhibits complex behavior (Wang et al. 2009) characterized by a connection with the eastward-propagating MJO (Chen and Murakami 1988; Wang and Rui 1990; Lawrence and Webster 2002), northwestward propagation from the equatorial western Pacific, merging of an equatorial eastward-moving convective systems and westward propagating lower-level convergence anomaly located in the subtropics (Hsu and Weng 2001), and independent northward propagation (Wang and Rui 1990).

Key research questions to be addressed by YMC include:

- How does the Asian summer monsoon, especially over the SCS and western North Pacific, link to rainfall, air-sea interaction, and coastal upwelling in the MC?
- What are the physical processes governing the inter-event variability of the BSISO over the MC and SCS?
- What is the relative importance of moisture transport by different large-scale processes (monsoon, BSISO, and higher-frequency perturbations) and air-sea fluxes to the northward propagation of the MC convection?

The following hypothesis on the mechanisms for the northward propagation of MC convection and the monsoon over the SCS and western North Pacific is proposed:

Hypothesis 1.8 Northward propagation of the boreal summer intraseasonal oscillation arises from propagating air–sea interaction processes associated with the MJO and biweekly Rossby waves interacting with the SCS monsoon during the period from late May to Mid-July; the following Western North Pacific summer monsoon forms by remote monsoon flow through SCS and MC, and local air-sea interactions

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2.2 Ocean and Air-Sea Interaction

The MC is composed of over 17,000 islands within the complex array of shallow and deep marginal seas (Fig 2.6). The MC seas share a common trait of warm, relatively low salinity surface layer of <50 m thick, induced by river runoff and rainfall, which in the deeper seas are underlain by a strong thermocline, resulting in a salinity-stratified barrier layers and a warm mixed layer that trap surface fluxes.

These seas form an integral component of the larger scale ocean and climate, responding to and in turn influencing those systems (Sprintall et al., 2014). The convective activity and wind patterns are closely coupled with the sea surface temperature (SST) pattern, which varies across a wide range of spatial and temporal scales. Oceanic processes also have a significant role in mediating SST and modulating the air-sea flux. This upper-ocean process theme covers these topics within the seas of the Maritime Continent.

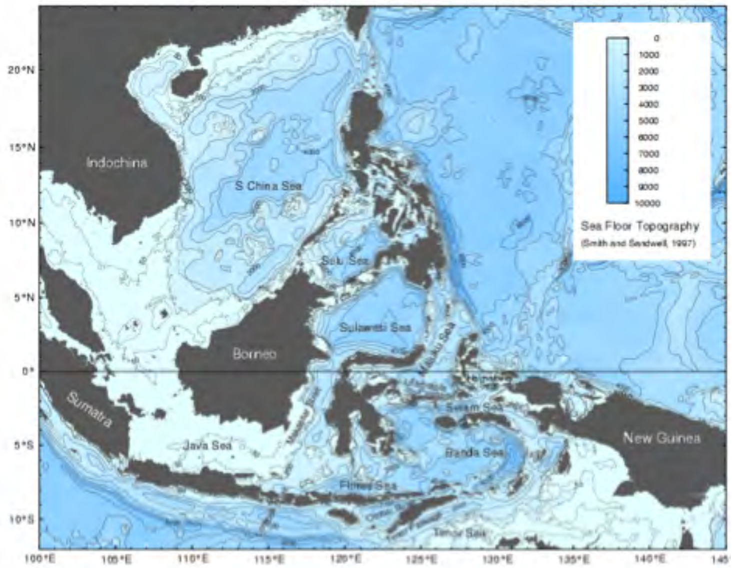

Figure 2.6 Sea floor topography (Smith and Sandwell, 1997)

2.2.1 Upper ocean processes

Significant oceanic advective and mixing processes within the Indonesian seas shape the SST spatial and temporal patterns and associated air-sea coupling, as well as the nutrient distribution in the surface ocean. On seasonal time scales, the upper ocean is forced by monsoonal winds, which change direction crossing the equator. The SST responds to the monsoonal forced radiation balance and wind field (Qu et al., 2005). From December to February (Northwest monsoon) warm SST (> 29°C) are shifted southward relative to the June-August (Southeast monsoon) pattern. In the expanse of the deep eastern seas (e.g. Banda Sea) a deeper thermocline with a thicker warm surface layer occurs during the northwest monsoon than during the Southeast monsoon when the wind stress curl intensifies the cyclonic circulation and upwelling within the Banda Sea, lifting the thermocline by ~ 40 m and leading to cooler SST by ~3°C (Gordon and Susanto, 2001). It is expected that the atmospheric forcing of SST will dominate when the thermocline is deep during the Northwest monsoon whereas during the Southeast monsoon the ocean's role in governing SST may be enhanced. Wind-induced Ekman upwelling results in cooler SST bands in the shallow Java and Flores Seas north of the island chain during the Northwest monsoon, and south of it in the Indian Ocean during the Southeast monsoon.

In addition to the regional wind forcing the SST patterns are further shaped by the circulation, notably the ITF consisting of ~15 Sv of Pacific water flowing towards the Indian Ocean, as well as vigorous tides that induce strong vertical mixing. An upper ocean heat-balance model suggested that during the northeast monsoon when vertical mixing and air-sea heat fluxes cool the SST, lateral advection from the ITF entering via Makassar Strait acts to warm the SST resulting in only a weak SST seasonality in the Flores Seas (Kida and Wijffels, 2012). Buoyant surface water derived from the SCS throughflow (Luzon Strait to the Sulu and Indonesian seas) varies both seasonally and with the ENSO phase, being stronger in boreal winter and during El Niño. This freshwater influences the ITF profile, resulting in a velocity maximum within the upper thermocline and a cooler ITF than if it were surface intensified (Gordon et al., 2003, 2012). The outflow of SCS throuflow in Karimata Strait can contribute to ITF about 20% during winter (He et al., 2014). Thus, the SCS throughflow has the effect of significantly reducing the ITF heat transport, with considerable impact on heat distribution in the MC and the tropical Indian Ocean (Song and Gordon, 2004), as well as affecting the western Pacific warm pool (Sprintall et al., 2014). The equatorial wind stress in the tropical Pacific plays an important role in regulating both the SCS throughflow and ITF (Wang et al., 2006; Liu et al., 2006).

Imprinted on the seasonal patterns of SST are the intraseasonal signals imposed by ocean Kelvin waves (Drushka et al., 2010; Pujiana et al., 2013) and from the MJO. Intraseasonal variation accounts for about 40% of SST variability, with the strongest signature observed in Banda Sea and Timor Seas (Napitu et al., 2015). The MJO signature in SST is evident with an SST variance energy peak at 35 days that amplifies during the northwest monsoon and propagates eastward. In the Banda Sea, the influence of the MJO on SST is greatest during the northwest monsoon, when the thicker mixed layer and deeper thermocline (Gordon and Susanto, 2001) act to diminish the role of ocean processes driving vertical heat transfer between subsurface and surface layers. Consequently, surface air-sea heat fluxes associated with the MJO largely govern intraseasonal SST variability (Zhang 2005). However, during the southeast monsoon the shallower mixed layer and shallower thermocline are favorable for the role of ocean processes to mediate heat transfer between the lower and upper layers of the ocean. During this period, the heat transfer competes with surface the MJO heat fluxes in governing SST variability as indicated by a less pronounced eastward propagation. It is likely that many of the same ocean processes that play a role governing SST variability on seasonal time scales also influence intraseasonal SST variability. For example, modulation of SST by barrier layer thickness can have significant consequences for the response of the ocean to MJO and in turn, the feedbacks of the ocean to the atmosphere on MJO time scales (Drushka et al., 2014). A thick barrier layer reduces entrainment cooling during active MJO events resulting in a weaker SST anomaly. Conversely, a thinner barrier layer results in a 15% stronger heat flux and wind stress, 10% more precipitation and a higher mixed layer temperature. Waters on the shallow continental shelves are also likely influenced by lateral advective processes, river runoff and wind mixing that can mix the entire water column (Kida and Richards, 2009)

Dissipation of the energetic tide within the Indonesian seas results in large diapycnal mixing coefficients of the order 1-10 cm^2/sec that act on the stratified pycnocline (Ffield and Gordon 1992), leading to a cooler SST, and inhibiting atmospheric convection (Ffield and Gordon1996; Koch-Larrouy et al. 2008a, b and 2010). The dissipation and vertical diffusivity and its imprint on SST varies markedly both spatially and temporally, notably with the tidal patterns but also in relation to wind bursts associated with the monsoon and MJO variability. Models that include parameterizations of the mixing in the Indonesian seas decrease the annual mean SST by ~0.5°C, increase ocean heat uptake by ~20 W/m^2 and reduce the overlying deep convection by as much as 20%, all changes that align the model output in better agreement with the observations (Koch-Larrouy et al., 2010, Sprintall et al. 2014). Consequently, the trade wind convergence is reduced, decreasing the thermocline tilt in the Pacific Ocean, and in turn modifying the interannual variability of the Pacific and Indian Ocean. Similarly, on intraseasonal time scales, coupled models show SST variability modulated due to internal tidal mixing, again in better agreement with observations: over the annual cycle rainfall is reduced over the MC, while during the Northwest monsoon, rainfall is reduced over the entire tropical Indian Ocean due to mixing within the Indonesian Seas. While models suggest small-scale mixing plays a significant role in SST variability, mixing observations within the Indonesian seas are still few. Turbulent mixing at the inertial time scale has been observed at the base of the mixed layer in the Banda Sea (Alford and Gregg, 2001), and strong tidal mixing above sharp topography and in energetic narrow straits has been inferred from temperature profiles (Ffield and Gordon 1996; Ffield and Robertson, 2005) and more recently from the first direct measurements in regions of high energy of internal tidal dissipation (Koch-Larrouy et al. 2015). The intense mixing also likely contributes to a large flux of nutrients that support high productivity of the Indonesian seas, although again there are few observational studies to support this.

The Eastern Indian Ocean Upwelling (EIOU) region is driven by the monsoonal wind but also lies along the porous western boundary of the Indonesian archipelago where the ITF exits into the Indian Ocean. The EIOU develops during boreal summer, but also has profound impacts on regional and global climate through its intensive interaction with the atmosphere during Indian Ocean Dipole (IOD) events. The Indo-Australian monsoon onset often coincides with the arrival of the first eastward propagating MJO event during austral summer (Hendon and Liebmann 1990), although the structure and mechanism of this first event are still not fully understood. Over the Bay of Bengal, the Asian monsoon onset was recently shown to be phase-locked to the local SST maximum and the arrival of the first northward propagating intraseasonal oscillation (Li et al. 2013). More generally, it is not clear why the tropical Indian Ocean intraseasonal oscillation veers northward (eastward) from its previous eastward (northward) propagation route during the boreal spring (autumn). The EIOU decay coincides with increasing SST over the southeastern Indian Ocean, and this is hypothesized to precondition the Indonesian-Australian monsoon onset through its role in steering the MJO from its boreal summer state to its austral summer mode. An anomalously early or late onset of the Indonesian-Australian monsoon could be due to either the SST anomaly in southeastern Indian Ocean or the anomalous intraseasonal oscillation behavior over the tropical Indian Ocean. ENSO and IOD provide possible sources of these anomalies.

The SCS is the largest semi-enclosed marginal sea in the western tropical Pacific, connecting to the Indonesian Seas through the shallow Mindoro and Karimata Straits, and to the Pacific Ocean through the deep Luzon Strait. The SCS throughflow plays an important role on the upper salinity changes in the northern SCS. The freshening of up to 0.4 psu in the upper-ocean of the northern SCS, confirmed by in situ and satellite observations, can be caused by a combined effect of abundant local freshwater flux and limited Kuroshio intrusion (Zeng et al. 2014). The SCS experiences a monsoon wind transition from northeasterly to southwesterly during boreal spring, which is also characterized by the existence of spring warm water pool (SWP), with SST > 29°C. The SWP strengthens until the onset of the summer monsoon, then weakens and eventually disappears at the end of May. The SWP variability from April to May is mainly controlled by the net surface heat flux, which is large before the onset of the summer monsoon due to more shortwave radiation absorbed by the ocean and weaker wind speed, resulting in reduced loss by latent heat flux. After the onset of the summer monsoon, the increased cloudiness and rainfall and stronger wind result in an increase in the loss of latent heat flux from the ocean to the atmosphere. In addition, the advection of cold water into the mixed layer due to corresponding oceanic circulation changes leads to the decay of the SWP. Yet how the SWP feeds back to local atmospheric interaction, it's impact on climate and weather events such as tropical cyclones and the MJO is still poorly understood. The variations of the SCS sea surface temperature are also closely associated with ENSO (Wang et al. 2006; Liu et al. 2014). Over the past decade, much effort has been dedicated to develop and improve regional air-sea coupled models and an increased observational effort in the SCS. Nonetheless our understanding of the regional pattern of air-sea interaction and the related mechanisms and their impact on the large-scale atmospheric circulation is still limited. Oceanic and atmospheric data products based on remotely sensed measurements may qualitatively reproduce the climatological patterns of the SCS in comparison to *in situ* observations, but they differ substantially in quantity.

2.2.2 Air-Sea Interaction

Systematic error in the diurnal cycle of precipitation of the MC can rectify not only the seasonal mean climate locally but also global weather and climate patterns from the MJO, monsoons, and the Walker circulation (Neale and Slingo 2003). It has been well documented that the diurnal maximum of convective cloud systems and precipitation is observed during the morning hours (AM) over the ocean, whereas the maximum is during the afternoon hours (PM) over land. However, the difference between AM and PM precipitation in the coastal/adjacent seas over the MC is 2-3 times larger than anywhere else in the tropics (e.g., Yang and Slingo 2001). Previous studies have speculated that the convection and precipitation over the adjacent seas may be a result of the propagating convective systems from the islands to the sea during the night, which are forced by the enhanced land breeze from the high mountains of the islands in the MC. Observations have shown that convective systems often initiate over the seas during the diurnal maximum of SST in the afternoon and continue to grow into the night and maximize during the early morning (Chen and Houze 1997). The two factors together may explain the large diurnal amplitude over the adjacent seas of the MC than that of the open ocean.

In addition to the surface forcing of the SST diurnal cycle on convective initiation, Chen and Houze (1997) showed that large convective systems produce large areas of cold pools and canopies of clouds shade the ocean surface from the sunlight and so are unfavorable for the convection the following day. However, stronger low-level wind during the active phase of the MJO and/or monsoon surge can increase the air-sea fluxes and reduce the boundary layer recovery time. This wind can also interact with the land breeze to produce stronger low-level convergence over the adjacent seas. These mechanisms are supported by the observations of enhanced morning precipitation over the coastal seas during the northwesterly monsoon surge (Houze et al. 1981) and the MJO active phases (Peatman et al., 2014).

It is evident that air-sea interaction can play an important role in the diurnal cycle of convection and precipitation and, more importantly, its complexity varies with the large-scale flow regimes and properties of the upper ocean in the MC. How these multi-scale interactions affect the local mean climate and the large-scale circulations such as the MJO and its eastward propagation from the Indian Ocean to the West Pacific remains largely unknown. Large systematic biases still exist in available air-sea flux fields due to the unique air-sea interaction characteristics, such as high wind speed and evaporation, strong convection, and heavy precipitation. Model errors specifically related to coupling need to be reduced. Additional observations are essential.

Key Questions for the Ocean Processes component of YMC

Developing a quantitative understanding of the combined atmospheric and oceanic processes governing SST is required to understand the atmospheric convection over the MC across a broad ranges of time scales. The surface circulation and ocean processes shape the SST and stratification pattern in the MC; the spatially and temporally variable tidal effects elevate vertical mixing; Ekman pumping, coastal upwelling and buoyancy input from precipitation and river outflow act to stabilize the surface layer allowing generation of warm SST anomalies via air-sea fluxes. Yet despite recent progress, key scientific questions concerning ocean processes and air-sea interaction in the MC remain to be addressed:

- What processes control the SST cycle and upper ocean stratification in the MC from diurnal to seasonal time scales? What is the relative role of air-sea fluxes, lateral advection, mixing, upwelling and other processes on each time scale?
- What is the relative importance of the complex bathymetry of the MC in regulating the atmospheric response to oceanic forcing? What key regions are most important to the atmosphere (e.g., upwelling regions; elevated mixing regions; shallow shelves; shelf-breaks; deep basins etc.)?
- How different is the air-sea interaction in the MC seas in comparison to the open Indian and Pacific Oceans? Particularly, how do the diurnal cycle of atmospheric convection and the MJO interact with the ocean under the influences of islands?

2.3 Stratosphere-Troposphere Interaction

Stratosphere-troposphere (S-T) dynamical coupling has been studied over decades, with focuses on mid-latitude and polar regions such as annular mode variability, impacts of the ozone hole on surface climate, and mid-latitude cross-tropopause mixing. The one-way influence of the troposphere on the stratosphere by upward propagating tropical waves has also been studied extensively (e.g., Baldwin et al. 2001, Kawatani et al 2010, Yuan et al. 2014). Connections between the troposphere in the deep tropics and extratropical stratosphere are relatively poorly understood, with evidence suggesting the Asian monsoon circulation plays a major role (Randel et al. 2010). A broader motivation for studying S-T coupling includes a better understanding of how large-scale stratospheric variations, such as stratospheric sudden warming (SSW), polar vortex intensification (PVI), the quasi-biennial oscillation (QBO), the semi-annual oscillation (SAO), and an anthropogenic cooling trend, may influence tropical moist convection.

The downward control principle of extratropical diabatic circulations by eddy-induced mean zonal forces given in the extratropical stratosphere (Haynes et al. 1991) is a key theoretical concept of stratosphere-troposphere dynamical coupling. Coherent interannual variations of dynamical structure associated with the residual mean circulation in the tropics and Southern Hemisphere exist most noticeably during northern winter (Salby and Callaghan 2004, 2005). SSW events in the Southern Hemisphere may affect clouds and moisture fields in the tropical tropopause layer (Eguchi and Kodera 2010). The tropical troposphere may change suddenly in association with SSW events in the Northern Hemisphere (Kodera et al. 2011). Extreme events in the polar stratosphere such as SSW or PVI might be significantly related to the tropical troposphere where the stochastic nature of space-time variations dominates. The QBO may modulate tropical deep convection through the modulations of tropopause height and cross-tropopause zonal wind shear (Collimore, et al. 1998, 2003) in the context of monsoon and ENSO (Claud and Terray 2007; Liess and Geller 2012). Influence of the QBO on Atlantic tropical cyclones (TCs) (Gray 1984; Camargo and Sobel 2010) is a case in point.

Tropical waves generated in the troposphere propagate upward and interact with the mean zonal flow in the stratosphere to produce rather periodic variations of the mean zonal flow in the equatorial stratosphere, such as the quasi-biennial oscillation (QBO) and the semi-annual oscillation (SAO). Moist convection is the major source of these tropical waves. Multi-scale interactions of moist convection produce a wide variety of coherent motions and structures of the tropical atmosphere. But tropospheric-lower stratospheric winds exhibit geographical differences in the MC (Widiyatmi et al. 2001; Okamoto et al. 2004; Tabata et al. 2011a). The scale separation is not very straightforward. The moist convection and larger scales are so tightly coupled. It is hard to extract causality in their interactions.

The MC is one of the most important regions for the generation of gravity waves in the tropics (e.g., Tsuda et al. 2000; Sakazaki et al. 2015). The MC region is an ideal location to study the generation of such waves and their interactions with the stratosphere. The array of precipitation radar observations collected during the YMC campaign will provide a wealth of information on the spatial and temporal scales of heating variability (e.g., Schumacher et al. 2004) and associated waves.

The tropical tropopause layer (TTL) is a region between the convective outflow maximum (~14 km or 150 hPa) and the cold-point tropopause (~18 km or 70 hPa) where a transition occurs in major dynamical processes from direct cumulus-convective influence to wave-driven slow upwelling in the tropics (Folkins et al. 1999, Sherwood and Dessler 2000, Fueglistaler et al. 2009). The TTL is the main entrance to the stratosphere for gases and particles emitted from the surface or photochemically produced in the troposphere and thus controls the ozone layer and global stratospheric composition (Gettelman and Birner 2007, Butchart 2014). The dehydration and cirrus-cloud processes in the TTL are of particular importance because they determine the water vapor concentration in the stratosphere, which contributes to the ozone-layer photochemistry and the radiative balance of the atmosphere (Fujiwara et al., 2010; Randel and Jensen 2013). The TTL is also a direct pathway from the troposphere to the midlatitude lower stratosphere through the monsoon circulations and Rossby wave activity. In the long term, the side boundaries of the TTL and, more generally, the tropics are not steady; instead, they are known to be widening (e.g., Davis and Rosenlof 2012, Birner et al. 2014).

High above the warm waters of the MC warm pool lies a region of extremely cold TTL temperatures in the tropical Western Pacific. High altitude cirrus preferentially form and sediment in this region (Massie et al. 2007, Virts et al. 2010) leaving extremely dry air that eventually enters the tropical stratosphere and is transported globally through the global equator-to-pole Brewer-Dobson transport circulation (Butchart 2014). Water vapor concentrations entering the stratosphere are set by the coldest temperature parcels experience in the TTL, the so-called "cold point" (Gettelman et al. 2002). Water vapor variations originating in the Western Pacific TTL influence global radiative forcing (Solomon et al. 2010) and polar ozone loss (Shindell 2001).

