

Chapter 2

Technical and Infrastructure Modality for Extreme Climate Early Warning in Indonesia



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Abstract The Indonesian archipelago is situated between the Asia and Australia continents and the Pacific and Indian Oceans. It has a typical monsoon climate, with monsoon rainfall generally peaking during boreal winter. The seasonal asymmetries annual cycle is geographically complex and reflects multiscale interactions between lands and seas. Monsoon rainfall exhibits pronounced variability and affecting variability on all timescales from diurnal to interannual and longer in interannual timescale. There are some extreme phenomena in this region. This chapter discusses some phenomena from the daily up to interannual variability for the extreme and how the country, Indonesia, manages the extreme cases. It aims to give educations and introductions to other regions of the world. On intraseasonal and synoptic scales, the region is heavily influenced by the MJO and cold surges especially during the peak of the rainy season, which can interact with each other as well as with in situ synoptic systems such as the Borneo vortex, often leading to torrential rainfall, flash floods, and severe storms, including the possible rare case, a typhoon. The chapter also discusses the type of observation and analyses and the type of instruments for extreme analysis. Further, this chapter introduces major institutions that are involved for early warning for weather and climate in the country.

2.1 Introduction

Indonesia is a tropical archipelago whose climate is mainly monsoonal by definition. It lies between two continents and two oceans. Monsoon is the area's major climate control, simply because it is located in the location above and affected by the solar solstice movement. The situation is similar to land and sea breeze over the coastal area but on a continental scale. Although not all locations are monsoonal, some areas

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with two times solar solstice over them will have an equatorial climate, when the same place will experience higher and much extreme weather. The most prominent climate phenomenon for this region is the El Niño–Southern Oscillation (ENSO), modulating the regular monsoonal system and bringing extreme rainfall in high and low variability. On the annual scale, the prominent phenomenon modulated the total rainfall amount on the quasi-biennial scale.

2.2 Annual Cycle

Indonesia experiences a marked seasonal cycle in precipitation characteristic of a monsoon climate. The north–south movement is not exactly straight north–south because Asia and the Australian continent are slightly deflected toward northeast and southeast. Chang et al. (2005) showed that the greater Asian–Australian monsoon region’s annual cycle is characterized by two fundamental asymmetries between boreal summer and winter and between boreal spring and fall. The exact monsoonal movement follows the solar solstice location, where the high solar radiation is directly reflected perpendicular to the earth’s surface. This precise location of the solstice movement is usually marked with the location of ITCZ or the Inter-Tropical Convergence Zone (Chang et al. 2004, 2005; Wheeler and McBride 2005). According to the solar solstice, ITCZ modulates north and south, but the exact location depends on the wind convergence. Usually, in the equator, the wind flows to the equator as the trade wind. While this wind flows to the west, their convergence zone is where wind flows to the east. The location of ITCZ does not follow the straight line but follows the lowest point where the surface pressure is at the lowest. Since then, the location is highly wet and has much precipitation. The ITCZ does not only draw pressure for extreme but also the main engine in the tropics. One of the large phenomena, such as the Madden Julian Oscillation, is similar to the ITCZ, exerting eastward in the tropics. The MJO propagates to the east in the tropics and is also a significant phenomenon controlling extreme in the tropics. Indonesia’s monsoonal processes will eventually bring the wet or rainy season on the half of the year or around months ONDJF, during the dry season during the other second half of the year, or during months MJJAS (Aldrian and Susanto 2003; Giannini et al. 2007). The southern part of Indonesia is a monsoonal type, while the northern part is mostly the equatorial type (see Fig. 2.1). The very different type over a small area exists in the eastern part, mainly related to the Indonesian throughflow. The Indonesian throughflow in the water mass flows from the Pacific Ocean to the Indian Ocean through Indonesia that flows in the eastern part. The incoming water mass over this region determines the type of climate in the area. The monsoonal pattern or type has one clear peak of dry and one the wet season, while the equatorial type has two peaks of dry and wet seasons.