Deep convection transports lower tropospheric ozone-poor air into the TTL (Folkins et al. 2002). The tropospheric heating due to deep convection causes localized cooling near the tropopause (e.g., Johnson and Kriete 1982, Paulik and Birner 2012), which influences dehydration. Waves generated by deep convection further influence TTL temperatures and tracer transports. These processes are particularly enhanced over the MC.

The transport of gas and particles in the TTL and more generally, in the upper troposphere and lower stratosphere (UTLS), and dehydration/hydration processes for the case of water vapor, is influenced and controlled by both small and large-scale processes. Previous studies revealed the role of various dynamical processes such as turbulence in the TTL (Mega et al. 2010, Flannaghan and Fueglistaler 2014), cumulonimbus convection (Liu and Zipser 2005, Iwasaki et al. 2012), diurnal variability including atmospheric tides (Fujiwara et al. 2009, Sakazaki et al. 2015), and organized convection and equatorial waves (Suzuki et al. 2013). However, measurements of turbulence and diurnal variability are especially limited, and relative contributions of small to large-scale processes remain an open question. Understanding of the microphysical processes in the TTL dehydration/hydration remains uncertain due to limited observation cases of aerosol and cirrus particle measurements there (e.g., Shibata et al. 2012, Jensen et al. 2013).

Under the YMC S-T theme, key processes and dynamics of S-T interaction will be investigated through approaches of field observations and numerical modeling.

Field Observations

To quantify dehydration/hydration mechanisms in the UTLS, the following mechanisms are proposed. The first two mechanisms focus on smaller scale phenomena associated with convection and are more suited to localized field campaign measurements, while the third set of mechanisms describe large-scale processes that can be informed by field campaign observations and further studied by numerical models.

1) Deep convection

Only the deepest convective towers directly impact stratospheric composition since cloud ice detrained below 14 km will typically descend back to the middle troposphere. Cloud detrainment above 14 km can be transported upward by the large-scale ascent in the TTL and some overshooting towers can even reach the lower stratosphere. Deep convection can either hydrate or dehydrate the lower stratosphere. Hydration occurs when ice from the deep convective tower sublimates in the TTL and/or lower stratosphere (Corti et al. 2008). Dehydration occurs when lofted ice particles grow at the expense of TTL water vapor through vapor deposition followed by sedimentation (Danielsen 1982, 1993). Based on a modeling study, Jensen et al. (2007) argued that dehydration only happens if the TTL is initially supersaturated with respect to ice.

While satellite data, including lightning data, can provide some sense of the relative occurrence of deep convection into the TTL and lower stratosphere and its role in dehydration/hydration of the stratosphere (e.g., Liu and Zipser 2005, Luo et al. 2008, Panwar et al. 2011, Tzella and Legras 2011, Iwasaki et al. 2012, Carminati et al. 2014), detailed measurements of the convective cloud ice and UTLS temperature and relative humidity (including its diurnal variation) are essential to truly understand the relative occurrence of each scenario and the overall impact deep convection has on the water vapor content in the stratosphere. In addition, the amount and character of ice material that reaches the UTLS is dependent on the strength of the convection, so measurements of convective system evolution are also important to understand dehydration/hydration of the stratosphere by deep convective towers. It is well known that deep convection over land is in general more intense with more lightning and higher radar reflectivity than convection over ocean (Zipser et al. 2006). However, the role of different convective intensity over land and ocean in the transport of water vapor to the TTL has received much less attention. Convection with different intensities peaks at different local times over land and oceanic regions and could directly modulate diurnal variations of temperature and water vapor in the TTL (Liu and Zipser 2009). Deep convection over the MC has significant diurnal variations between islands and coastal ocean (Nesbitt and Zipser 2003), which makes MC a natural laboratory to examine the role of convective intensity in the TTL.

2) Organized convection and equatorial waves in the TTL

Equatorial atmospheric waves driven by organized convection (e.g., Rossby, gravity, and Kelvin waves) can modulate temperatures and upwelling in the TTL (Boehm and Lee 2003, Grise and Thompson 2013, Kim and Alexander 2015) that can in turn impact stratospheric water vapor (Brewer 1949). For example, Suzuki et al. (2013) observed that water vapor in the TTL showed complex variability when more than two different types of waves co-exist. Thus, temperature variability and vertical motion directly due to wave disturbances and sedimentation of cloud particles are both key to the dehydration processes in the TTL. The dense network of upper-air sounding measurements collected during YMC will provide new insights into the spatial and temporal scales and sources of wave impacts on TTL cold-point temperature needed to improve the representation of UTLS dehydration in global models.

The impact of tropical wave disturbances on the TTL is dependent on the spatial and temporal variations of tropical convective heating and the background wind field (Ortland and Alexander 2014). Heating profiles associated with convective processes are difficult to estimate without detailed environmental and/or convective measurements over an area large enough to encompass the organized convection, thus requiring sounding arrays and scanning precipitation radars as observational constraints. These system-scale observations will be linked with the cloud-scale ice and in situ measurements of UTLS temperature and humidity discussed previously to determine the relative contribution of direct ice injection versus waves induced by convection on the dehydration/hydration of the stratosphere during YMC.

3) Large-scale processes

i) Quasi-horizontal transports in the TTL – Exchange between the TTL and extratropical lower stratosphere impact atmospheric composition in both regions. Hasebe et al. (2013) and Inai et al. (2013) used the match technique that combines multi-point balloon soundings over the Maritime Continent and trajectory calculations using global meteorological analysis data to quantify Lagrangian water vapor changes associated with quasi-horizontal transport within the TTL. They found several dehydration cases in the lower part of the TTL, but could not quantify the dehydration around the cold-point tropopause where the stratospheric entry value of water vapor is finally determined. During the YMC, we will improve the match technique by adjusting the locations and season of the sounding campaigns and by applying new particle instruments.

ii) Cross-tropopause transports by the Asian monsoon - Based on ozonesonde data taken at Hanoi, Vietnam, Ogino et al. (2013) showed that ozone transport over the subtropical region is strongly controlled by the monsoon circulation. We will investigate detailed processes of the ozone and water vapor transport by the Asian monsoon circulation in both winter and summer seasons to evaluate their budget in the TTL.

iii) Diurnal atmospheric tide - Fujiwara et al. (2009) investigated a case of diurnal variations in cirrus clouds in the TTL and discussed that at least part of the variations was due to diurnal atmospheric tides. Diurnal variations in tropical precipitation and waves are generally poorly represented in global models used for climate prediction and reanalysis (e.g., Kim and Alexander 2013a, 2013b). We will investigate diurnal variations in the TTL, from the viewpoints of direct/indirect effects from local- and regional-scale convection as well as global-scale tidal effects. This analysis will help us understand the role of diurnal variability in transport and dehydration in the TTL.

Much has been learned about UTLS interactions using satellite observations and previous field campaign data sets. However, YMC will provide previously unavailable cloud and environmental observations of deep convective impacts on TTL and stratospheric water vapor over the region of the globe where some of the strongest UTLS interactions take place (Schoeberl and Dessler 2011). These observations can also be used to evaluate models in this region since a range of atmospheric model types have significant disagreements on the vertical profiles of water vapor and diabatic heating in the UTLS (Russo et al. 2011, Wright and Fueglistaler 2013).

Numerical Modeling

S-T dynamical coupling associated with the stratospheric variations and change could be investigated by numerical experiments with general circulation models (GCMs) of the atmosphere. Even though high-end numerical models could include the S-T dynamical coupling process associated with SSW, PVI, QBO or cooling trend, little attempt has been made to analyze possible coupling process including the troposphere, perhaps due to too weak signals or limitation in spatial resolutions of these global models. For example, some parameterization schemes on cumulus convection and/or small-scale gravity waves are necessary to simulate the QBO, and those are considered as major sources of model uncertainty. Recently, Hitchcock and Simpson (2014) studied the downward influence of SSWs with a GCM using a well-designed nudging technique and confirmed the downward influence on the troposphere through an annular mode response with synoptic- and planetary-scale eddy feedbacks. The downward influence obtained in a comprehensive model with moist processes also contains the response in the tropics, which could be studied from the viewpoint of the S-T dynamical coupling in the tropics.

Regional cloud-resolving models (CRMs) have been used to investigate convectively generated stratospheric gravity waves (e.g., Fovell et al. 1992) and their possible role in forcing the QBO in the equatorial stratosphere (e.g., Alexander and Holton 1997, Piani et al. 2000). CRMs have also been used to develop and refine parameterizations that describe sub grid-scale convectively generated gravity wave drag for climate model applications (e.g. Richter et al. 2010, Choi and Chun 2011), but large uncertainties related to the spectrum of waves remain, and the wave spectrum is in turn related to fine scale variations in convective latent heating. Observations from YMC can be used to greatly reduce these uncertainties with idealized CRMs that use radar-based precipitation as input (Grimsdell et al. 2010, Stephan and Alexander 2015).

Another type of two-dimensional CRM is one with a periodic lateral boundary condition to obtain a radiative-moist convective quasi-equilibrium state (Held et al. 1993, Yoden et al. 2014). In such models, internal oscillations dynamically analogous to the equatorial QBO are robustly obtained. The QBO-like oscillation has a clear signal in the zonal mean zonal wind and temperature even in the troposphere, and the oscillation also influences moist convective systems, with alternative appearance of two types of precipitation patterns, back building and squall line types, depending on the phase of the mean zonal wind oscillation. The vertical flux of horizontal momentum is modulated in association with the time variations of slantwise moist convection and gravity waves in the oscillation. A three-dimensional CRM was also used to investigate the impact of the tropopause temperature on the intensity of idealized TCs (Wang et al. 2014).

Numerical model studies with global GCMs or regional CRMs are necessary to understand the dynamics of S-T coupling processes observed in the tropics. However, current weather and climate models, both global and regional, still have systematic errors and uncertainties particularly in the tropics, largely due to the difficulty in modeling moist convective systems and their organization and multi-scale interactions, particularly over the MC (Lin et al. 2008, Tulich and Kiladis 2012, Kim and Alexander 2013a).

Global CRM simulations may provide useful information. A global simulation of 7-km mesh by the Nonhydrostatic Icosahedral Atmospheric Model (NICAM) demonstrates TTL variablities associated with gravity waves emanated from tropical cyclones, convectively coupled Kelvin waves, and the MJO (Kubokawa et al. 2012) and possible effects of stratospheric meridional circulation on cloud formation in the TTL (Eguchi et al. 2015). Further case studies for the YMC observation period are planned to deepen our understanding of the UTLS multi-scale processes and thermodynamics.

2.4 Aerosol

The MC and Southeast Asia (SA) are known major sources of biomass burning aerosol from agriculture practice and deforestation (Reid et al. 2013). Industrial pollution in the region is also increasing due to significant urban economic development (Salinas et al. 2013). Surrounded by open waters with frequent high-wind events, sea-spray generated aerosol are also abundant (Wang et al. 2012). The monsoon circulation and cold surges may bring aerosol from remote sources to the MC region.

Aerosol particles are an important part of the hydrological cycle, because they serve as nuclei for cloud droplet formation and primary ice formation. Ordinary cumulus and cumulus congestus clouds, frequently observed over land and seas in the region (Holz et al. 2008), are very likely affected by anomalous aerosol particle concentrations. In very clean conditions, when the numbers of aerosol particles present are relatively low, shallow cumulus clouds consist of fewer but larger cloud droplets, which tend to produce more frequent precipitation. In more polluted conditions, excess aerosol particles lead to larger numbers of smaller cloud droplets, and clouds that are generally less susceptible to precipitating.

The response of convective clouds to changes in regional aerosol is less clear. It is possible that it depends strongly on the meteorological conditions embedding the presence of the aerosol particles themselves. Convective updrafts with high numbers of smaller droplets tend to lift more liquid water to a cloud altitude where freezing starts. Latent heat released from the processes of condensation and freezing release enhances updrafts and may result in more intense thunderstorms. At the same time, the advection of free tropospheric dry layers may suppress convection, increasing aerosol lifetime and ultimately result in a confounded aerosol signal. The complex interactions between the liquid- and ice-phase microphysical processes, however, do not always result in higher precipitation rates under more polluted conditions. They do affect the storm outflow and thus the environment in which subsequent convection is initiated.

Biomass burning and industrial combustion in the MC and SA region result in polluted air in an otherwise extremely clean environment. Monsoonal flows transport pollution throughout the region. Extensive cloud cover and complex meteorology of the regions makes the monitoring and modeling of the environment extremely difficult (Campbell et al. 2015). However, these same factors make the region an almost ideal natural laboratory for seeking experimental answers on the role of aerosol particles in tropical cloud systems. A binding model is lacking to characterize how ice microphysical processes correlate with sensitivities in precipitation due to changing aerosol composition and physical properties, or how future severe weather and climate events (e.g., floods and drought) will react to changing anthropogenic emissions and future climate overall. The heavy aerosol loading that occurs in this region also likely results in strong absorption of solar radiation and modification of atmospheric thermal structure, another important aerosol-precipitation feedback.

The role of aerosol emissions in modulating the frequency and amount of precipitation in the MC and SA region under varying MJO, monsoon, and ENSO conditions needs further investigation. While it is clear from satellite data and some field observations that very high loadings of biomass burning and pollution aerosol are common in the region, we know very little about the characteristics of these particles in terms of their activities as cloud condensation nuclei or ice nucleating particles (INP). Modeling studies support the hypothesis that an increase in cloud condensation nuclei active at a few percent supersaturation acts to hinder precipitation formation in smaller clouds and can cause an increase in the convective intensity and localized precipitation in some deep convective clouds. Evidence suggests that this interaction is strongly influenced by the background meteorology, aerosol type (source), and the vertical distribution of the aerosol and cloud layers. Although these relationships have been extensively investigated through cloud and precipitation modeling, there is a lack of observational data for constraining and evaluating the models. Further, in the MC, very little is known about the abundance and characteristics of “background marine” aerosol to contrast with polluted scenarios.

The multi-scale variability of atmospheric convection and associated regional circulations inevitably affect aerosol production, transport, mixing and deposition. Variability of aerosol on the diurnal, synoptic, intraseasonal and seasonal timescales in the MC and SE Asian regions has yet to be fully documented and understood.

The following specific scientific issues need to be addressed:

- Influences of rainfall and wind on production, transport, mixing, deposition and distribution of aerosol, especially biomass burning smoke and natural marine aerosol, on diurnal, synoptic, intraseasonal, and annual timescales;
- Modulation of the aerosol size distributions by variability in rainfall, wind, and humidity on synoptic, intraseasonal, and annual timescales;
- Effects of anthropogenic and natural aerosol on microphysics (e.g., cloud drop size distribution) and cloud dynamics for different types of clouds;
- Changes in ice-phase cloud microphysical properties due to anomalous aerosol composition and physical properties within convective updrafts;
- Possible modulation of precipitation by anthropogenic aerosol in different tropical environments that fluctuate on synoptic, intraseasonal and seasonal timescales.

The highly variable aerosol loading in the MC suggests that aerosol exerts significant influences on circulation and cloud dynamics on many timescales. First, due to its absorbing characteristics, biomass burning aerosol can cause localized atmospheric heating, and its impact is sensitive to the vertical location of the absorbing layer

(McFarquhar and Wang 2006). Second, aerosol indirect effects on deep convection and precipitation may exist through aerosol modification of warm-, mixed-, and cold-cloud microphysics (Tao et al. 2012). Biomass burning emissions contain large number concentrations of particles that are CCN-active even shortly after emission (e.g., Petters et al. 2009a). Ongoing lab (Petters et al. 2009) and field (Prenni et al. 2013) studies find no clear associations between fuel type burned and emission of INP, although great variability exists. Clearly, more work is needed to understand the extent to which the details of the available particle populations can modulate the formation and evolution of convective clouds and precipitation. What is clear is that convection itself exerts a strong influence on aerosol loading (Tian et al. 2008), and that burning follows seasonal trends that are modulated by large-scale phenomena.

As emphasized by Reid et al. (2013), a major challenge in understanding aerosol-cloud interaction in the MC is the persistent cloudiness that precludes accurate retrievals of aerosol optical depth (AOD) and other aerosol properties from satellites and from ground-based sun photometers. Thus, we argue that there is a need for in situ observations to characterize the aerosol in the region to constrain and validate aerosol-cloud models. This goal was only partially met by previous ground-based and airborne observations (e.g., the 7SEAS campaign). The value of an extended deployment is evident from the strong seasonal variations in both aerosol loading and convection. There have been few larger-scale or longer-term studies of tropical convection that include aerosol observations as an integral component. Even the contributions of sea spray to total number concentrations and AOD are not well constrained, especially in areas where ocean productivity is high and variable, as in the MC (see Fig. 2.7).

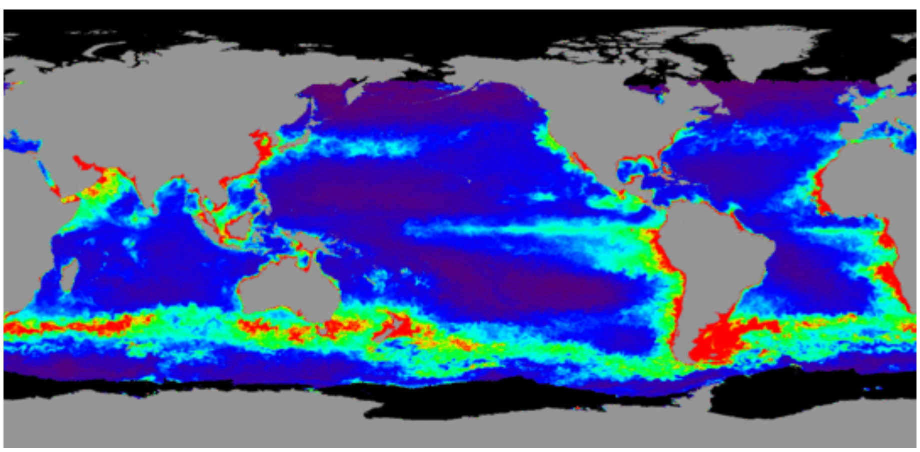

Figure 2.7 Net Primary Production using MODIS CHL and SST, SeaWiFS PAR, and z_eu = f(CHL) as inputs to the VGPM. Monthly net productivity for December 2004.
http://www.science.oregonstate.edu/ocean.productivity/

DeWitt et al. (2013) provide an excellent example of the information that can be gained from surface-based aerosol measurements. They used ship-based measurements during the AMIE/DYNAMO campaign to show complex interactions between transported continental pollution aerosol, convection, and generation of sea spray aerosol as functions of MJO phases. Their data helped clarify some of the processes that could not be resolve using satellite-based datasets alone (Tian et al. 2008). Considering multiple sources from biomass burning, sea spray, and local urban activities, and multi-scale convective activities in the MC region, we propose:

Hypothesis 4.1: Biomass burning particles dominate the MC aerosol during agricultural burning episodes regionally. Concentrations and the vertical distributions of biomass burning, sea spray and urban industrial aerosols are modulated by the monsoon, MJO, and land-sea breezes. MCS-driven precipitation is an essential scavenging mechanism that limits regional transport and the depth of aerosol layer presence. However, this comes at the expense of modified cloud microphysics within the convective core, which influences storm strength, precipitation, vertical depth, and cloud lifetimes.

Surface aerosol data are a key component of a larger integrated observational effort to address this hypothesis in combination with modeling at high spatial resolution and available/effective satellite observations. It is essential to characterize aerosol properties and large-scale forcing to drive cloud models and cumulus parameterizations for climate models, and, to the extent possible, cloud microphysical and dynamical properties. In particular, since updraft speeds are a major control on activation of liquid and ice particles in clouds (Phillips et al. 2007; Song et al. 2012), cumulus vertical velocities are critical. The robust diurnal, intraseasonal, and seasonal variability in the circulation, cloud, and precipitation over the MC provide a dynamical background for the aerosol-cloud interaction. Aerosol characteristics and interactions with cloud/precipitation in the MC region must be studied in the context of the diurnal cycle, MJO, and the monsoon. This requires aerosol measurements to taken simultaneously with observations of the dynamics and cover different phases and seasons of the MJO and monsoon.

2.5 Prediction Improvement

Improving prediction of weather and climate is an ultimate goal of YMC. This theme is focused on advancing predictions through improvement of representations of key processes in prediction models, taking advantage of the knowledge gained through the other four themes.

2.5.1 Known prediction problems within the MC region

Short-range forecasting has been more difficult in the tropics than mid-latitudes due to the more convective nature of weather-producing systems there. In mid-latitudes the weather is dominated by baroclinic disturbances, such as extratropical cyclones and fronts that have been better observed, studied, understood, and modelled than most of the weather-producing disturbances of the tropics. Weather in the tropics by comparison, is dominated by convective storms, especially around land and islands, with weak dynamic forcing, making them considerably more difficult to predict. This is demonstrated by the relatively lower skill for model predictions of rainfall over tropical land and island regions for the 1-day timescale (Fig. 2.8). In particular, skills are less over the islands of the MC than surrounding oceans and mid-latitudes.

As with other parts of the world, the major forecast concerns are extreme weather or high impact events. Given the high annual rainfall in the monsoon climate, a major issue is the prediction and warning of very heavy rainfall events, which depending on the duration that can result in flash flooding, landslides and large scale inundation. More case studies of these events are needed. However, experience tells that they are usually associated with large-scale phenomena such as the equatorially-trapped waves and monsoon surges and synoptic phenomena such as the Sumatra squall lines. It is anticipated that the YMC field campaign will take measurements to understand these major phenomena. Another form of severe weather hazard is the transboundary haze outbreaks associated with uncontrolled burning. On the 1-2 weeks ahead time frame, it is important to anticipate dry or warm spells leading to fire outbreaks or “hot spots”. During a haze event, the major forecast concern is prediction of changes in wind direction.

At longer timescales (medium-range forecasting and beyond), different processes and phenomena become important for prediction. Management of water resources is critical in tropical countries, so the major forecast issue on seasonal and interannual timescales is prediction of dry spells or drought. There is a rich literature on the impact of ENSO on rainfall in the MC (Haylock and McBride 2001; Hendon 2003, Kirono et al. 1999). A key feature is the strong seasonality and regionality of the ENSO-rainfall association (Hamada et al. 2002, 2012; Hendon 2003; Aldrian and Susanto 2003; Kubota et al. 2011), with the current prediction skill being limited to the winter hemisphere, or the dry and pre-monsoon (McBride et al. 2003; Chang et al. 2004b). A consequence is that the longer-range prediction skill of current models for monsoon rainfall in the MC region is still relatively poor, as demonstrated for the 1 week and 4 week timescales in Fig. 2.8.

Whereas ENSO provides predictability up to several months, the MJO should be more optimally targeted to the medium- to extended-range time scale (Goswami et al. 2011), and its impact on winds and cloud is especially large through the MC region (Wheeler and McBride 2011). One might therefore expect reasonable skill at predicting rainfall through the MC region for lead times of 1-3 weeks, which is the reported limit of predictive skill of the MJO in operational forecast systems (Rashid et al. 2011). However, model predictions of rainfall at this timescale are still lacking in the MC region, as also shown in Fig. 2.8. Recently it has been discovered that the MJO impact on rainfall over the larger MC islands is phase-shifted compared to the surrounding oceans (Peatman et al. 2014), and that although this interaction is present in prediction models, it is unrealistically weak (Peatman et al. 2015). Predicting MJO propagation through the MC is more difficult than predicting its propagation over the open ocean, which is known as the MJO prediction barrier (Seo et al. 2009).

Other relevant phenomena and processes for prediction in the MC region are the strong diurnal cycle, effects of topography, convectively-coupled equatorial waves, the Indian Ocean Dipole, and extratropical influences such as cold surges. There is evidence that the full prediction skill from these phenomena has not yet been realized, even partially. Predictions of weather and climate in the MC region are often complicated because of multi-scale interactions when more than one phenomenon is occurring at once.

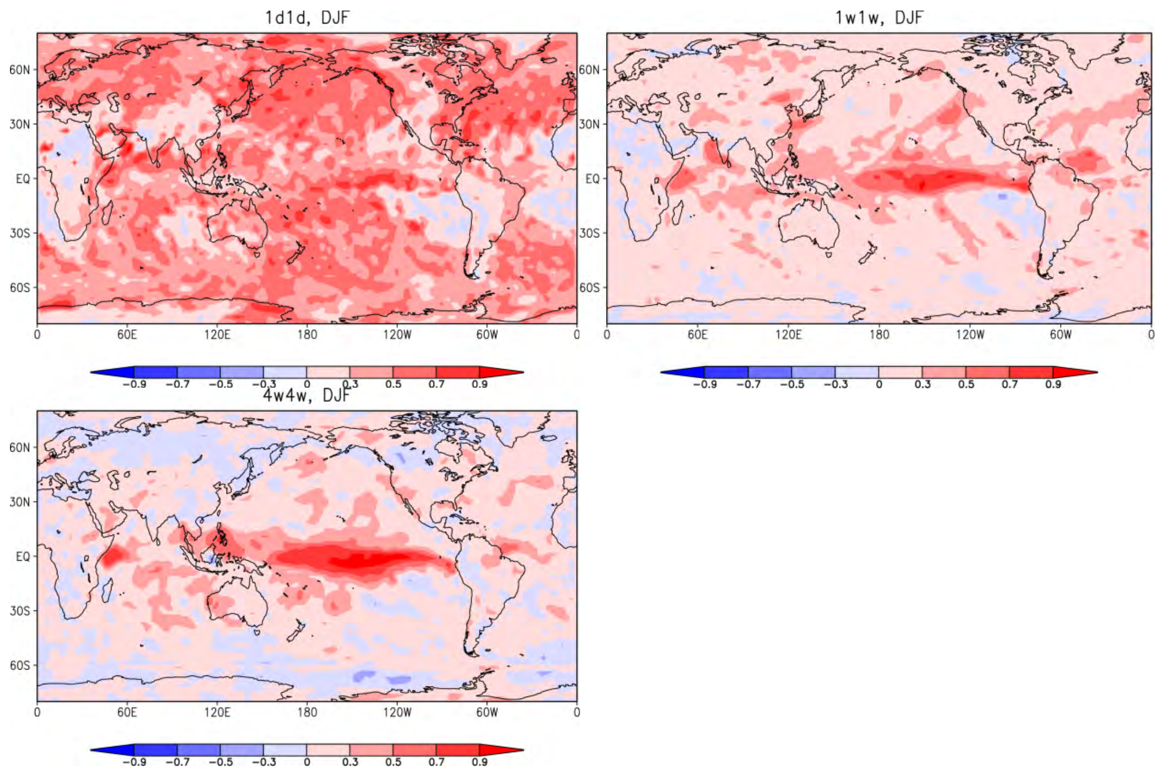

Figure 2.8 Prediction skill (correlations) for precipitation anomalies computed for hindcasts from the Predictive Ocean-Atmosphere Model for Australia (POAMA) version 2.4 against verifying observations of precipitation from the Global Precipitation Climatology Project (GPCP), for the months of December-January February, 1996-2009. "1d1d" refers to a 1-day window at a lead of 1 day. "1w1w" refers to a 1 week average at a lead of 1 week. "4w4w" refers to a 4 week average at a lead of 4 weeks. Adapted from Zhu et al. (2014).

2.5.2 Known global prediction problems related to the MC

An important consequence of the relative 'hole' in local prediction skill over the MC region (Fig. 2.8) is its negative impact on prediction skill elsewhere, an issue that is made more pronounced by the location of the MC at the centre of strongest large-scale rising motion on the globe (Lau and Yang 2002). With strong mean upward motion and large convective variability, the global circulation is especially sensitive to variations of rainfall in the MC region on timescales from weeks to seasons (Ferranti et al. 1994).

Related to this limited forecast skill in the MC region, most global models have large mean precipitation biases in the MC region (Hinton et al. 2009). When run in forecast mode, these biases often take only a few days to develop, suggesting that they are related to fast-physical processes such as convection (Martin et al. 2006), and their impact is spread around the globe via atmospheric wave propagation and teleconnections influencing extratropical forecasts after about 5 days (Ferranti et al. 1990).

Errors in the representation of MC variability, such as the MJO, similarly lead to medium to extended range forecast errors in the extratropics (Hendon et al. 2000). The MJO is known to be related to destructive events in the world (Zhang 2013). Its impact on the higher latitudes is particularly large when its convection center is propagating over the MC (Adames and Wallace 2014). The global impacts of MJO convection in the MC region can sometimes be quite extreme, such as the record warm temperatures over the USA in March 2012 being attributed to passage of an active MJO event through the MC region (Dole et al. 2014). Impacts are also felt on long-range forecasts via tropical-extratropical teleconnection pathways through the stratosphere that give the QBO a strong influence (Scaife et al. 2014). While coarse-resolution global model with parameterized convection have difficulties of propagating simulated MJO events through the MC, global cloud-permitting model simulations have demonstrated success in this regard (Miura et al. 2007; Miyakawa et al. 2014).

Given the sensitivity of global weather and climate to convective variability in the MC region, it follows that global climate change projections will be compromised as well. For example, there is no strong agreement between models on the projected change of Indonesian precipitation in the coming century (IPCC 2014), and this uncertainty is likely increasing uncertainty globally.

2.5.3 Prediction model improvement and links to other themes

There have been steady gains in the skill of numerical model prediction systems in recent decades, as is often demonstrated by the reduction in error of the 500 hPa geopotential height field (Magnusson and Källén 2013). It is now the case that for point-based forecasts of local conditions (e.g. temperature and precipitation), calibrated model output usually out-performs the most skillful human forecaster or statistical method. Therefore, future improvement in prediction will go hand-in-hand with model improvements, provided those model improvements are targeted to the phenomena and processes that are most relevant to prediction.

Some obvious candidate phenomena for improvement in the MC region are the mean precipitation, representation of the diurnal cycle, and the fine-scale MJO impact. Some improvements to these could be expected from increases in model resolution, especially due to the complex topography and land/sea mix of the MC. With modest increases in resolution, models continue to show deficiencies (Bush et al. 2015), showing a need for improvements in the model physical parameterizations (Jakob 2010).

The mean precipitation bias shows great sensitivity to changes in the physical parameterization of clouds and convection (Nguyen and Franklin 2015). The mean bias is also likely related to errors in the representation of the diurnal cycle of convection. The diurnal cycle of convection peaks at different times in different locations and is intimately tied to the local sea and land breeze circulations, making the boundary-layer parameterization and how it interacts with the convective parameterization also very important (Birch et al. 2015) (see Theme 1). Good observations of the sub-grid scale processes are required for improvements to these parameterizations.

The use of limited-area convection-permitting models for weather forecasts is becoming more common in the tropics. These models generally have a better functional behavior in terms of the formation, evolution and propagation of storms, the representation of cold pool outflows and the diurnal cycle (e.g. Love et al. 2011). However, large errors still exist in bulk measures such as the total rainfall, particularly over high orography (Love et al. 2011), and in the height and size of convective cores (Caine et al. 2013).

The impact of the MJO on rainfall in the MC region shows a complicated pattern that is quite different over the islands compared to the surrounding seas. Even though models have shown good progress at predicting the broad-scale structure and evolution of the MJO (Rashid et al. 2011), translating that down to local-scale weather remains a challenge (Hendon et al. 2011). For the MC region, it appears the MJO's interaction with the diurnal cycle is involved (Peatman et al. 2014), again pointing to a need for an improved representation of the same processes as mentioned above.

Finally, the ENSO rainfall signal in the MC region highlights yet another area requiring detailed process-scale observations for improvement, given the documented importance of local air-sea fluxes (Hendon 2003; Theme 2).

In summary, the following key science questions of the prediction improvement theme need to be addressed by YMC:

- How well do various types of numerical models (global, regional convection-permitting) represent the land/ocean breeze circulation and the triggering, organization and propagation of convection? Which aspects of these models require improvement?
- How do the known synoptic features such as the equatorially trapped waves and northeast monsoon surges interact with the diurnal convection to result in extreme monsoon rainfall events?
- What are the mechanisms governing the strong seasonality, spatial structure, and event-to-event variability of the relationship between ENSO and rainfall in the MC?
- Does a better representation of the atmospheric and oceanic diurnal cycle improve the propagation of the MJO across the MC?
- How does the initialization and representation of soil moisture in models impact the convection?
- To what extent does the representation of atmospheric and oceanographic processes in the MC impact forecast accuracy in remote regions?
- What are the key observations and model metrics necessary to evaluate models?
- How much would prediction of the MC region benefit from assimilating unconventional observations (e.g., radar radial wind and reflectivity) from the regional network?
- How should observations from the YMC field campaign be used directly to improve prediction in the MC region?

3. OBJECTIVES

The overall goal of YMC is 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 modeling exercises. YMC strive to achieve the following objectives:

Objective 1: *Build a comprehensive database of the MC weather-climate system.* This database will be the foundation for systematically documenting the multi-scale variability of the MC weather-climate system, exploring its predictability, advancing understanding of its key processes, better representing these processes in numerical models, and improving prediction of the local variability and global impact of the MC weather-climate system. This database will include existing data from regional and global observing networks, satellite observations, and global data assimilation products, special observations from a field campaign, special products of high-resolution data assimilation, and numerical model simulations.

Objective 2: *Advance modeling and prediction capability*. This will be pursued through integrating observations and modeling to allow more detailed quantification of model biases and errors in the MC region, numerical tests of model sensitivity to numerical configurations and physical representations, identification of root causes of model deficiencies, and demonstration of prediction improvements. Innovative applications of field observations to model evaluation and improvement, and advanced data assimilation technology to produce high-resolution products that synthesize observations from regional networks and the special field campaign are two approaches particularly valuable to the MC.

Objective 3: *Educate the next generation of scientists*. We need to produce scientists with proficiency in observations, modeling, prediction, and applications to bridge the gaps between observations and modeling, between research and operations, and between operation and public welfare. In addition, the general awareness of the nature of the MC weather-climate system and its global impact will help harness public long-term support for research.

4. MAIN ACTIVITIES

The YMC overall goal and objectives will be achieved through five main activities.

4.1 Data Sharing

There are extended observing networks in the MC region that include radiosondes, surface meteorological stations, marine observation stations, weather radars, and other instruments not used in operations. Currently, data from these networks are archived and used only by their respective hosting agencies/institutes. Often, results of analyses of these data are not shared beyond national borders. It would be of great benefit to all MC countries and the international research and operation communities if these data were shared. Through this YMC data sharing activity, these data will be collected, archived, and shared for at least the two-year (July 2017 – July 2019) YMC period. These shared data will be the central piece of a comprehensive database for the MC region. Other sources for the database include regional data from global observing networks (e.g., ARGO, TAO, RAMA), satellites (e.g., GPM, HIMAWARI-8/9, ADM-Aeolus, DSCOVR, and the ESA-Sentinel series), global data assimilation products, special regional high-resolution data assimilation products, and model simulations. This database will pave the road to a more comprehensive and detailed documentation of the multi-scale variability and interaction of the MC weather-climate system. It will also allow high-resolution data assimilation for the MC region to be tested as a new analysis tool and to be used as enhanced initial conditions for regional high-resolution prediction models. Data archives will be at several regional and international centers, all linked to and/or mirrored each other. Data access will be granted to all YMC participating individuals and institutes, and to the general public after the completion of YMC.

4.2 Field Campaign

Special observations targeting detailed physical processes key to the MC weather-climate variability and interaction are paramount to YMC and to research on MC in general. These data will be collected during a special two-year (July 2017 – July 1019) YMC field campaign. This field campaign will include observations from ground, airplanes, research vessels, and other manned and autonomic devices. Because of the intricacy of the land-sea distribution of the MC and ever-changing large-scale conditions associated with the MJO and monsoon, observations at a single location may not always represent other locations in the region. Ideally, field instruments should be deployed in as many places through the region as possible. Practically, a central concept of the YMC field campaign is to concentrate international resources into several intensive observing periods (IOPs) that cover dominant weather-climate regimes of the MC. The IOPs should (i) cover periods with both strong and weak signals of the diurnal cycle, synoptic-scale perturbations (e.g., equatorial waves, cold surges, Borneo vortices), the MJO, and the monsoon; (ii) sample over land, coasts, and oceans of both deep and shallow seas and coastal and open waters; and (iii) last sufficiently long to ensure adequate sample sizes either to build reliable statistics or to collect all different scenarios. Possible locations for the IOPs include the western MC (e.g., Sumatra and the adjacent ocean), the central MC (e.g., the South China Sea, Kalimantan/Borneo, Sulawesi, Java, Indonesian Seas, the Timor Sea, northern Australia), and the eastern MC (e.g., the Philippine Sea, New Guinea). Possible times for the IOPs are austral summer during the peak of the MC monsoon season when the MJO activity level is also high, and the boreal later spring and early summer when MC convection moves north during the Southeast/East Asian monsoon onset. Appendix A lists potential participations in the YMC field campaign. Detail design of the field campaign will be made in a YMC Implementation Plan.

4.3 Modeling

The ultimate goal of YMC is to help improve understanding and prediction of the MC weather-climate system. Improving prediction models is a critical step toward this goal. It is anticipated that both global and limited domain models will be important to this effort, including coupled models that encompass atmosphere, ocean, and land-surface components. Model biases and errors in the MC region needs to be further quantified using both conventional data and special field observations. In particular, root causes of model deficiencies need to be identified through innovative integration of field observations and modeling activities. Coordinated numerical experiments will help reveal common model maladies and model sensitivities to numerical configurations and representations of physical processes, and also help us to improve our physical understanding and numerical prediction capability in the MC region and elsewhere. Efforts will be made to design, test, and implement improved or new physical parameterization schemes. Models with known and quantified biases and errors against observations serve as powerful tools for hypothesis testing. High-resolution (cloud-permitting) model simulations and predictions for the MC region will be an important activity, as these models allow more natural interactions between convection, local topography, and the oceanic and atmospheric environments. Of particular note, high-resolution data assimilation including conventional and unconventional data (Activity 1) will yield products that bridge the gaps of YMC field observations, synthesize all available observational data in the MC region, and provide initial conditions that may lead to improved prediction (Activity 4).

4.4 Prediction and Applications

Enhancing societal benefit of predicting the MC weather-climate system can be achieved in two general ways. First and most importantly, prediction models must be improved. This is a long-lasting painstaking process that will not end because of any special project. YMC will contribute to this through activity (3). Second, current models and their products can be used more wisely. This could involve the use of more optimized model configurations, ensemble and probabilistic forecasts, more advanced data assimilation technology, and better initial conditions. One possible consequence of the data sharing activity (1) is better initial conditions that may lead to improved prediction skill. But this would have to be demonstrated. High-resolution (cloud-permitting) regional model prediction will be tested with conventional and unconventional data (e.g., radar data) being assimilated to produce better initial conditions. Special forecast products targeting particular sectors of society need to be carefully designed. Disseminating forecast products, especially those for high-impact events, through social media is another venue that will lead unprecedented benefit of prediction. The success of the Prediction and Applications activity will hinge uoon the involvement of the national weather and hydrometeorological services in the MC region. In this context it will be explored as to whether a WMO World Weather Research Programme Forecast Demonstration project, or similar, can be incorporated into the YMC field campaign.

4.5 Outreach and Capacity Building

General public support and new generations of scientists with advanced knowledge and skill for improving forecast of the MC weather- climate system are essential for the success and lasting legacy of YMC. Public awareness of the MC weather-climate system, its local variability and global impact can be brought to a higher level through traditional means (TV, radio, newspapers, pamphlets, open houses, school visits, etc.) and modern social media. Specific education is needed to familiarize general public with probabilistic forecast. Most importantly, training the next generation of scientists, forecasters, and technicians for future research, operations, and applications of prediction and simulation tools is the only way to make YMC research directly benefit society in a timely fashion. College and graduate students will involve in all levels of YMC activities. Special workshop and courses will be offered to cover materials about the MC weather-climate systems outside regular curricula. Elevated YMC research will allow more talented and motivated students to enroll in MS and PhD programs at home or abroad. Training provided to local forecasters will help them exploit potential prediction skills of global and regional high-resolution non-hydrostatic models that might be operational in the future, appreciate ensemble and probabilistic forecasts, apply modern radar and satellite products, and build conceptual models of local weather-climate systems, especially destructive events. Collectively, a "MC forecaster's handbook" can be written to guide forecasters to navigate through the seas of modern technology and products, and experience that can be acquired only through practice.

5. SYNERGY AND LEVERAGE WITH OTHER PROJECTS

Several established and planned international projects share common scientific interests with YMC. Their coordination and leverage will be mutually beneficial.

5.1 Propagation of Intra-Seasonal Tropical Oscillations (PISTON)

The US Office of Naval Research Departmental Research Initiative PISTON is expected to involve ship and airborne process-oriented field observations planned for late Summer and Fall 2018, tentatively to be based from the Philippines. Its scientific objective is to improve understanding of the atmosphere-ocean-land interactions in tropical archipelagos that modulate and control the structure and propagation of Intraseasonal Oscillations as they move from the Indian Ocean into the South China Sea or Western Pacific. A primary focus of PISTON will be improving our understanding and numerical simulation of the multi-scale interactions between diurnally forced convection and the large convective envelopes as they propagate eastward across shallow marginal seas and highly variable land and sea surface and atmospheric composition gradients. The ultimate goal is to improve forecast skill of local weather phenomena, as well as propagation of the MJO at longer lead times, in coupled mesoscale and synoptic prediction systems. This effort will potentially coordinate with CAMPEx and YMC field campaigns to cover a broader area and to augment each group's planned contributions.