Most climate analysis of Indonesia will eliminate the normal seasonal pattern or the monsoonal pattern first. Then the rest of the analysis is conducted. Over the area, monsoonal patterns occupy more than 70% of the whole pattern, thus need to

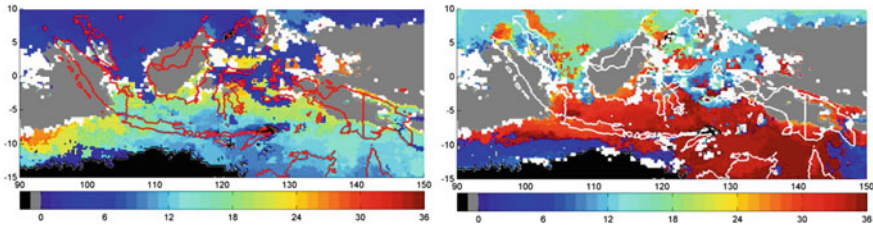


Fig. 2.1 Advancement of monsoon onset in the scale of decade (10 days) in the color bar for dry season (left) onset and wet season (right). Gray color means an area with always > 50 mm per decade (non-monsoonal) and black areas with always < 50 mm per decade (non-monsoonal). One year has 36 decade, and each month has 3 decade. Data from Tropical Rainfall Measuring Mission (TRMM) satellite observation 1998–2010

be eliminated first. In the basic monsoonal criteria, which are the wind differences on the peak of the dry and wet season, i.e., in January and July, most areas will be monsoonal. By modern definition, using the difference of precipitation difference in two seasons, the definition is obscure. The monsoonal region will be remaining in the southern region.

2.3 Definition of Extreme Rainfall of the Area

The Indonesian Agency for Meteorology Climatology and Geophysics BMKG does not clearly define the definition of extreme. By their definition, daily water budget or the precipitation and evaporation account roughly for 5 mm (Wati et al. 2019). This number is from the average evaporation pan number for a day. An excess of water at the surface will occur if the precipitation reaches above 5 mm a day. Although in some areas, the number is less than that. The double and quadruple amount would be excess to rapid surface saturation or flood. This may be one way to define extreme rainfall besides the population definition. Statistically, usually, people will take 5% or even 1% top population as the definition of extreme rainfall. The following definition of extreme rainfall constitutes the return period or ranking of occurrence. If the event often occurs, then they are not part of the local area. The event becomes local normality, and this makes the definition of extreme that could vary locally. The following definition also considers the impact of the environment on the rainfall that occurs. In certain areas, the same rainfall amount could constitute a flood but not to the other area. Although the same amount, one could be considered extreme but not for the other. Occasionally, the duration of extreme even matters, and the duration could increase the vulnerability in certain areas.

There are three types of floods in the areas which are often occurring. First is the local flood or inundation due to long periods of heavy or extreme rainfall pour over the local specific areas. The second type is the flash flood, which occurs when the rainfall falls over an upstream region and causes a flood in the downstream region. Again

it is possible that the upstream region has long-term local rainfall and is flooded or spilled over to the downstream region. The third type of flood is due to the inundation of water from the sea or ocean's incoming event. In most cases, it would be the tides or waves of the coast. The inundation is also possible due to local inundation at the land area due to the land subsidence.

In Indonesia where the climate is tropical, the extreme type is dominated by rainfall extreme. The extreme temperature events somehow occurred over specific location, for instance daytime temperature more than 35 °C occurred over Nusa Tenggara which is area with the lowest annual rainfall in the country. Also, the nighttime temperature below freezing point sometimes occurred over Dieng highland, recognized by frost in the morning damaging crops (Pradana et al. 2018; Aini and Faqih 2021). Other types of extremes of this area include extreme wave and air quality pollution. Even though extreme events do not often occur, they often follow the regular monsoonal pattern; they can have the most marked impacts: causing significant devastation to infrastructure, affecting our economy and health, and resulting in the loss of life. It is essential for meteorological communities to improve the understanding and characterization of extreme weather and climate events in time and space with regionally and globally consistent methodologies.

2.4 Extreme Phenomena of the Area

To understand the extreme situations of the area, we also need to understand climate phenomena contributing to extreme situations.