5.2 Cloud-Aerosol-Monsoon Philippines Experiment (CAMPEx)

CAMPEx is an airborne field campaign planned for August and September 2018 supported by NASA tentatively to be based out of Subic Bay, Philippines. Its scientific objectives are to (i) determine the extent to which aerosol are responsible for modulating warm and mixed phase precipitation in tropical environments; (ii) understand how the presence of aerosol and the resulting increase in cloud droplet number changes the heat budget in convective clouds, and whether this change influences which clouds grow into deep convection; and (iii) characterize the aerosol-cloud lifecycle in the Asian Monsoon. Philippine partners will also focus on the impact of land surface change such as deforestation and urbanization influence coastal flows and convection. These objectives share commonality with those of the YMC Aerosol Theme. The planned CAMPEx airborne field campaign can potentially coordinate with the YMC airborne observations to cover a broader area and to augment each other’s instrumental capability.

5.3 Tropical Pacific Observing System (TPOS) 2020

This project was proposed to sustain the Tropical Pacific Observing System to support ENSO research, modeling and forecasting. TPOS 2020 recognizes the importance of the MC as its western boundary region and the crucial roles of the ITF in ocean dynamics and climate variability on both regional and global scales. It regards the MC as an integral part of the TPOS and recommends that observations in the MC need to be adequately covered by the TPOS. Observations to be taken by YMC and TPOS will contribute to both projects.

5.4 International Indian Ocean Expedition 2 (IIOE-2)

This project is proposed to be the second phase of the highly successful IIOE. Its overarching goal is to advance our understanding of interactions between geologic, oceanic and atmospheric processes that give rise to the complex physical dynamics of the Indian Ocean region, and to determine how those dynamics affect climate, extreme events, marine biogeochemical cycles, ecosystems and human populations. Its themes of Boundary current dynamics, upwelling variability and ecosystem impacts (Theme 2) and Monsoon Variability and Ecosystem Response (Theme 3) share common interests with the YMC themes of Ocean and Air-Sea Interaction and Atmospheric Convection. Observations of upwelling along the west coast of Sumatra and Java directly contribute to both IIOE-2 and YMC. Monsoon variability over the MC is a study target of both projects. YMC observations of MC convection and its connection to the SE Asian monsoon will complement IIOE-2 observations over the Indian Ocean.

5.5 Subseasonal-to-Seasonal Prediction Project (S2S)/MJO Task Force (MJOTF) Joint Maritime Continent Initiative

The WGNE MJOTF has the goal to facilitate improvements in the representation of the MJO in weather and climate models in order to increase the predictive skill of the MJO and related weather and climate phenomena. The main goal of the WWRP/THORPEX/ WCRP S2S project is to improve forecast skill and understanding on the subseasonal to seasonal timescale, and promote its uptake by operational centres and exploitation by the applications community. The S2S and MJOTF highlighted the interaction of the Martine Continent (MC) with the MJO as a high priority research question that has significant bearing on assessing shortcomings and improving operational MJO predictions, and hence recently developed a joint research initiative for the MC. This joint effort was initiated not only as a means of addressing basic science questions on process and prediction, but also as a means of contributing to and helping guide YMC and taking advantage of the unprecedented data for process-oriented diagnostics of modeling experiments that YMC will provide. This project and YMC will share a similar modeling experiment design that focuses on understanding interactions between the MJO and MC. A full description of this joint effort can be found here: http://www.s2sprediction.net/xwiki/bin/view/Main/MJO

5.6 CORDEX-Southeast Asia (CORDEX SA)

This is a project under the WCRP Coordinated Regional Climate Downscaling Experiment (CORDEX) with a focus on the Southeast Asia. With the MC covered by its domain, CORDEX SA is poised to address the following questions: What are the key processes and mechanisms in the MC that are not captured by the regional climate model, resulting to poor model performance and inability to capture seasonal dynamics? What are the appropriate adjustments and modifications to cumulus parameterization schemes for the model to properly simulate rainfall and rainfall dynamics in the MC region? How do variations in SSTs affect the simulated model climatology in the MC? Does the model adequately capture the diurnal cycle, MJO, and the extreme rainfall events associated with MJO and ENSO events and are the associated physical dynamics simulated well? The downscaling exercise of CORDEX SA is an integrated component of the YMC modeling theme. YMC observations will provide unprecedented validate data for CORDEX SA models.

5.7 Year of Polar Prediction (YOPP)

This project, planned to take place from mid-2017 to mid-2019 coincidently with the YMC, is a central activity of WWRP's Polar Prediction Project (PPP). It is designed to enable a significant improvement in environmental prediction capabilities for the polar region and beyond, by encompassing intensive observations, modeling/forecast experiments, verification of forecast, and a special educational effort. As for the observations, coordination with the international field experiment called the Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC) will be a major component. In particular, after the 2-year campaign, based on the enhanced observations as well as improved skill of the modeling and prediction, it is planned to produce a special high-resolution global reanalysis. YMC observations will contribute to this special reanalysis. Coordination with YOPP and YMC will bring a new synergy covering from the source to the sink of global circulation, where both are sensitive to the climate change and key areas to understand the global weather and climate.

5.8 7 Southeast Asian Studies (7SEAS)

The 7SEAS program was initiated in 2007 to study the extent to which aerosol particles impact regional weather, climate, and the environment. It covers aerosol lifecycle and air quality, tropical meteorology, radiation and heat balance, clouds and precipitation, land processes and fire, physical and biological oceanography, and environmental characterization through satellite analyses, model predictions, and verification. While 7SEAS may nominally disestablish by the YMC time, associations between investigators and networks are firmly in place and can quite easily work within a YMC construct. Their expertise and experience are invaluable to the planning and operation of the YMC field campaign and modeling work.

5.9 Stratosphere-troposphere Processes and their Role in Climate (SPARC)

Activities of the WCRP SPARC project are organized under three overarching themes that call for an integration of process studies, observations and modeling. SPARC activities are directly related to YMC Theme 3 “Stratosphere-Troposphere Interactions”, of which the objective is to improve understanding of processes governing the dynamical coupling of the stratosphere and troposphere and their mass exchanges over the MC. The dynamical coupling processes include not only the upward influence of tropospheric convection on the stratospheric circulation through multi-scale tropical waves but also possible downward influence of stratospheric variations (such as stratospheric cooling trend, QBO, and sudden warming events) on the tropical deep convection, its organization, and multi-scale interactions. The transport of gas and particles in the Tropical Tropopause Layer is the key process that controls the ozone layer and global climate. Deep convection and its organization, equatorial waves, the Asian monsoon, and their multi-scale variations largely control the transport processes. Coordinated observations, data analyses and numerical model studies will be promoted in the YMC activities.

5.10 Strateole-2

Observations from this long-duration balloon campaign in 2017-2019 will overlap the YMC period and will provide global observations of the tropical tropopause region. The balloons represent a Lagrangian platform at altitudes just above the tropical tropopause from which numerous measurements will be made related to the dynamics and composition of the tropopause region and lower stratosphere. Planned measurements include water vapor, ozone, clouds, aerosols, winds and temperatures at very high spatial and temporal resolution. The suite of instruments and the unique nature of the numerous balloon platforms, each with durations of several months, will advance scientific inquiries in gravity wave and equatorial wave dynamics, fluxes of trace gases, clouds and aerosols, stratospheric dehydration, and validation of satellite retrievals and model simulations that will be synergistic with the goals of YMC.

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7. REFERENCES

Adames, A.F. and J.M. Wallace, 2014: Three-Dimensional Structure and Evolution of the MJO and Its Relation to the Mean Flow, *J. Atmos. Sci*, 71, 2007-2026.

Aldrian, E., and Y. S. Djamil, 2008: Spatio-temporal climatic change of rainfall in East Java Indonesia. *Int. J. Climatol.*, 28, 435–448.

Aldrian, E., and D. Susanto, 2003: Identification of three dominant rainfall regions within Indonesia and their relationship to sea surface temperature. *Int. J. Climatol.*, 23, 1435-1452.

Alexander, M. J., and Holton, J. R., 1997: A model study of zonal forcing in the equatorial stratosphere by convectively induced gravity waves. *J. Atmos Sci.*, *54*, 408-419.

Alexander, M. J., J. R. Holton, and D. R. Durran, 1995: The gravity wave response above deep convection in a squall line simulation. *J. Atmos. Sci.*, 52, 2212–2226.

Alford, M.H. and Gregg, M.C. (2001). Near-inertial mixing: Modulation of shear, strain and microstructure at low latitude. *Journal of Geophysical Research 106: doi: 10.1029/2000JC000370.*

Allan, R.J., 1991: Australasia. *Teleconnections Linking Worldwide Climate Anomalies: Scientific Basis and Societal Impact*. Glantz, M. H., et al. Eds., Cambridge University Press, 73–120.

Araki, R., M. D. Yamanaka, F. Murata, H. Hashiguchi, Y. Oku, T. Sribimawati, M. Kudsy and F. Renggono, 2006: Seasonal and interannual variations of diurnal cycles of local circulation and cloud activity observed at Serpong, West Jawa, Indonesia. *J. Meteor. Soc. Japan*, 84A, 171-194.

Baldwin, M. P., et al., 2001: The quasi-biennial oscillation, Rev. Geophys., 39(2), 179–229,

Bellon, G., and A. Sobel, 2008: Instability of the axisymmetric monsoon flow and intraseasonal oscillation, *Journal of Geophysical research*, 113, D07108, doi: 10.1029/2007JD009291.

Bellon, G., A. H. Sobel, and J. Vialard, 2008: Ocean-atmosphere coupling in the monsoon intraseasonal oscillation: a simple model study, *Journal of Climate*, 20 (21), 5254–5270.

Birch, C. E., M. Roberts, L. Garcia-Carreras, D. Ackerley, M. Reeder, 2015: Sea breeze dynamics and convection initiation: the influence of convective parameterisation on climate model biases. *J. Climate*, in review.

Birner, T., S. M. Davis, and D. J. Seidel, 2014: The changing width of Earth’s tropical belt, *Phys. Today*, *67*(12), 38-44.

Kuang, 2010 : Mechanisms of poleward-propagating, intraseasonal convective anomalies in cloud-system resolving models, *J. Atmos. Sci.*, 67, 3673-3691

Birch, C. E., M. Roberts, L. Garcia-Carreras, D. Ackerley, M. Reeder, 2015: Sea breeze dynamics and convection initiation: the influence of convective parameterisation on climate model biases. *J. Climate*, in review.

Bjerknes, J., 1969: Atmospheric teleconnections from the equatorial Pacific. *Mon. Wea. Rev*., 97, 163–172.

Boehm, M. T., and Lee, S., 2003: The implications of tropical Rossby waves for tropical tropopause cirrus formation and for the equatorial upwelling of the Brewer-Dobson circulation. *Journal of the atmospheric sciences*, *60*(2), 247-261.

Boos, W. R., and Kuang, Z., 2010: Dominant control of the South Asian monsoon by orographic insulation versus plateau heating. *Nature*, *463*(7278), 218-222.

Brewer, A. W., 1949: Evidence for a world circulation provided by the measurements of helium and water vapour distribution in the stratosphere. *Quarterly Journal of the Royal Meteorological Society*, *75*(326), 351-363.

Bush, S. J., R. C. Levine, A. G. Turner, G. M. Martin, S. J. Woolnough, R. Schiemann, M. S. Mizielinski, M. J. Roberts, P. L. Vidale, M. –E. Demory, J. Strachan, 2015: The resolution sensitivity of the South Asian Monsoon and Indo-Pacific in a global 0.3° AGCM. *Clim. Dyn*., in review.

Butchart, N., 2014: The Brewer-Dobson circulation, *Rev. Geophys., 52*, doi: 10.1002/2013RG000448.

Caine, S., Lane, T. P., May, P. T., Jakob, C., Siems, S. T., Manton, M. J., and Pinto, J., 2013: Statistical assessment of tropical convection-permitting model simulations using a cell-tracking algorithm. *Monthly Weather Review*, *141*(2), 557-581.

Camargo, S. J., and A. H. Sobel, 2010: Revisiting the influence of the quasi-biennial oscillation on tropical cyclone activity. *J.Climate*, 23, 5810-5825.

Campbell, J. R., C. Ge, J. Wang, E. J. Welton, A. Bucholtz, E. J. Hyer, E. A. Reid, B. N. Chew, S.-C. Liew, S. V. Salinas, S. Lolli, K. Kaku, P. Lynch, M. Mahamod, M. Mohamad, and B. N. Holben, 2015: Applying advanced ground-based remote sensing in the Southeast Asian Maritime Continent to characterize regional proficiencies in smoke transport modeling. J. Appl. Meteorol. Clim, in revision.

Chang, C.-P., P. A. Harr, and H. J. Chen, 2005: Synoptic disturbances over the equatorial South China Sea and western Maritime Continent during boreal winter. *Mon. Wea. Rev.,* 133, 489-503.

Chang, C-P., P. Harr, J. McBride and H. Hsu, 2004a: The maritime continent monsoon. In *East Asian Monsoon*, (C-P Chang, editor), World Scientific Series of Meteorology of East Asia, World Scientific Publishing.

Chang, C. P., Liu, C. H., and Kuo, H. C., 2003: Typhoon Vamei: An equatorial tropical cyclone formation. *Geophysical research letters*, *30*(3).

Chang, C-P, Z. Wang, J. Ju and T. Li, 2004b: On the relationship between western Maritime Continent monsoon rainfall and ENSO during northern winter. *J. Climate*, 17, 665-672

Chang, C.-P. and K. M. Lau,1982: Short-term planetary-scale interactions over the tropics and midlatitude during northern winter. Part I: Contrasts between Active and Inactive Periods. *Mon. Wea. Rev.*, 110, 933-946.

Chang, C.-P., M.-M. Lu, and H. Lim, 2015: Monsoon Convection in Maritime Continent: Interaction of Large-Scale Motion and Complex Terrain. *AMS Monograph on Multi-scale Convection-Coupled Systems in the Tropics, a tribute to the late Professor Yanai*, in press.

Chang, C.-P., Z. Wang, and H. Hendon, 2006: The Asian Winter Monsoon. *The Asian Monsoon, B. Wang, Ed.*, Praxis, Berlin, 89-127.

Chang, C.-P., Z. Wang, J. McBride, and C.-H. Liu, 2005: Annual cycle of southeast Asia—Maritime continent rainfall and the asymmetric monsoon transition. *J. Climate*, 18, 287-301.

Chen, S. S., and R. A. Houze, Jr., 1997: Diurnal variation and life-cycle of deep convective systems over the tropical Pacific warm pool. *Quart. J. Roy. Meteor. Soc.*, 123, 357–388.

Chen, S. S., R. A. Jr Houze, and B. E. Mapes, 1996: Multi-scale variability of deep convection in relation to large-scale circulation in TOGA COARE. J. Atmos. Sci., 53, 1380–1409.

Chen, T.-C., M. Murakami, 1988: The 30–50 day variation of convective activity over theWestern Pacific-Ocean with Emphasis on the Northwestern Region. *Mon.Wea. Rev.*, 116, 892–906.

Choi, H.-J. and H.-Y. Chun, 2011: Momentum Flux Spectrum of Convective Gravity Waves. Part I: An Update of a Parameterization Using Mesoscale Simulations. *J. Atmos. Sci.*, 68, 739–759.

Churchill, D. D., and R. A. Houze Jr., 1984a: Development and structure of winter monsoon cloud clusters on 10 December 1978. *J. Atmos. Sci.*, 41, 933–960.

Churchill, D. D., and R. A. Houze Jr., 1984b: Mesoscale updraft magnitude and cloud-ice content deduced from the ice budget of the stratiform region of a tropical cloud cluster. *J. Atmos. Sci.*, 41, 1717–1725.

Claud, C., and P. Terray, 2007: Revisiting the possible links between the quasi-biennial oscillation and the Indian summer monsoon using NCEP R-2 and CMAP fields. *J. Climate*, 20, 773-787.

Collimore, C. C., D. W. Martin, M. H. Hitchman, A. Huesmann, and D. E. Waliser, 2003: On the relationship between the QBO and tropical deep convection. *J. Climate*, 16, 2552-2568.

Collimore, C. C., M. H. Hitchman, and D. W. Martin, 1998: Is there a quasi-biennial oscillation in tropical deep convection? *Geophys. Res. Lett.*, 25-3, 333-336.

Corti, T. et al., 2008: Unprecedented evidence for deep convection hydrating the tropical stratosphere. *Geophysical Research Letters*, *35*(10).

Davis, S. M., and Rosenlof, K. H., 2012: A multidiagnostic intercomparison of tropical-width time series using reanalyses and satellite observations. *Journal of Climate*, *25*(4), 1061-1078.

DeWitt, L., H., D. J. Coffman, K. J. Schulz, W. Alan Brewer, T. S. Bates, and P. K. Quinn, 2013: Atmospheric aerosol properties over the equatorial Indian Ocean and the impact of the Madden-Julian Oscillation, J. Geophys. Res. Atmos., 118, 5736-5749.

Dole, M. H., and Coauthors, 2014: The making of an extreme event: Putting the pieces together. *Bull. Amer. Meteor. Soc.*, 95, 427–440.

Drbohlav, H.-K. L., B. Wang, 2005: Mechanism of the northward propagating intraseasonal oscillation in the south Asian monsoon region: insights from a zonally averaged model. *J. Climate*, 18, 952–972.

Drushka, K., Sprintall, J., and Gille, S.T., 2010: Vertical structure of Kelvin waves in the Indonesian Throughflow exit passages. *J. Phys. Oceanogr.* 40, 1965-1987.

Drushka, K., J. Sprintall and S.T. Gille, 2014: Subseasonal variations in salinity and barrier layer thickness in the eastern equatorial Indian Ocean. *Journal of Geophysical Research*, 119, DOI: 10.1002/2013JC009422

Eguchi, N., and K. Kodera, 2010: Impacts of stratospheric sudden warming event on tropical clouds and moisture fields in the TTL: A case study. *SOLA*, 6, doi: 10.2151/sola.2010-035

Eguchi, N., K. Kodera, T. Nasuno, 2015: A global non-hydrostatic model study of a downward coupling through the tropical tropopause layer during a stratospheric sudden warming, Atmospheric Chemistry and Physics, 15, 297-304.

Emanuel, K., S. Solomon, D. Folini, S. Davis, and C. Cagnazzo, 2013: Influence of tropical tropopause layer cooling on Atlantic hurricane activity. *J. Climate*, 26, 2288–2301.

Fadnavis, S., P. E. Raj, P. Buchunde, and B. N. Goswami, 2013: In search of influence of stratospheric Quasi-Biennial Oscillation on tropical cyclones tracks over the Bay of Bengal region. *Int. J. Clim.*, 34, 567-580.

Ferranti, L., T.N. Palmer, F. Molteni, and E. Klinker, 1990: Tropical-extratropical interaction associated with the 30–60 Day oscillation and its impact on medium and extended range prediction. *J. Atmos. Sci.*, 47, 2177–2199.

Ferranti, L., F. Molteni, and T. Palmer, 1994: Impact of localized tropical and extratropical SST anomalies in ensembles of seasonal GCM integrations. *Quart. J. Roy. Meteor. Soc.*, 120, 1613–1645.

Ffield, A. and Robertson, R., 2005: Indonesian Seas finestructure variability. Oceanogr. 18, 108-111.

Ffield, A., and A. L. Gordon, 1992: Vertical Mixing in the Indonesian Thermocline, Journal of Physical Oceanography, 22, 184-195.

Ffield, A., and Gordon, A.L., 1996: Tidal mixing signatures in the Indonesian Seas. J. Phys. Oceanogr. 26, 1924-1937.

Flannaghan, T. J. and S. Fueglistaler, 2013: The importance of background state for the climatology of equatorial Kelvin wave propagation into the stratosphere, *J. Geophys. Res. Atmos.*, 118, 5160-5175.

Flannaghan, T. J. and S. Fueglistaler, 2014: Vertical mixing and the temperature and wind structure of the tropical tropopause layer, *J. Atmos. Sci.*, *71*(5), 1609-1622.

Folkins, I., C. Braun, A. M. Thompson, J. Witte, 2002: Tropical ozone as an indicator of deep convection, J. Geophys. Res., 107, D13, 4184, 10.1029/2001JD001178.

Folkins, I., Mitovski, J. R., Pierce, 2014: A simple way to improve the diurnal cycle in convective rainfall over land in climate models. J. Geophys. Res. Atmos. 0.1002/2013JD020149

Folkins, I. A., M. Loewenstein, J. Podolske, S. Oltmans, and M. Proffitt, 1999: A barrier to vertical mixing at 14 km in the tropics: Evidence from ozonesondes and aircraft measurements, *J. Geophys. Res.*, 104, 22,095–22,101.

Fovell, R., D. Durran, and J. R. Holton, 1992: Numerical simulations of convectively generated stratospheric gravity waves, *J. Atmos. Sci.*, 49, 1427–1442.

Frederiksen, J. S., and H. Lin, 2013: Tropical–extratropical interactions of intraseasonal oscillations. *J. Atmos. Sci.*, 70, 3180–3197.

Fu, X., B. Wang, 2004: Differences of boreal summer intraseasonal oscillations simulated in an atmosphere–ocean coupled model and an atmosphere-only model. *J. Climate*, 17, 1263-1271.

Fu, X., B. Wang, T. Li, J. McCreary, 2003: Coupling between northward-propagating. intraseasonal oscillations and sea surface temperature in the Indian Ocean. *J. Atmos. Sci.*, 60, 1733–1753.

Fueglistaler, S., A. E. Dessler, T. J. Dunkerton, I. Folkins, Q. Fu, and P. W. Mote, 2009: Tropical tropopause layer, *Rev. Geophys. 47*, 1–31.

Fueglistaler, S., H. Wernli, and T. Peter, 2004: Tropical troposphere-to-stratosphere transport inferred from trajectory calculations. *J. Geophys. Res.*, 109, D03108, doi:10.1029/ 2003JD004069.

Fujiwara, M., S. Iwasaki, A. Shimizu, Y. Inai, M. Shiotani, F. Hasebe, I. Matsui, N. Sugimoto, H. Okamoto, N. Nishi, A. Hamada, T. Sakazaki, and K. Yoneyama, 2009: Cirrus observations in the tropical tropopause layer over the western Pacific, *J. Geophys. Res., 114,* D09304, doi: 10.1029/2008JD011040.

Fujiwara, M., H. Vömel, F. Hasebe, M. Shiotani, S.-Y. Ogino, S. Iwasaki, N. Nishi, T. Shibata, K. Shimizu, E. Nishimoto, J. M. Valverde-Canossa, H. B. Selkirk, and S. J. Oltmans, 2010: Seasonal to decadal variations of water vapor in the tropical lower stratosphere observed with balloon-borne cryogenic frostpoint hygrometers, *J. Geophys. Res.*, *115*, D18304, doi: 10.1029/2010JD014179.

Gettelman, A., and Birner, T., 2007: Insights into tropical tropopause layer processes using global models. *Journal of Geophysical Research: Atmospheres (1984–2012)*, *112*(D23).

Gettelman, A., P. M. de F. Forster, M. Fujiwara, Q. Fu, H. Vömel, L. K. Gohar, C. Johanson, and M. Ammerman, 2004: Radiation balance of the tropical tropopause layer, J. Geophys. Res., 109, D07103, doi:10.1029/2003JD004190.

Gettelman, A., Salby, M. L., and Sassi, F., 2002: Distribution and influence of convection in the tropical tropopause region. *Journal of Geophysical Research: Atmospheres (1984–2012)*, *107*(D10), ACL-6.

Gordon, A. L., 2005: Oceanography of the Indonesian seas and their throughflow, Oceanography, 18, 14–27.

Gordon, A.L., Susanto, R.D. and Vranes, K., 2003: Cool Indonesian Throughflow as a consequence of restricted surface layer flow. Nature 425, 824-828.

Gordon, A.L., Huber, B.A., Metzger, E.J., Susanto, R.D., Hurlburt, H.E., and Adi, T.R., 2012: South China Sea Throughflow impact on the Indonesian Throughflow. Geophys. Res. Lett. 39, L11602.

Gordon, A. L., and R. D. Susanto, 2001: Banda Sea Surface Layer Divergence. Ocean Dynamics, 52: 2-10.

Goswami, B.N., M.C. Wheeler, J.C. Gottschalck, and D.E. Waliser, 2011: Intraseasonal variability and forecasting: A review of recent research. In: C.-P. Chang, Y.H. Ding, N.-C. Lau, R. Johnson, B. Wang, and T. Yasunari (eds), *The Global Monsoon System: Research and Forecast (2nd edition)*. World Scientific Series on Asia-Pacific Weather and Climate, Vol. 5, pages 389-408.

Gray, W. M., 1984: Atlantic seasonal hurricane frequency. Part I: El Niño and 30 mb quasi-biennial oscillation influences. *Mon. Wea. Rev.*, 112, 1649-1668.

Grimsdell, A.W., M. J. Alexander, P. T. May, and L. Hoffmann, 2010: Model Study of Waves Generated by Convection with Direct Validation via Satellite. *J. Atmos. Sci.*, 67, 1617–1631.

Grise, K. M., and Thompson, D. W., 2013: On the signatures of equatorial and extratropical wave forcing in tropical tropopause layer temperatures. *Journal of the Atmospheric Sciences*, *70*(4), 1084-1102.

Hadi, T. W., T. Horinouchi, T. Tsuda, H. Hashiguchi and S. Fukao, 2002: Sea-breeze circulation over Jakarta, Indonesia: A climatology based on boundary layer radar observations. *Mon. Wea. Rev.*, 130, 2153-2166.

Hagos, S., Z. Feng, S. McFarlane, and L. R. Leung, 2013: Environment and the lifetime of tropical deep convection in a cloud-permitting regional model simulation. *J. Atmos. Sci.*, 70, 2409–2425.

Hamada, J.-I., M. D. Yamanaka, J. Matsumoto, S. Fukao, P. A. Winarso and T. Sribimawati, 2002: Spatial and temporal variations of the rainy season over Indonesia and their link to ENSO. *J. Meteor. Soc. Japan*, 80, 285-310.

Hamada, J.-I., S. Mori, M. D. Yamanaka, U. Haryoko, S. Lestari, R. Sulistyowati and F. Syamsudin, 2012: Interannual rainfall variability over northwestern Jawa and its relation to the Indian Ocean dipole and El Niño-southern oscillation events, *SOLA*, 8, 69-72.

Hasebe, F., Y. Inai, M. Shiotani, M. Fujiwara, H. Vömel, N. Nishi, S.-Y. Ogino, T. Shibata, S. Iwasaki, N. Komala, T. Peter, and S. J. Oltmans, 2013: Cold trap dehydration in the Tropical Tropopause Layer characterized by SOWER chilled-mirror hygrometer network data in the Tropical Pacific, *Atmos. Chem. Phys., 13*, 4393-4411.

Hashiguchi, H., S. Fukao, M. D. Yamanaka , T. Tsuda, S. W. B. Harijono and H. Wiryosumarto, 1995a: Boundary layer radar observations of the passage of the convection center over Serpong, Indonesia (6°S, 107°E) during the TOGA-COARE intensive observation period . *J. Meteor. Soc. Japan*, 30 , 543-548.

Hattori, M., S. Mori, and J. Matsumoto, 2011: The cross-equatorial northerly surge over the maritime continent and its relationship to precipitation patterns. *J. Meteor. Soc. Japan*, 89A, 27-47.

Haylock, M., and J. McBride, 2001: Spatial Coherence and predictability of Indonesian wet season rainfall. *J. Climate*. 14, 3882-3887.

Haynes, P. H., M. E. McIntyre, T. G. Shepherd, C. J. Marks, and K. P. Shine, 1991: On the "downward control" of extratropical diabatic circulations by eddy-induced mean zonal forces. *J. Atmos. Sci.*, 48, 651-678.

He, J., H. Lin, and Z. Wu, 2011: Another look at influences of the Madden-Julian oscillation. *J. Geophys. Res.*, 116, D03109.

Held, I. M., R. S. Hemler, and V. Ramaswamy, 1993: Radiative-convective equilibrium with explicit two-dimensional moist convection. *J. Atmos. Sci.*, 50, 3909–3927.

Hendon, H. H., 2003: Indonesian rainfall variability: Impacts of ENSO and local air–sea interaction. *J. Climate,* 16, 1775–1790.

Hendon, H. H., and B. Liebmann, 1990: The Intraseasonal (30-50 day) Oscillation of the Australian Summer Monsoon. *Journal of the Atmospheric Sciences*, 47, 2909-2923

Hendon, H.H., B. Liebmann, M. Newman, J.D. Glick, and J. E. Schemm, 2000: Medium-range forecast errors associated with active episodes of the Madden–Julian oscillation. *Mon. Wea. Rev.*, 128, 69–86.

Hendon, H.H., K.R. Sperber, D.E. Waliser, and M.C. Wheeler, 2011: Modelling monsoon intraseasonal variability: From theory to operational forecasting. *Bull. Amer. Meteor. Soc.*, 92, ES32-ES35. doi:10.1175/2011BAMS3164.1.

Hidayat, R., and S. Kizu, 2010: Influence of the Madden-Julian Oscillation on Indonesian rainfall variability in austral summer. *Int. J. Climatol.*, 30, 1816-1825.

Hinton, T. J., B. J. Hoskins, and G. M. Martin, 2009: The influence of tropical sea-surface temperatures and precipitation on North Pacific atmospheric blocking. *Climate Dyn.*, 33, 549–563.

Hitchcock, P., and I. R. Simpson, 2014: The downward influence of stratospheric sudden warmings. *J. Atmos. Sci.*, 71, 3856-3876.

Ho, C.-H., H.-S. Kim, J.-H. Jeong, and S.-W. Son, 2009: Influence of stratospheric quasi-biennial oscillation on tropical cyclone tracks in the western North Pacific. *Geophys. Res. Lett.*, 36, L06702, doi: 10.1029/2009GL037163.

Holz, R. E., S. A. Ackerman, F. W. Nagle, R. Frey, S. Dutcher, R. E. Kuehn, M. A. Vaughan, and B. Baum, 2008: Global Moderate Resolution Imaging Spectroradiometer (MODIS) cloud detection and height evaluation using CALIOP. *J. Geophys. Res.*, 113, D00A19, doi:10.1029/2008JD009837.

Houze, R. A., Jr., S. S. Chen, D. E. Kingsmill, Y. Serra, and S. E. Yuter, 2000: Convection over the Pacific warm pool in relation to the atmospheric Kelvin-Rossby wave. *J. Atmos. Sci.*, 57, 3058–3089.

Houze Jr, R.A., S.G. Geotis, F. D. Marks Jr., and A. K. West, 1981: Winter Monsoon Convection in the Vicinity of North Borneo. Part I: Structure and Time Variation of the Clouds and Precipitation. *Mon. Wea. Rev.*, 109, 1595–1614.

Hsu, H.-H., C.-H. Weng, 2001: Northwestward propagation of the intraseasonal oscillation in the western North Pacific during the boreal summer: structure and mechanism. *J. Climate*, 14, 3834–3850.

Ichikawa, H., and T. Yasunari, 2006: Time–space characteristics of diurnal rainfall over Borneo and surrounding oceans as observed by TRMM-PR, *Journal of Climate*, 19, 1238–1260.

Ichikawa, H., and T. Yasunari, 2007: Propagating diurnal disturbances embedded in the Madden-Julian Oscillation, *Geophysical Research Letters*, 34, L18811.

Inai, Y., F. Hasebe, M. Fujiwara, M. Shiotani, N. Nishi, S.-Y. Ogino, H. Vömel, S. Iwasaki, and T. Shibata, 2013: Dehydration in the tropical tropopause layer estimated from the water vapor match, *Atmos. Chem. Phys.*, *13*, 8623-8642.

Inness, P. M., J. M. Slingo, E. Guilyardi, and J. Cole, 2003: Simulation of the Madden-Julian oscillation in a coupled general circulation model. Part II: The role of the basic state, *Journal of Climate*, 365-382.

Inness, P. M., and J. M. Slingo, 2006: *The interaction of the Madden-Julian Oscillation with the Maritime Continent in a GCM, Quarterly Journal of the Royal Meteorological Society*, 132 (618),1645-1667.

Inoue T., and H. Ueda 2009: Evaluation for the Seasonal Evolution of the Summer Monsoon over the Asian and Western North Pacific Sector in the WCRP CMIP3 Multi-model Experiments. J. Meteor. Soc. Japan, 87, 539—560.

IPCC, 2014: Summary for Policymakers. In: *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1-32.

Iwasaki, S., T. Shibata, H. Okamoto, H. Ishimoto, and H. Kubota (2012), Mixtures of stratospheric and overshooting air measured using A-Train sensors, *J. Geophys. Res.*, *117*, D12207, doi: 10.1029/2011JD017402.

Jakob, C., 2010: Accelerating progress in global atmospheric model development through improved parameterizations - Challenges, opportunities and strategies. *Bull. Amer.*

Meteorol. Soc., 91, 869-875.

Jeong, J.-H., B.-M. Kim, C.-H. Ho, and Y.-H. Noh, 2008: Systematic variation in wintertime precipitation in East Asia by MJO-induced extratropical vertical motion. *J. Climate*, 21, 788–801.

Jiang, X.N., T. Li, B. Wang, 2004: Structures and mechanisms of the northward propagating boreal summer intraseasonal oscillation. *J. Climate*, 17, 1022–1039.

Johnson, R. H., and R. A. Houze, Jr., 1987: Precipitating cloud systems of the Asian monsoon. *Monsoon Meteorology*, C.-P. Chang and T. N. Krishnamurti, Eds., Oxford University Press, 298-353.

Johnson, R. H., and D. C. Kriete, 1982: Thermodynamic and circulation characteristics of winter monsoon tropical mesoscale convection, Mon. Wea. Rev., 110, 1898-1911.

Johnson, R.H., and D. L. Priegnitz, 1981: Winter Monsoon Convection in the Vicinity of North Borneo. Part II: Effects on Large-Scale Fields. *Mon. Wea. Rev.*, 109, 1615–1628.

Kamimera, H., S. Mori, M. D. Yamanaka, and F. Syamsudin, 2012: Modulation of Diurnal Rainfall Cycle by the Madden-Julian Oscillation Based on One-Year Continuous Observations with a Meteorological Radar in West Sumatera. *SOLA*, 8, 111-114.

Kanamori, H., T. Yasunari, and K. Kuraji, 2013: Modulation of the Diurnal Cycle of Rainfall Associated with the MJO Observed by a Dense Hourly Rain Gauge Network at Sarawak, Borneo. *J. Climate*, 26, 4858–4875.

Kang, I.-S., D. Kim, and J.-S. Kug, 2010: Mechanism for northward propagation of boreal summer intraseasonal oscillation: Convective momentum transport, *Geophys. Res. Lett.*, 37, L24804.

Karpechko, A. Y., and E. Manzini, 2012: Stratospheric influence on tropospheric climate change in the Northern Hemisphere. J. Geophys. Res., 117, D05133, doi:10.1029/2011JD017036.

Kirono, D. G., Tapper, N. J., and McBride, J. L., 1999: Documenting Indonesian rainfall in the 1997/1998 El Nino event. *Physical Geography*, 20(5), 422-435.

Kawatani Y., S. Watanabe, K. Sato, T. J. Dunkerton, S. Miyahara, and M. Takahashi, 2010: The Roles of Equatorial Trapped Waves and Internal Inertia–Gravity Waves in Driving the Quasi-Biennial Oscillation. Part I: Zonal Mean Wave Forcing. *J. Atmos. Sci.*, 67, 963–980.

Keenan, T.D., and R. E. Carbone, 2008: Propagation and Diurnal Evolution of Warm Season Cloudiness in the Australian and Maritime Continent Region. *Mon. Wea. Rev.*, 136, 973–994.

Kida, S., and K. J. Richards, 2009: Seasonal sea surface temperature variability in the Indonesian Seas, J. Geophys. Res., 114, C06016, doi:10.1029/2008JC005150.

Kida, S., and Wijffels, S.E., 2012: The impact of the Indonesian throughflow and tidal mixing on the summertime sea surface temperature in the western Indonesian seas. *J. Geophys. Res*. 117, C09007.

Kikuchi, K., B. Wang, and Y. Kajikawa, 2012: Bimodal representation of the tropical intraseasonal oscillation. *Clim. Dyn*., 38, 1989-2000.

Kim, Ji-Eun and M. Joan Alexander, 2013: Tropical Precipitation Variability and Convectively Coupled Equatorial Waves on Submonthly Time Scales in Reanalyses and TRMM. *J. Climate*, 26, 3013–3030.

Kim, J.-E., and M. Joan Alexander, 2013b: A new wave scheme for trajectory simulations of stratospheric water vapor, Geophys. Res. Lett., 40, 5286–5290,

Kim, Ji-Eun and M. Joan Alexander, 2015: Direct impacts of waves on tropical cold point tropopause temperature. Accepted manuscript online: DOI: 10.1002/2014GL062737.

Kirono, D. G., Tapper, N. J., and McBride, J. L., 1999: Documenting Indonesian rainfall in the 1997/1998 El Nino event. *Physical Geography*, 20(5), 422-435.

Koch-Larrouy, A., A. Atmadipoera, P. van Beek, G. Madec, J. Aucan, F. Lyard, J. Grelet, M. Souhaut, 2015: Estimates of tidal mixing in the Indonesian archipelago from multidisciplinary in-situ data. Deep Sea, in revision.

Koch-Larrouy A., Madec, G., Iudicone, D., Molcard, R. and Atmadipoera, 2008a: A. Physical processes contributing in the water mass transformation of the Indonesian ThroughFlow. *Ocean Dyn.* 58, 275-288.

Koch-Larrouy A., Madec, G., Blanke, B. and Molcard, R., 2008b: Quantification of the water paths and exchanges in the Indonesian archipelago. *Ocean Dyn*. 58, 289-309.

Koch-Larrouy, A., Lengaigne, M., Terray, P., Madec, G. and Masson, S., 2010: Tidal mixing in the Indonesian Seas and its effect on the tropical climate system. *Climate Dyn,* 34, 891 – 904.

Können, G. P., P. D. Jones, M. H. Kaltofen and R. J. Allan, 1998: Pre-1866 extensions of the southern oscillation index using early Indonesian and Tahitian meteorological readings. *J. Climate*, 11, 2325–2339.

Kodera, K., N. Eguchi, J. N. Lee, Y. Kuroda, and S. Yukimoto, 211: Sudden changes in the tropical stratospheric and tropospheric circulation during January 2009. *J. Meteor. Soc. Japan*, 89, 283-290. doi: 10.2151/jmsj.2011-308

Kosaka Y. , J. S. Chowdary, S.-P. Xie, Y.-M. Min and J.-Y. Lee, 2012: Limitations of seasonal predictability for summer climate over East Asia and the Northwestern Pacific. *J. Climate*, 25, 7574–7589.

Koseki, S., T.-Y. Koh, and C.-K. Teo, 2013: Borneo vortex and mesoscale convective rainfall, *Atmos. Chem. Phys. Discuss.*, 13, 21079-21124.

Kubokawa, H., M. Fujiwara, T. Nasuno, M. Miura, M. K. Yamamoto, and M. Satoh, 2012: Analysis of the tropical tropopause layer using the Nonhydrostatic ICosahedral Atmospheric Model (NICAM): 2. An experiment under the atmospheric conditions of December 2006-January 2007, *J. Geophys. Res., 117*, D17114, doi: 10.1029/2012JD017737.

Kubota, H., Y. Kosaka, and S.-P. Xie, 2014: A 116-year long index of the Pacific-Japan pattern and its interdecadal variability. *J. Climate*, submitted.

Kubota, H., R. Shirooka, Hamada J.-I., and F. Syamsudin, 2011: Interannual rainfall variability over the eastern maritime continent. *J. Meteor. Soc. Japan*, 89A, 11-22.

Lau, K.-M., P. H. Chan, 1986: Aspects of the 40–50 day oscillation during the northern summer as inferred from outgoing longwave radiation. *Mon. Wea. Rev.*, 114, 1354–1367.

Lau, K.-M., and C.-P. Chang, 1987: Planetary scale aspects of winter monsoon and teleconnections. *Monsoon Meteorology*, C.-P. Chang and T. N. Krishnamurti, Eds., Oxford University Press, 161–202.

Lau, K.-M., C. P. Chang, and P. H. Chan, 1983: Short-term planetary-scale interactions over the tropics and mid-latitudes during northern winter. Part II: Winter-MONEX period. *Mon. Wea. Rev.*, 111, 1372–1388.

Lau, K.-M., and T. J. Phillips, 1986: Coherent fluctuations of extratropical geopotential height and tropical convection in intraseasonal time scales. *J. Atmos. Sci*., 43, 1164–1181.

Lau, K.-M., and S. Yang, 2002: Walker circulation. In *Encyclopedia of Atmospheric Sciences*, edited by J. Holton, J. P. Pyle, and J. Curry, 2505–2509.

Lau, K.-M., G. J. Yang, and S. H. Shen, 1988: Seasonal and intraseasonal climatology of summer monsoon rainfall over East Asia. Mon. Wea. Rev., 116, 18-37.

Lawrence, D. M., P. J. Webster, 2002: The boreal summer intraseasonal oscillation: relationship between northward and eastward movement of convection. *J. Atmos. Sci*., 59, 1593–1606.

Le Bars, D., Dijkstra, H. A., and De Ruijter, W. P. M., 2013: Impact of the Indonesian Throughflow on Agulhas leakage. *Ocean Sci*, *9*(5), 773-785.

Lee, J.-Y., B. Wang, M. C. Wheeler, X. Fu, D. E. Waliser, and I.-S. Kang, 2013: Real-time multivariate indices for the boreal summer intraseasonal oscillation over the Asian summer monsoon region. *Clim Dyn,* 40, 493-509.

Lee J.-Y., and B. Wang, 2012: Future change of global monsoon in the CMIP5. Clim. Dyn., DOI 10.1007/s00382-012-1564-0.

Li, K. et al., 2013. Structures and mechanisms of the first-branch northward-propagating intraseasonal oscillation over the tropical Indian Ocean, *Climate Dynamics,* DOI 10.1007/s00382-012-1492-z

Li, J. D. Wang, J. Chen and L. Yang, 2012: Comparison of remote sensing data with in-situ wind observation during the development of the South China Sea monsoon. *Chinese J. Oceanol. Limno*., 30 (6), 933-943.

Liess, S., and M. A. Geller, 2012: On the relationship between QBO and distribution of tropical deep convection. *J. Geophys. Res.*, 117, doi: 10.1029/2011JD016317

Lim, S. Y., C. Marzin, P. Xavier, W. K. Cheong, and R. Rahmat, 2013: Relative impacts of cold surges and MJO on the Southeast Asia rainfall. Abstracts Papers Fifth WMO International Workshop on Monsoons. *WWRP Report* 2013-3, WMO, Geneva, 87.

Limpasuvan, V., D. L. Hartmann, D. W. J. Thompson, K. Jeev, and Y. L. Yung, 2005: Stratosphere-troposphere evolution during polar vortex intensification. *J. Geophys. Res.*, 110, D24101, doi:10.1029/2005JD006302.

Lin, Jia-Lin, et al., 2008: The impacts of convective parameterization and moisture triggering on AGCM-simulated convectively coupled equatorial waves." *Journal of Climate.*, 21, 883-909.

Liu, C., and E. Zipser, 2005: Global distribution of convection penetrating the tropical tropopause, *J. Geophys. Res.*, 110, D23104, doi:10.1029/2005JD006063.

Liu, C., and E. J. Zipser, 2009: Implication of the day vs. night differences of water vapor, carbon monoxide and thin cloud observations near tropical tropopause, J. Geophys. Res.,114, D09303, doi:10.1029/2008JD011524.

Love, B. S., A. J. Matthews, and G. M. S. Lister, 2011: The diurnal cycle of precipitation over the Maritime Continent in a high-resolution atmospheric model, *Quarterly Journal of the Royal Meteorological Society*, 137, 934–947.

Lu, R., and S. Lu, 2014: Local and remote factors affecting the SST–precipitation relationship over the Western North Pacific during summer. *J. Climate*, 27, 5132-

5147.
Madden R. A., and P. R. Julian, 1971: Detection of a 40-50 day oscillation in the zonal wind in the tropical Pacific, *J. Atmos. Sci*., 28, 702-708.
Madden, R. A., and P. R. Julian, 1972: Description of global-scale circulation cells in the tropics with a 40-50 day period. *J. Atmos. Sci.*, 29, 1109-1123.
Magnusson, L. and E. Källén, 2013: Factors influencing skill improvements in the ECMWF forecasting system. *Mon. Wea. Rev*., 141, 3142–3153
Mapes, B.E., T.T. Warner, and M. Xu, 2003: Diurnal Patterns of Rainfall in Northwestern South America. Part III: Diurnal Gravity Waves and Nocturnal Convection Offshore. *Mon. Wea. Rev.*, 131, 830–844.
Margono, B.A., P.V. Potapov, S. Turubanova, F. Stolle and M.C. Hansen, 2014: Primary forest cover loss in Indo- nesia over 2000–2012, *Nature Climate Change* 4(June): 730–735.
Martin, G. M., M. A. Ringer, V. D. Pope, A. Jones, C. Dearden, and T. J. Hinton, 2006: The physical properties of the atmosphere in the new Hadley Centre Global Environmental Model (HadGEM1). Part I: Model description and global climatology. *J. Climate*. 19, 1274-1301.
Massie, S., et al., 2007: High Resolution Dynamics Limb Sounder observations of polar stratospheric clouds and subvisible cirrus, *J. Geophys. Res.*, 112, D24S31, doi:10.1029/2007JD008788.
Massie, S. T., J. Gille, C. Craig, R. Khosravi, J. Barnett, W. Read, and D. Winker, 2010: HIRDLS and CALIPSO observations of tropical cirrus, J. Geophys. Res., 115, D00H11, doi:10.1029/2009JD012100.
Matsumoto, J., 1992: The seasonal changes in Asian and Australian monsoon regions. *J. Meteor. Soc. Japan*, 70, 257-273.
Matsumoto, J., 1997: Seasonal transition of summer rainy season over indochina and adjacent monsoon region. *Adv. Atmos. Sci.*, 14, 231-245.
Matsumoto, J., and T. Murakami, 2000: Annual changes of tropical convective activities as revealed from equatorial symmetric OLR data. *J. Meteor. Soc. Japan*, 78, 543-561.
Matthews, A. J., B. J. Hoskins, and M. Masutani, 2004: The global response to tropical heating in the Madden–Julian oscillation during the northern winter. *Quart. J. Roy. Meteor. Soc*., 130, 1991–2011.
McBride, J.L., 1998: Indonesia, Papua New Guinea, and Tropical Australia, Chapter 3A of Meteorology of the Southern Hemisphere, *Meteorological Monograph No. 49,* American Meteorological Society. 89–100.
McBride, J.L., M. Haylock and N. Nicholls, 2003: Relationships between the maritime Continent heat source and the El Niňo – Southern Oscillation phenomenon. *J. Climate*, 16, 2905-2914.
Meehl, G. A., 1987: The annual cycle and interannual variability in the tropical Pacific and Indian Ocean regions. *Mon. Wea. Rev.*, 115, 27-50.
McFarquhar, G. M., and Wang, H., 2006: Effects of aerosols on trade wind cumuli over the Indian Ocean: Model simulations. *Quarterly Journal of the Royal Meteorological Society*, *132*(616), 821-843.
Mega, T., M. K. Yamamoto, H. Luce, Y. Tabata, H. Hashiguchi, M. Yamamoto, M. D. Yamanaka, and S. Fukao, 2010: Turbulence generation by Kelvin-Helmholtz instability in the tropical tropopause layer observed with a 47 MHz range imaging

radar, *J. Geophys. Res., 115*, D18115, doi: 10.1029/2010JD013864.

Miura, H., M. Satoh, T. Nasuno, A. T. Noda, and K. Oouchi, 2007: A Madden-Julian Oscillation event realistically simulated by a global cloud-resolving model, *Science*, 277, 1763-1765.

Miyakawa, T., M. Satoh, H. Miura, H. Tomita, H. Yashiro, A. T. Noda, Y. Yamada, C. Kodama, M. Kimoto, K. Yoneyama, 2014: Madden–Julian Oscillation prediction skill of a new-generation global model demonstrated using a supercomputer, *Nature Comm*., 5, doi:10.1038/ncomms4769.

Moncrieff, M.W., M.A. Shapiro, J. Slingo, and F. Molteni, 2007: Collaborative research at the intersection of weather and climate. *WMO Bulletin*, 56 (3), 204-211.

Mori, M., and M. Watanabe, 2008: The growth and triggering mechanisms of the PNA: A MJO-PNA coherence. *J. Meteor. Soc. Japan*, 86, 213–236,

Mori, S., J.-I. Hamada, Y. I. Tauhid, M. D. Yamanaka, N. Okamoto, F. Murata, N. Sakurai and T. Sribimawati, 2004: Diurnal rainfall peak migrations around Sumatera Island, Indonesian maritime continent observed by TRMM satellite and intensive rawinsonde soundings. *Mon. Wea. Rev.*, 132, 2021-2039.

Murakami, T., and J. Matsumoto, 1994: Summer monsoon over the Asian continent and western North Pacific. *J. Meteor. Soc. Japan*, 72, 719–745.

Murata, F., M. D. Yamanaka, M. Fujiwara, S.-Y. Ogino, H. Hashiguchi, S. Fukao, M. Kudsy, T. Sribimawati, S. W. B. Harijono and E. Kelana, 2002: Relationship between wind and precipitation observed with a UHF radar, GPS rawinsonde and surface meteorological instruments at Kototabang, West Sumatera during September-October 1998. *J. Meteor. Soc. Japan*, 80, 347-360.

Napitu, A., A. L. Gordon, K. Pujiana 2015: Intraseasonal sea surface temperature variability across the Indonesian Seas, Journal of Climate,subm

Neale, R. and J. Slingo, 2003: The Maritime Continent and its role in the global climate: A GCM Study. *J. Climate*, 16, 834-848.

Neena, J. M., J. Y. Lee, D. Waliser, B. Wang, X. Jiang, 2014: Predictability of the Madden–Julian Oscillation in the Intraseasonal Variability Hindcast Experiment (ISVHE), *Journal of Climate*, 27 (12), 4531-4543.

Nesbitt, S.W. and E.J. Zipser, 2003: The Diurnal Cycle of Rainfall and Convective Intensity according to Three Years of TRMM Measurements. *J. Climate*, 16, 1456–1475.

Nguyen, H., and C. Franklin, 2015: Evaluation of cloud properties over the Maritime Continent in ACCESS using CloudSat and CALIPSO simulators, in preparation.

Nitta, T., 1987: Convective activities in the tropical western Pacific and their impact on the northern-hemisphere summer circulation. *J. Meteorol. Soc. Jpn.*, 65, 373-390

Nitta, Ts., and S. Sekine, 1994: Diurnal variation of convective activity over the tropical western Pacific. *J. Meteor. Soc. Japan*, 72, 627-641.

Nitta, Ts, T. Mizuno and K. Takahashi, 1992: Multi-scale convective systems during the initial phase of the 1986/87 El Niño. *J. Meteor. Soc. Japan*, 70, 447-466.

Ogino, S-Y., M. Fujiwara, M. Shiotani, F. Hasebe, J. Matsumoto, T. H. T. Hoang, and T. T. T. Nguyen, 2013: Ozone variations over the northern subtropical region revealed by ozonesonde observations in Hanoi, *J. Geophys. Res., 118*(8), 3245-3257.

Oh, J., K. Kim, and G. Lim, 2012: Impact of MJO on the diurnal cycle of rainfall over the western Maritime Continent in the austral summer, *Clim. Dyn.*, 38,1167–1180.

Ohsawa, T., H. Ueda, T. Hayashi, A. Watanabe and J. Matsumoto, 2001: Diurnal variations of convective activity and rainfall in tropical Asia. *J. Meteor. Soc. Japan*, 79, 333-352.

Okamoto, N., M. D. Yamanaka, S.-Y. Ogino, H. Hashiguchi, N. Nishi, T. Sribimawati and A. Numaguti, 2003: Seasonal variation of tropospheric wind over Indonesia: Comparison between collected operational rawinsonde data and NCEP reanalysis for 1992-99. *J. Meteor. Soc. Japan*, 81, 829-850.

Ortland, D. A. and M. Joan Alexander, 2011: Solutions to the Vertical Structure Equation for Simple Models of the Tropical Troposphere. *J. Atmos. Sci.*, 68, 2061–2072.

Paulik, L. C., and T. Birner, 2012: Quantifying the deep convective temperature signal within the tropical tropopause layer (TTL). Atmos. Chem. Phys., 12, 12183-12195.

Peatman, S. C., A. J. Matthews, and D. P. Stevens, 2014: Propagation of the Madden–Julian Oscillation through the Maritime Continent and scale interaction with the diurnal cycle of precipitation, *Quarterly Journal of the Royal Meteorological Society*, 140, 814–825.

Peatman, S.C., A J. Matthews, and D.P. Stevens, 2015: Propagation of the Madden–Julian Oscillation and scale interaction with the diurnal cycle in a high-resolution GCM, *Climate Dyn*., doi:10.1007/s00382-015-2513-5.

Petters, M. D., Carrico, C. M., Kreidenweis, S. M., Prenni, A. J., DeMott, P. J., Collett, J. L., and Moosmueller, H., 2009: Cloud condensation nucleation activity of biomass burning aerosol. *Journal of Geophysical Research: Atmospheres (1984–2012)*, *114*(D22).

Philander, S. G. H., 1985: El Niño and La Niña. *J. Atmos. Sci.*, 42, 652–662.

Piani, C., D. Durran, M. J. Alexander, and J. R. Holton, 2000: A Numerical Study of Three-Dimensional Gravity Waves Triggered by Deep Tropical Convection and Their Role in the Dynamics of the QBO. *J. Atmos. Sci.*, 57, 3689–3702.

Ploshay, J.J., N.-C. Lau, 2010: Simulation of the diurnal cycle in tropical rainfall and circulation during boreal summer with a high-resolution GCM. *Mon. Wea. Rev.* 138, 3434–3453,

Petters, M. D., Kreidenweis, S. M., Prenni, A. J., Sullivan, R. C., Carrico, C. M., Koehler, K. A., and Ziemann, P. J., 2009: Role of molecular size in cloud droplet activation. *Geophysical Research Letters*, *36*(22).

Philips, V. T., Donner, L. J., and Garner, S. T., 2007: Nucleation processes in deep convection simulated by a cloud-system-resolving model with double-moment bulk microphysics. *Journal of the atmospheric sciences*, *64*(3), 738-761.

Prenni, A. J., et al., 2013: The impact of rain on ice nuclei populations at a forested site in Colorado. *Geophysical Research Letters*, *40*(1), 227-231.

Pritchard, M. S., and R. C. J. Somerville, 2009: Assessing the Diurnal Cycle of Precipitation in a Multi‐Scale Climate Model. *Journal of Advances in Modeling Earth Systems* 1, #4.

Pujiana, K., Gordon, A.L. and Sprintall, J., 2013: Intraseasonal Kelvin waves in Makassar Strait. *J. Geophys. Res*. 118, 2023-2034.

Qian, J.-H., 2008: Why Precipitation Is Mostly Concentrated over Islands in the Maritime Continent. *J. Atmos. Sci.*, 65, 1428–1441.

Qian, J.-H., A. W. Robertson, and V. Moron, 2013: Diurnal Cycle in Different Weather Regimes and Rainfall Variability over Borneo Associated with ENSO. *J. Climate*, 26, 1772–1790.

Qiu, C., D. Wang, H. Kawamura, L. Guan, H. Qin, 2009: Validation of AVHRR and TMI-derived sea surface temperature in the northern South China Sea. *Continental Shelf Res.*, 29, 2358–2366.

Qu, T., Y. Du, J. Strachan, G. Meyers, and J. Slingo, 2005: Sea surface temperature and its variability in the Indonesian region. *Oceanography*, 18 (4), 50–61.

Randall, D. A., Harshvardhan, and D. A. Dazlich, 1991: Diurnal variability of the hydrologic cycle in a general circulation model. *J. Atmos. Sci.*, 48, 40–62.

Randel, W. J., and E. J. Jensen, 2013: Physical processes in the tropical tropopause layer and their roles in a changing climate, *Nature Geoscience, 6*, 169–176.

Randel, W. J., and co-authors, 2010: Asian monsoon transport of pollution to the stratosphere. *Science*, *328*(5978), 611-613.

Rashid, H.A., H.H. Hendon, M.C. Wheeler, and O. Alves, 2011: Prediction of the Madden-Julian oscillation with the POAMA dynamical prediction system. *Climate Dyn.*, 36, 649-661.

Rauniyar, S. P., and K. J. E. Walsh, 2013: Influence of ENSO on the diurnal cycle of rainfall over the Maritime Continent and Australia, *Journal of Climate*, 26, 1304–1321.

Rauniyar, S. P., and K. J. E. Walsh, 2011: Scale interaction of the diurnal cycle of rainfall over the Maritime Continent and Australia: Influence of the MJO, *Journal of Climate*, 24, 325–348.

Reid, J. S., and Coauthors, 2012: Multi-scale meteorological conceptual analysis of observed active fire hotspot activity and smoke optical depth in the Maritime Continent. *Atmos. Chem. Phys.*, 12, 2117–2147.

Richter, J.H., F. Sassi, and R.R. Garcia, 2010: Toward a physically based gravity wave source parameterization in a general circulation model. *Journal of the Atmospheric Sciences*, 67, 136-156

Robertson, A. W., V. Moron, J.-H. Qian, C.-P. Chang, F. Tangang, E. Aldrian, T. Y. Koh, and L. Juneng, 2011: The Maritime Continent monsoon, *The Global Monsoon System Research and Forecast*, Chap. 6, World Scientific Publication Company, (Eds.) C.-P. Chang *et al.*, 85-98.

Saji, N. H., Goswami, B. N., Vinayachandran, P. N., and Yamagata, T., 1999: A dipole mode in the tropical Indian Ocean. *Nature*, *401*(6751), 360-363.

Sakazaki1, T., K. Sato, Y. Kawatani, and S. Watanabe, 2015: Three-dimensional structures of tropical nonmigrating tides in a high-vertical-resolution global circulation model. *J. Geophys. Res.*, accepted.

Sakurai, N., F. Murata, M. D. Yamanaka, H. Hashiguchi, S. Mori, J.-I. Hamada, Y.-I. Tauhid, T. Sribimawati and B. Suhardi, 2005: Diurnal cycle of migration of convective cloud systems over Sumatera Island. *J. Meteor. Soc. Japan*, 83, 835-850.

Salby, M. L., and P. F. Callaghan, 2004: Interannual changes of the stratospheric circulation: Influence on the tropics and Southern Hemisphere. *J. Climate*, 17, 952-964.

Salby, M. L., and P. F. Callaghan, 2005: Interaction between the Brewer-Dobson circulation and the Hadley circulation. *J. Climate*, 18, 4303-4316.

Salinas, S. V., B. N. Chew, J. Miettinen, J. R. Campbell, E. J. Welton, J. S. Reid, L. E. Yu, S. C. Liew, 2013: Physical and optical characteristics of the October 2010 haze event over Singapore: a photometric and lidar analysis. *Atmos. Res.*, http://dx.doi.org/10.1016/j.atmosres.2012.05.021.

Sardeshmukh, P. D., and B. J. Hoskins, 1988: The generation of global rotational flow by steady idealized tropical divergence. *J. Atmos. Sci.*, 45, 1228–1251.

Sato, T., H. Miura, M. Satoh, Y. N. Takayabu, Y. Wang, 2009: Diurnal Cycle of Precipitation in the Tropics Simulated in a Global Cloud-Resolving Model. J. Climate, 22, 4809–4826.

Scaife, A. A., et al., 2014: Skillful long-range prediction of European and North American winters, Geophys. Res. Lett., 41, 2514–2519

Schneider, N., 1998: The Indonesian throughflow and the global climate system, J. Clim., 11, 676–689.

Schoeberl, M. R., and Dessler, A. E., 2011: Dehydration of the stratosphere. *Atmospheric Chemistry and Physics*, *11*(16), 8433-8446.

Schumacher, C., R. A. Houze, Jr., and I. Kraucunas, 2004: The tropical dynamical response to latent heating estimates derived from the TRMM Precipitation Radar. *J. Atmos. Sci.*, 61, 1341-1358.

Seo, K.-H., W. Wang, J. Gottschalck, Q. Zhang, J.-K. E. Schemm, W. R. Higgins, and A. Kumar, 2009: Evaluation of MJO forecast skill from several statistical and dynamical forecast models. *J. Climate*, 22, 2372–2388.

Sherwood, S. C., and Dessler, A. E., 2000: On the control of stratospheric humidity. *Geophysical research letters*, *27*(16), 2513-2516.

Shibata, T., M. Hayashi, A. Naganuma, N. Hara, K. Hara, F. Hasebe, K. Shimizu, N. Komala, Y. Inai, H. Vömel, S. Hamdi, S. Iwasaki, M. Fujiwara, M. Shiotani, S.-Y. Ogino, and N. Nishi, 2012: Cirrus cloud appearance in a volcanic aerosol layer around the tropical cold point tropopause over Biak, Indonesia, in January 2011. *J. Geophys. Res.*, *117*, D11209, doi: 10.1029/2011JD017029.

Shimizu, K., and F. Hasebe, 2010: Fast-response high-resolution temperature sonde aimed at contamination-free profile observations. *Atmos. Meas. Tech.*, *3*, 1673-1681.

Shindell, D.T., 2001: Climate and ozone response to increased stratospheric water vapor. *Geophys. Res. Lett.* 28, 1551-1554.

Shu, Y., J. Zhu, D. Wang, 2011: Assimilating remote sensing and in situ observations into a coastal model of northern South China Sea using ensemble Kalman filter. *Continental Shelf Res.* 31, S24–S36.

Shu, Y., J. Zhu, D. Wang, C. Yan, X.Xiao, 2009: Performance of four sea surface temperature assimilation schemes in the South China Sea. *Continental Shelf Res.* 29,1489–1501.

Sobel, A. H., Maloney, E. D., Bellon, G., and Frierson, D. M., 2008: The role of surface heat fluxes in tropical intraseasonal oscillations. *Nature Geoscience*, *1*(10), 653-657.

Solomon, S., Rosenlof, K. H., Portmann, R. W., Daniel, J. S., Davis, S. M., Sanford, T. J., and Plattner, G. K., 2010: Contributions of stratospheric water vapor to decadal changes in the rate of global warming. *Science*, *327*(5970), 1219-1223.

Song, M., Marcolli, C., Krieger, U. K., Zuend, A., and Peter, T., 2012: Liquid-liquid phase separation and morphology of internally mixed dicarboxylic acids/ammonium sulfate/water particles. *Atmospheric Chemistry and Physics*, *12*(5), 2691-2712.

Song Q. and Gordon, A.L., 2004: Significance of the vertical profile of the Indonesian Throughflow transport on the Indian Ocean. *Geophys. Res. Lett.* 31, L16307.

Sprintall, J., A. L. Gordon, A. Koch-Larrouy, T. Lee, J. T. Potemra, K. Pujiana, and S. E. Wijffels, 2014: The Indonesian Seas and their impact on the Coupled Ocean- Climate System. *Nature Geoscience*, doi:10.1038/ngeo2188

Smith, W. H. F. and D. T. Sandwell, 1997: Global Seafloor Topography from Satellite Altimetry and Ship Depth Soundings, Science 277: 1956-1962,

Stratton R.A., and A.J. Stirling, 2011: Improving the diurnal cycle of convection in GCMs. Q J R Meteorol Soc.

Stephan, C. and Alexander, M. J., 2015: Realistic simulations of atmospheric gravity waves over the continental U.S. using precipitation radar data. J. Adv. Model. Earth Syst. Accepted. doi:10.1002/2014MS000396

Susanto, R. D., A. L. Gordon, Q. Zheng, 2001: Upwelling along the coast of Java and Sumatra and its relation to ENSO. *Geophys. Res. Lett.*, 28, 1599-1602.

Suzuki, J., M. Fujiwara, T. Nishizawa, R. Shirooka, K. Yoneyama, M. Katsumata, I. Matsui, and N. Sugimoto, 2013: The occurrence of cirrus clouds associated with eastward propagating equatorial n = 0 inertio-gravity and Kelvin waves in November 2011 during the CINDY2011/DYNAMO campaign, *J. Geophys. Res.*, *118*(23), 12941-12947.

Tabata, Y., H. Hashiguchi, M. K. Yamamoto, M. Yamamoto, M. D. Yamanaka, S. Mori, F. Syamsudin and T. Manik, 2011a: Lower tropospheric horizontal wind over Indonesia: A comparison of wind-profiler network observations with global reanalyses. *J. Atmos. Solar Terr. Phys.*, 73, 986–995.

Tabata, Y., H. Hashiguchi, M. K. Yamamoto, M. Yamamoto, M. D. Yamanaka, S. Mori, F. Syamsudin, and T. Manik, 2011b: Observational study on diurnal precipitation cycle in equatorial Indonesia using 1.3-GHz wind profiling radar network and TRMM precipitation radar, *J. Atmos. Solar Terr. Phys.*, 73, 1031-1042.

Takayabu, Y. N., and M. Kimoto, 2008: Diurnal variations in rainfall simulated using the CCSR/NIES/FRCGC AGCM and dependence on cumulus schemes, J. Meteor.Soc. Japan, 86A, 163-173.

Tangang F.T., Salimun E., Juneng L., Vinayachandran P.N., Yap K.S., Reason C.J.C., Behera S.K., Yasunari T., 2008: On the roles of northeast cold surge, the Borneo vortex, the Madden-Julian Oscillation and the Indian Ocean Dipole during the worst 2006/2007 flood in Peninsular Malaysia. *Geophysical Research Letters* 35: L14S07. DOI:10.1029/2008GL033429.

Tao, W.-K., J.-P. Chen, Z.-Q. Li, C. Wang, and C. Zhang, 2012: Impact of Aerosols on Convective Clouds and Precipitation. Geophy. Rev., 50, DOI 8755-1209/12/2011RG000369

Teo, C.-K., T.-Y. Koh, J. C.-F. Lo, and B. C. Bhatt, 2011: Principal component analysis of observed and modeled diurnal rainfall in the Maritime Continent, *Journal of Climate*, 24, 4662–4675.

Tian, B., D. E. Waliser, and E. J. Fetzer, 2006: Modulation of the diurnal cycle of tropical deep convective clouds by the MJO, *Geophys. Res. Lett.*, 33, L20704, doi:10.1029/2006GL027752.

Tian, B., et al., 2008: Does the Madden-Julian Oscillation influence aerosol variability?. *Journal of Geophysical Research: Atmospheres (1984–2012)*, *113*(D12).

Tsuda, T., M. Nishida, C. Rocken, and R. H. Ware, 2000: A global morphology of gravity wave activity in the stratosphere revealed by the GPS occultation data

(GPS/MET). *J. Geophys. Res.*, 105(D6), 7257–7273, doi:10.1029/1999JD901005.
Tulich, S.N. and G. N. Kiladis, 2012: Squall Lines and Convectively Coupled Gravity Waves in the Tropics: Why Do Most Cloud Systems Propagate Westward?. *J. Atmos. Sci.*, 69, 2995–3012.
Tzella, A., and Legras, B., 2011: A Lagrangian view of convective sources for transport of air across the Tropical Tropopause Layer: distribution, times and the radiative influence of clouds. *Atmospheric Chemistry and Physics*, *11*(23), 12517-12534.
Ueda, H., T. Yasunari, and R. Kawamura, 1995: Abrupt seasonal change of large-scale convective activity over the western Pacific in the northern summer. J. Meteor. Soc. Japan, 73, 165–17.
Ueda, H., M. Ohba, and S.-P. Xie, 2009: Important factors for the development of the Asian–northwest Pacific summer monsoon. J. Climate, 22, 649-669.
Vecchi, G. A., S. Fueglistaler, I. M. Held, T. R. Knutson, and M. Zhao, 2013: Impacts of atmospheric temperature trends on tropical cyclone activity. *J. Climate*, 26, 3877-3891.
Vintzileos, A. and H.-L. Pan. 2007. On the importance of horizontal resolution and initial conditions to forecasting tropical intraseasonal oscillations: the maritime continent prediction barrier. NOAA CTB–COLA Joint Seminar, Sep. 19, 2007. Available at *http://www.nws.noaa.gov/ost/climate/STIP/CTB-COLA/Augustin_091907.pdf*, accessed July 26, 2010.
Katrina S. Virts, John M. Wallace, Qiang Fu, and Thomas P. Ackerman, 2010: Tropical Tropopause Transition Layer Cirrus as Represented by CALIPSO Lidar Observations. *J. Atmos. Sci.*, 67, 3113–3129.
Wajsowicz, R. C. and Schneider, E. K., 2001: The Indonesian Throughflow's Effect on Global Climate Determined from the COLA Coupled Climate System, J. Climate, 14, 3029–3042.
Wang, B., 1994: Climatic regimes of tropical convection and rainfall. J. Climate, 7, 1109-1118.
Wang, B., 2006: The Asian Monsoon. Springer Praxis Publishing, 787pp.
Wang, B., Q. Ding, X. Fu, I.-S. Kang, K. Jin, J. Shukla, and F. Doblas-Reyes, 2005: Fundamental challenge in simulation and prediction of summer monsoon rainfall. *Geophys. Res. Lett.*, 32, L15711, doi:10.1029/2005GL022734.
Wang, B., F. Huang, Z. Wu, J. Yang, X. Fu, K. Kikuchi, 2009: Multi-scale variability of the South China Sea monsoon: A review. *Dyn. of Atmospheres and Oceans*, 47, 15–37.
Wang, B., and LinHo, 2002: Rainy seasons of the Asian-Pacific monsoon. J. Climate, 10, 1071-1085.
Wang, B., and H. Rui, 1990: Synoptic climatology of transient tropical intraseasonal convection anomalies 1975–1985. *Meteorol. Atmos. Phys.*, 44, 43–61.
Wang, B., X. Xie, 1998: Coupled modes of the warm pool climate system. Part I. The role of air–sea interaction in maintaining Madden–Julian Oscillation. *J. Climate*, 11, 2116–2135
Wang, C., W. Wang, D. Wang, and Q. Wang, 2006: Interannual variability of the South China Sea associated with El Nino. *J. Geophys. Res.*, 111, C03023, doi:10.1029/2005JC003333.
Wang, D., L. Zeng, X. Li, and R. Shi, 2013: Validation of Satellite-Derived Daily Latent

Heat Flux over the South China Sea, Compared with Observations and Five Products. *J. Atmos. Oceanic Technol.*, 30, 1820–1832.

Wang, J., C. Gei, Z. Yang, E. Hyer, J. S. Reid, B. N. Chew, M. Mahmud, 2013: Mesoscale modeling of smoke transport over the South Asian maritime continent: vertical distributions and topographic effect. *Atmos. Res.*, doi:10.1016/j.atmosres.2012.05.009.

Wang, S., S. J. Camargo, A. H. Sobel, and L. M. Polvani, 2014: Impact of the tropopause temperature on the intensity of tropical cyclones: An idealized study using a mesoscale model. *J. Atmos. Sci.*, 71, 4333-4348.

Wapler, K., and T.P. Lane, 2012: A case of offshore convective initiation by interacting land breezes near Darwin, Australia. *Meteor. Atmos. Phys.*, 115, 123-137.

Webster, P. J., Moore, A. M., Loschnigg, J. P., and Leben, R. R., 1999: Coupled ocean–atmosphere dynamics in the Indian Ocean during 1997–98. *Nature*, *401*(6751), 356-360.

Wei, J., R. E. Dickinson, and H. Chen, 2008: A Negative Soil Moisture–Precipitation Relationship and Its Causes. *J. Hydrometeor*, 9, 1364–1376.

Weickmann, K. M., 1983: Intraseasonal circulation and outgoing longwave radiation modes during Northern Hemisphere winter. *Mon. Wea. Rev.*, 111, 1838–1858,

Wheeler, M.C., and J.L. McBride, 2011: Australasian monsoon. In: W.K.M. Lau and D.E. Waliser (eds), *Intraseasonal Variability in the Atmosphere-Ocean Climate System (2nd edition)*. Springer, pages 147-198.

Widiyatmi, I., H. Hashiguchi, S. Fukao, M. D. Yamanaka , S.-Y. Ogino, K. S. Gage, S. W. B. Harijono, S. Diharto and H. Djojodihardjo, 2001: Examination of 3-6 day disturbances over equatorial Indonesia based on boundary layer radar observations during 1996-1999 at Serpong, Biak and Bukittinggi. *J. Meteor. Soc. Japan*, 79, 317-331.

Williams, M., and R. A. Houze Jr., 1987: Satellite-Observed Characteristics of Winter Monsoon Cloud Clusters. *Mon. Wea. Rev.*, 115, 505–519.

Wu, C.-H., and H.-H. Hsu, 2009: Topographic influence on the MJO in the Maritime Continent. *J. Climate*, 22, 5433–5448.

Wu, P.-M., J.-I. Hamada, S. Mori, Y. I. Tauhid, M. D. Yamanaka and F. Kimura, 2003: Diurnal variation of precipitable water over a mountaneous area in Sumatera Island. *J. Appl. Meteor.*, 42, 1107-1115.

Wu, P.-M., M. Hara, H. Fudeyasu, M. D. Yamanaka, J. Matsumoto, F. Syamsudin, R. Sulistyowati and Y. S. Djajadihardja, 2007: The impact of trans-equatorial monsoon flow on the formation of repeated torrential rains over Java Island. *SOLA*, 3, 93-96.

Wu, P.-M., M. D. Yamanaka and J. Matsumoto, 2008: The formation of nocturnal rainfall offshore from convection over western Kalimantan (Borneo) Island. *J. Meteor. Soc. Japan*, 86A, 187-203.

Wu, P.-M., M. Hara, J.-I. Hamada, M. D. Yamanaka and F. Kimura, 2009: Why heavy rainfall occurs frequently over the sea in the vicinity of western Sumatera Island during nighttime. *J. Appl. Meteor. Climatol.*, 48, 1345-1361.

Wu, P.-M., A. A. Arbain, S. Mori, Hamada J.-I., M. Hattori, F. Syamsudin and M. D. Yamanaka, 2013: The effects of an active phase of the Madden-Julian oscillation on the extreme precipitation event over western Java Island in January 2013, *SOLA*, 9, 79-83.

Yang, G.-Y., and J. Slingo, 2001: The Diurnal Cycle in the Tropics. *Mon. Wea. Rev.*, 129, 784–801.

Yang, L., Y. Du, S-P. Xie and D. Wang, 2012: An inter-decadal change of tropical cyclone activity in the South China Sea in early 1990s. *Chinese J. Oceanolo. and Limnolo.*, 30 (6), 138-144.

Yang, L., Y. Du, D. Wang, C. Wang and X. Wang, 2014: Impact of intraseasonal oscillation on the tropical cylone track in the South China Sea. *Clim. Dyn.*, doi:10.1007/s00382-014-2180-y.

Yang, L., D. Wang, J. Huang, X. Wang, L. Zeng, R. Shi, Y. He, Q. Xie, S. Wang, R. Chen, J. Yuan, Q. Wang, J. Chen, T. Zu, J. Li, D. Sui, S. Peng, 2015: Toward a mesoscale hydrological and marine meteorological observation network in the South China Sea, *Bull. Amer. Meteor. Soc.*, DOI: 10.1175/BAMS-D-14-00159.1, in press.

Yoden, S., H.-H. Bui, and E. Nishimoto, 2014: A minimal model of QBO-like oscillation in a stratosphere-troposphere coupled system under a radiative-moist convective quasi-equilibrium State. *SOLA*, 10, 112–116, doi: 10.2151/sola.2014-023.

Yokoi, S., and J. Matsumoto, 2008: Collaborative effects of cold surge and tropical depression.type disturbance on heavy rainfall in central Vietnam. *Mon. Wea. Rev.*, 136, 3275.3287.

Yoneyama, K., C. Zhang, and C. N. Long, 2013: Tracking pulses of the Madden–Julian Oscillation. *Bull. Amer. Meteor. Soc*., 94, 1871–1891, doi:10.1175/BAMS-D-12-00157.1

Yuan, W., Geller, M. A. and Love, P. T., 2014: ENSO influence on QBO modulations of the tropical tropopause. Q.J.R. Meteorol. Soc., 140: 1670–1676.

Zeng, L., P. Shi, W. T. Liu, D. Wang 2009: Evaluation of a satellite-derived latent heat flux product in the South China Sea: A comparison with moored buoy data and various products. *Atm. Res.*, 94(91-105), doi:10.1016/j.atmosres.2008.12.007.

Zeng, L., Q. Wang, Q. Xie, P. Shi, L. Yang, Y. Shu, J. Chen, D. Sui, Y. He, R. Chen, and D. Wang, 2015: Hydrographic field investigations in the Northern South China Sea by open cruises during 2004 -2013. *Sci. Bull.*, 60(6), 607-615.

Zhang, C. 2005: Madden-Julian Oscillation. *Reviews of Geophysics*, 43, 1-36

Zhang, C., 2013: Madden-Julian Oscillation: Bridging Weather and Climate. Bull. Amer. Met. Soc., 94, 1849–1870.

Zhu, H., M.C. Wheeler, A.H. Sobel, and D. Hudson, 2014: Seamless precipitation prediction skill in the tropics and extratropics from a global model. *Mon. Wea. Rev*., 142, 1556-1569.

Zipser, E., C. Liu, D. Cecil, S. W. Nesbitt, and S. Yorty, 2006: where are the most intense thunderstorms on Earth?, Bull. Am. Meteorol. Res., 87, 1057-1071.

APPENDIX A

POTENTIAL PARTICIPATIONS IN THE YMC FIELD CAMPAIGN

1. Ground observations

1.1 Indonesian observing network: 120 surface met stations, 23 radiosonde stations, 35 harbor AWSs, 38 weather (C-band) radars.

1.2 Malaysian observing network: 44 principle meteorological stations (surface observations), 490 auxiliary weather stations including 140 automatic weather stations (AWS) and rain gauges, 8 upper-air sounding stations, 23 air pollution stations, 12 weather (S- and C-band) radars (7 over the Peninsular Malaysia, 3 over Sarawak and 2 over Sabah), 4 Acoustic Doppler Current Profiler (ADCP) and 2 Recording Doppler Current Profiler (RDCP), Voluntary Observing Ship (VOS).

1.3 Singapore observing network: 1 radiosonde station, 1 wind profiler, 2 weather (S-/C-band DP) radars, 64 rain gauges, 20 AWSs

1.4 AERONET (NASA, US): 15 sunphotometers

1.5 MPLNET (NASA, US): 6 Micro-Pulse Lidars

1.6 Japan field campaign
Boreal Winter Rainfall Study
Targets: precipitation mechanism off and on Sumatra, with a focus on the relationship to (a) the diurnal cycle near the coast of south-west Sumatra, (b) the MJO, and (c) SST condition over the oceanic upwelling region.
Facilities: R/V Mirai, land-based sites (Bengkulu, Kototabang) of radars, lidar, radiosondes, AWS, disdrometers, etc., moorings,
Time: Nov 2017 - Jan 2018
Location: Sumatra, Indonesia

Stratosphere-Troposphere Interaction Study
Target: equatorial waves, dehydration process
Facilities: Equatorial Atmosphere Radar (EAR), Water vapor/Ozone sonde, etc.
Time: TBD
Location: Kototabang, Biak (Indonesia), Hanoi (Vietnam), etc.

Boreal Sumer Monsoon Study
Targets: Seasonal March of Western Pacific Monsoon
Facilities: enhanced radiosondes, X-band Doppler radar, lidar, AWS, disdrometers, etc.
Time: July - Aug 2017
Location: Vietnam, Philippines, Palau

1.7 Taiwan consortium National Taiwan University, Chinese Culture University, Taiwan

Central University, and Academia Sinica) field campaign
Targets: mid latitude-tropical interaction, boreal summer monsoon and climate variability (QBWO, BSISO, MJO), convection Interactions in the SCS-MC area, air-land interaction, land use, and convection over the MC
Facilities: radiosondes, disdrometers, wind profiler, land flux, soil moisture, surface met (Plan A) + aircraft dropsondes (Plan B) + (C-/X-band) radars (Plan C)
Time: May 2017-Jul 2019; Winter IOP Jan-Feb, 2018; Meiyu IOP May-Jun, 2018
Location: South China Sea

1.8 Swiss Federal Institute of Technology (*ETH) field campaign*
Target: Ice Nucleating Particle
Facilities: ice chamber
Time: TBD
Location: TBD

1.9 The Karlsruhe Institute of Technology (*KIT) field campaign*
Targets: diurnal cycle of convection, cloud-aerosol interaction
Facilities: KITCube (lidars, K-/X-band radars, radiosondes, rain gauges, disdrometers, etc.)
Time: 2 months in 2018 – 2019
Location: Sarawak, Malaysia

1.10 US field campaign
Targets: mechanisms for the convective diurnal cycle and its interaction with MJO and monsoon, stratosphere-troposphere interaction
Facilities: DOE ARM AMF-1 + C-band scanning radar + S-band profiler, NCAR S-Pol radar, Integrated Sounding System (ISS), Doppler on Wheels (DOWs) (X-band) radars
Time: 2018-2019 (AMF-1), 2 months between October 2018 - March 2019 (S-Pol, ISS, DOWs)
Location: TBD

1.11 UK field campaign
Targets: boundary layer, surface fluxes, turbulence, aerosol, convective diurnal cycle
Facilities: tethered balloon, flux towers, mobile X-band radar, cloud radar, lidar, MWR, wind profiler
Time: TBD
Location: TBD

1.12 LAPAN field campaign
Targets: convection, aerosol-cloud interaction
Facilities: transportable (X-band) radar, Mobile Air Quality Monitoring System,
Time: TBD
Location: TBD

1.13 BMKG field campaign
Targets: diurnal cycle

Facilities: X-band mobile radar, wind profiler, lidar, etc.
Time: TBD
Location: TBD

1.14 Consiglio Nazionale delle Ricerche (*CNR) field campaign*
Targets: profiles of water vapor, temperature, clouds, aerosol
Facilities: Rayleigh-Mie-Raman Lidar
Time: TBD
Location: TBD

2. Ocean and Air-Sea Interaction Observations

2.1 First Institute of Oceanography
Targets: air-sea coupling, MJO over the MC, eastern Indian Ocean upwelling, monsoon system over western Pacific and eastern Indian Ocean
Facilities: AWS, radiosondes, CDTs, ADCPs from *R/V Xiang Yang Hong 01/18;* Seabird, seagliders, buoy, etc.
Time: 2018
Location: eastern Indian Ocean, Timor Sea

2.2 Bureau of Meteorology/CSRIO
Targets: atmospheric convection and the diurnal cycle
Facilities: C-band DP radar, cloud radar and lidar, surface fluxes, atmospheric composition, radiosondes, seagliders, CDTs, ADCPs, etc. from *R/V Investigator*
Time: 60 days in late 2018 – early 2019
Location: TBD

2.3 JAMSTEC
Targets: relationships between local atmospheric circulation associated with the Maritime Continent, the MJO, and IOD (SST condition over the oceanic upwelling region)
Facilities: C-band DP radar, Radiosonde, surface meteorology, CTD + water sampling, LADCP, etc. from *R/V Mirai*
Time: Dec 2017 – Jan 2018
Location: offshore Sumatra

2.4 Taiwan Oceanography Research Institute (TORI)
Targets: interaction between monsoon and surface circulation; deep-basin circulation, water masses
Facilities: CTD/ADCP/CM, buoy, lidar, wind profiler, radionsondes, EM-APEX, Seagliders
Time: TBD
Location: southern South China Sea

2.5 Indonesian cruises
Targets: internal tides, upper-ocean mixing, coastal upwelling, interaction between the

throughflow and monsoon and its impact on fluxes of biogeochemistry and fishery
Facilities: CTD/LADCP/VMP, seagliders
Time: 2015 - 2019
Location: Indonesian Seas

2.6 US
Targets: atmospheric convection, air-sea interaction, upper-ocean mixing, upwelling
Facilities: observations onboard R/V Sally Ride; Surface/subsurface mooring; bottom station, etc.
Time: 2018 - 2019
Location: south Philippine Sea (R/V Sally Ride), Indonesian Seas

2.7 South China Sea Institute of Oceanography
Targets: SCS processes
Facilities: ocean and atmosphere observations from *R/V Shiyan-3*.
Time: 2017 - 2019
Location: South China Sea

3. Airborne observations

3.1 UK consortium
Targets: land–sea contrasts, boundary layer, surface fluxes, cloud microphysics
Facilities: FAAM BAe146-301 (sampling of air, aerosol, and cloud particles, radiation, etc.), UAS
Time: TBD
Location: TBD

3.2 NCAR
Targets: deep convection, cloud microphysics, atmospheric profiles, air-sea interaction
Facilities: C-130
Time: Nov – Dec 2018
Location: TBD

3.3 LAPAN
Targets: diurnal cycle, boundary layer, land-sea contrast
Facilities: Lapan Surveillance UAV (LSU), Lapan Surveillance Aircraft (LSA), Cessna 206, N-219
Time: TBD
Location: TBD

3.4 CNES/CNRS and LAPAN
Targets: Convection, Stratosphere-Troposphere Interaction, air-sea fluxes
Facilities: Stratospheric balloons with dropsondes (Strateole), Aeroclippers
Time: Boreal winters 2017-2018 and 2018-2019
Location: Stratospheric flights above the MC, western Pacific and/or eastern IO for the Aeroclippers

APPENDIX B

REGIONAL OBSERVING NETWORKS

The regional observing networks in the MC include weather radars (Fig. B1), radiosondes (Fig. B2), surface automatic weather stations (Fig. B3), surface meteorology and climate observing stations (Fig. B4), AERONET and MPLNET sites (Fig. B5), and rain gauges (Fig. B6).

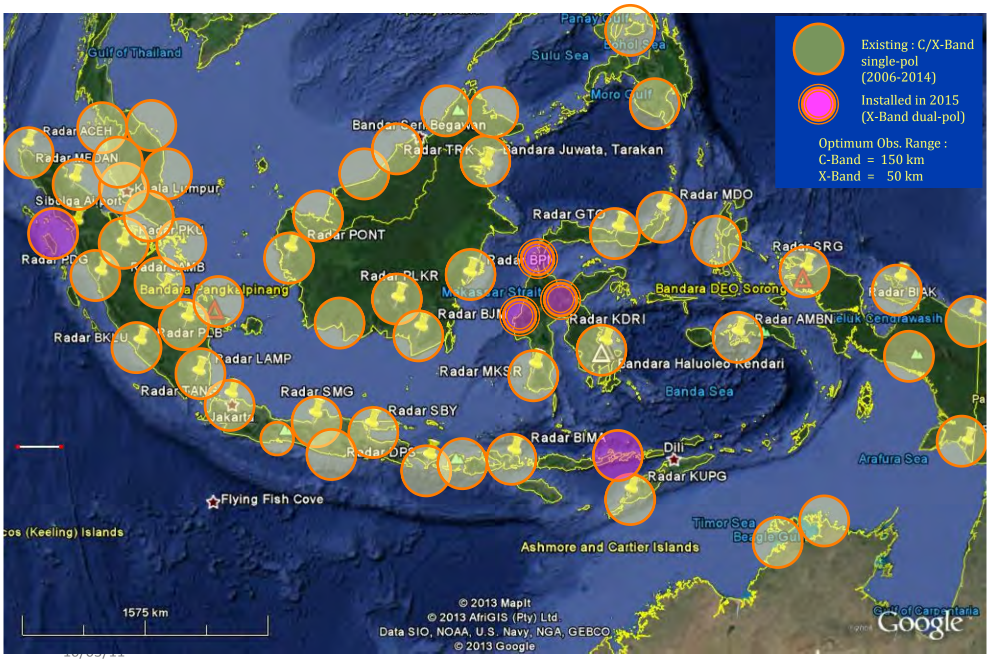

Figure B1 Regional weather radar network.

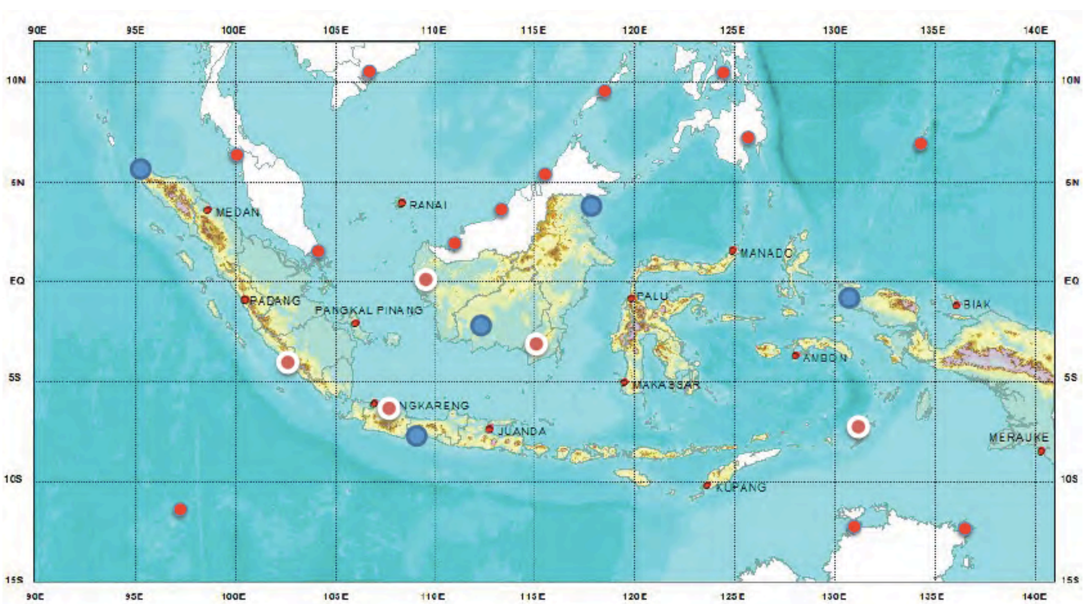

Figure B2 Regional radiosonde network including existing operational sites with twice daily sonde launches (red dots), new sounding sites starting in 2014 (blue) and 2015 (red in white).

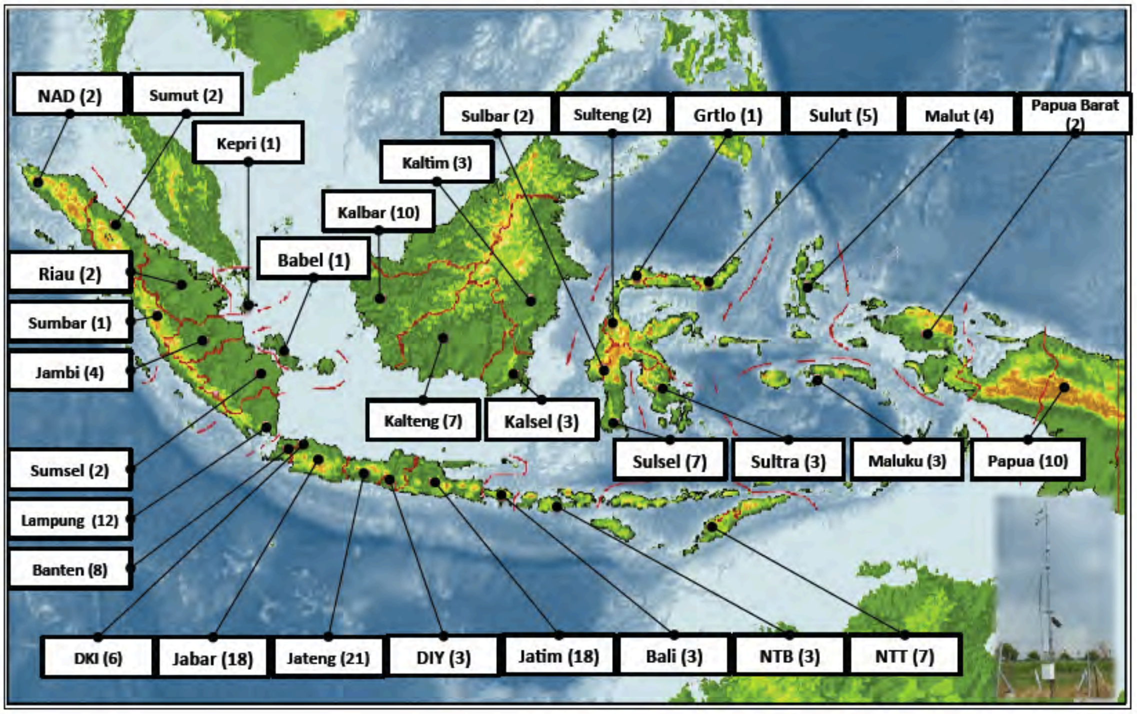

Figure B3 BMKG surface automatic weather stations.

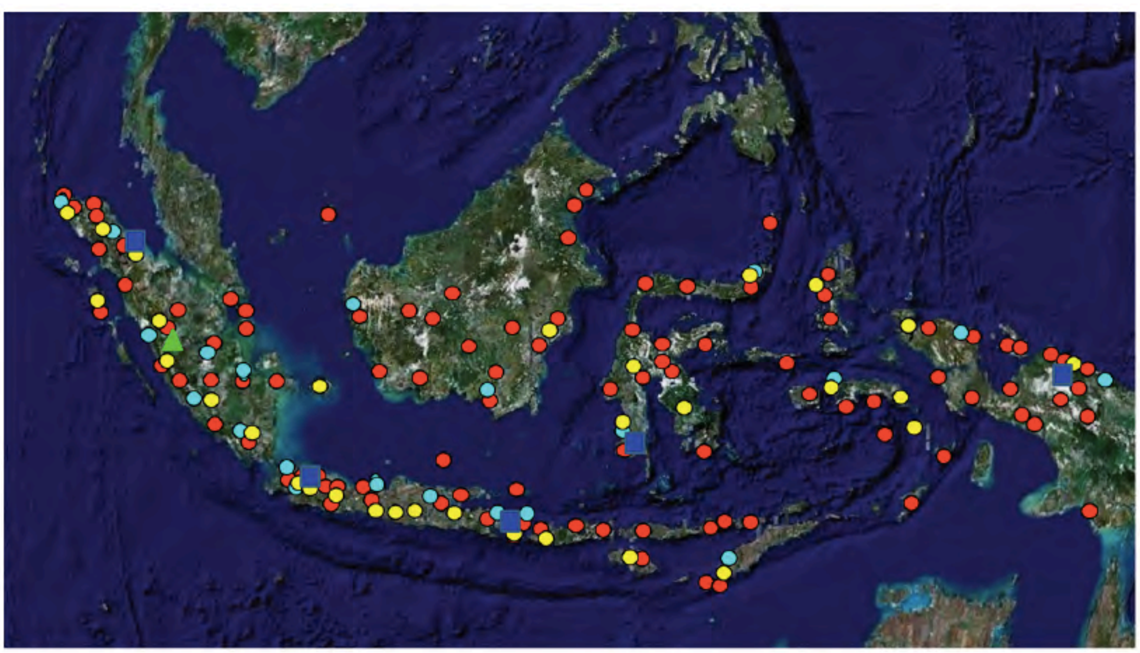

Figure B4 BMKG stations, including meteorology stations (red dots), climatology stations (cyan), geophysical stations (yellow), and regional centers (blue squares).

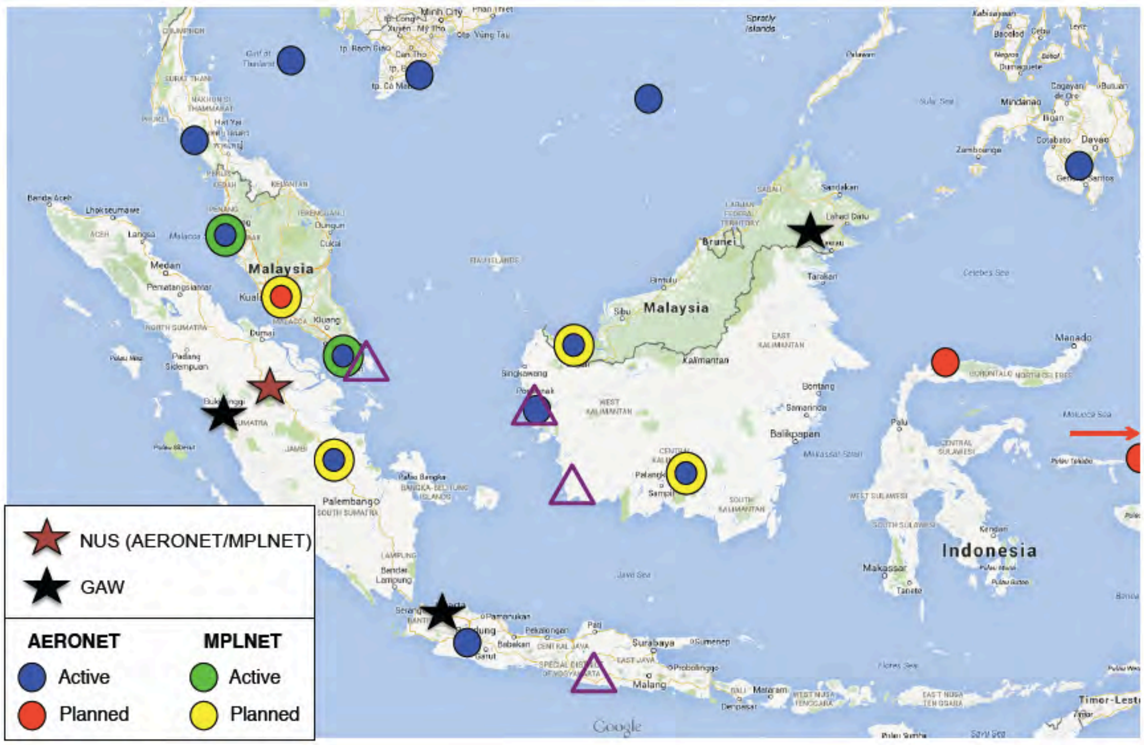

Figure B5 Regional network of the AERONET and MPLNET.

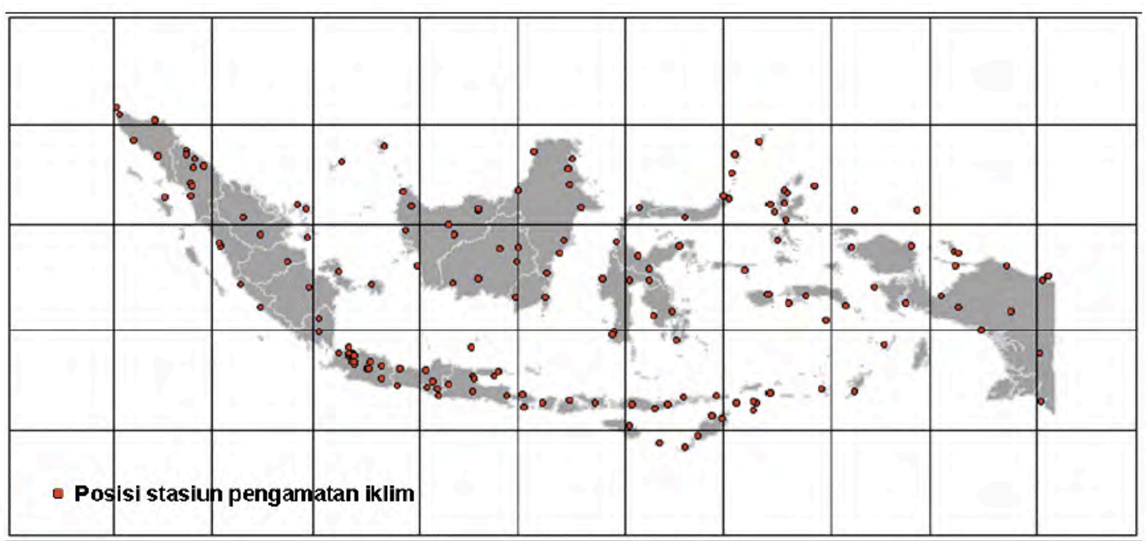

Figure B6 Indonesian rain gauge network.

APPENDIX C

PREVIOUS FIELD CAMPAIGNS IN THE MC

Several past field campaigns have taken place in the MC and adjacent regions:

- The International Winter Monsoon Experiment (WMONEX; Houze et al. 1981) deployed a C-band radar operated near the northern coast of Borneo at Bintulu, Malaysia (550 km northeast of Pontianak, Indonesia) during December 8-31, 1978.
- The Australian Monsoon Experiment (AMEX, Holland et al. 1986; Keenan et al. 1989a) collected sounding and radar observations during two phases over the tropical Australian land and ocean during the 1986 – 88 monsoon seasons.
- The Equatorial Mesoscale Experiment (EMEX, Webster and Houze 1991) collected aircraft measurement over the ocean north of Australia during January – February 1987.
- The Island Thunderstorm Experiment (ITEX; Keenan et al. 1989) collected precipitation radar data, surface and upper-air observations, and aircraft flight-level data during 20 November - 10 December 1988 near the Tiwi Islands just north of Darwin.
- The Down Under Doppler and Electricity Experiment (DUNDEE, Rutledge et al. 1992) deployed dual-Doppler radars, soundings, and lightning measurement around Darwin during two monsoon seasons of 1988-89 and 1989-1990.
- The South China Sea Monsoon Experiment (SCSMEX, Ding et al. 1997; Ciesielski and Johnson 2006) collected data from a sounding array and Doppler radars over the South China Sea during 1 May – 30 June 1998.
- The Maritime Continent Thunderstorm Experiment (MCTEX; Keenan et al. 2000) collected observations of PBL circulations and turbulence, structure, microphysics and electricity of clouds, radiation, and atmospheric profiles, among others, during November-December 1995, also in the Tiwi Islands.
- The Coupled Process in the Equatorial Atmosphere (CPEA, Kodama et al. 2006) deployed a sounding array, a 47-MHz Equatorial Atmospheric Radar, an X-band radar, among others, during 10 April - 9 May 2004.
- The Hydrometeorological ARray for Isv-Monsoon AUtomonitoring (HARIMAU, Yamanaka et al. 2008) collected data from a network including X- and C-band radars and UHF and VHF profilers during 2005 – 2010 in Indonesia.
- The Tropical Warm Pool-International Cloud Experiment (TWP-ICE, May et al. 2008) included a ship, aircraft, soundings, and enhance surface observations near the ARM site Darwin.

Data collected from these field campaigns and the multiyear deployment of the ARM TWP sites at Manus, Nauru, and Darwin (Long et al. 2013) have significantly improved our understanding of deep convection, including its diurnal cycle, microphysical, radiative, and dynamical processes, and interaction with the large-scale environment at those locations. The proposed YMC-ARM field campaign is built upon the experience and achievement of these field campaigns, and will expand upon what have been learned from their data.

The YMC field campagin is distinct from previous field observations in the MC in three aspects:

(a) The YMC field campaign will provide detailed information of physical processes using the most advanced observing technology, especially the multi-wavelength vertical pointing and polarimetric scanning radars that were not available before, to cover the life cycle of the entire spectrum of cloud population under different large-scale conditions due to various combinations of MJO and monsoon phases. This combination of detailed and multiscale observations in the MC were not available from any previous field campaign and long-term observations at the ARM TWP sites.

(b) Multi-nation international collaboration on radar observations through the YMC field campaign will facilitate sharing of data from regional observing networks, including an extensive weather radar network (Appendix B). This would allow forcing data for CRMs to be derived at many locations of the MC. Detailed cloud and precipitation processes at these locations can then be compared and tested in CRMs to identify their similarities and distinctions due to local geographic settings. This was impossible for any of the previous field campaign and long-term observations at the ARM TWP sites.

(c) The YMC field campaign with participations from 16 countries to date will deploy many complementary instruments at various locations in the MC during several intensive observing periods. Their observations will contribute to an unprecedented comprehensive database composed of observations from the YMC field campaign and regional observing networks. This database will lead to detailed documentation and advanced understanding of physical processes key to life cycles of clouds and precipitation in the MC. This database will also allow high-resolution regional data assimilation products synthesizing observations for the entire MC. None of these can be achieved by any previous special field campaign and long-term monitoring at a single location.

The YMC field campaign field campaign will also expand the observations collected from the TOGA COARE (Webster and Lucas 1993) and CINDY/DYNAMO (Yoneyama et al. 2013), which took place in the western Pacific in 1992-1993 and central equatorial Indian Ocean in 2011-2012, respectively. The evolution of convective cloud populations and their interactions with the large-scale environment in the MC are expected to be very different from those over the open water in the Indian and western Pacific Ocean documented by TOGA COARE and CINDY/DYNAMO.