2.4.1 ENSO Variability

El Nino–Southern Oscillation is the most persistent climate phenomenon in the tropics (Hackert and Hastenrath 1986; Aldrian et al. 2007). So much consistency that the phenomenon will come at a certain time of the year and almost has a similar cycle. It starts at the end of boreal spring and reaches a peak at the end of the year and will end in the next year boreal spring. The phenomenon is measured with the anomaly of sea surface temperature over the Pacific Ocean and peaks at the end of the year near Christmas Eve. There are the El Nino and La Nina situations, whereby the first one happens when the anomaly is positive and negative for the second type. The year is declared as the El Nino and La Nina year when the anomaly exceeded a certain threshold over a certain period, usually above three months.

The impact of ENSO will usually be the opposite of Indonesia. When the positive anomaly occurs over the Pacific Ocean, then Indonesia will be a negative anomaly. Consequently, the negative anomaly of sea surface temperature will be less evaporation and means less precipitation. Consequently, there will be dryer situations (see Fig. 2.2). Since the onset and withdrawal of the phenomena are known, there will

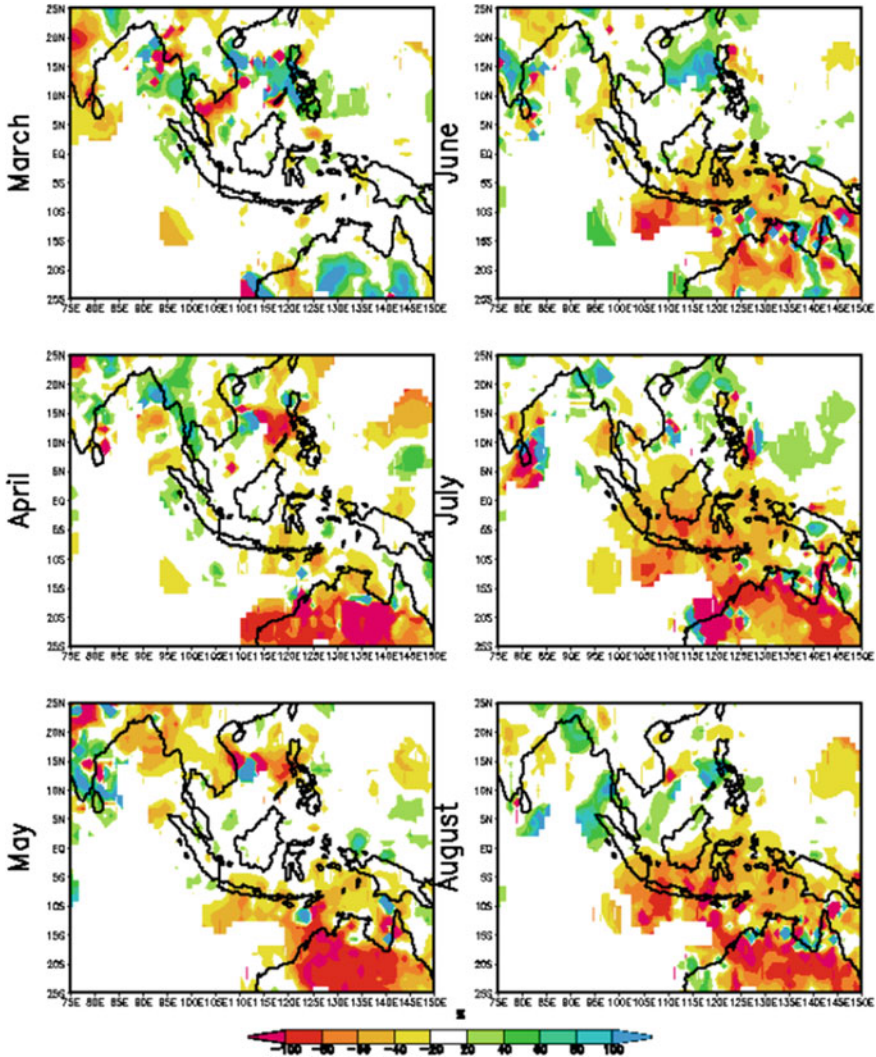


Fig. 2.2 Spatial patterns of rainfall anomaly during specific months of ensemble El Nino year in summer of El Nino year. The ensemble ENSO years are a combination of 1965, 1969, 1972, 1982, 1987, and 1991. The contour scales are given in percentage of rainfall anomaly. For complete spatial analysis of other seasons for El Nino and La Nina cases, please see Aldrian (2002)

be an anomaly during the dry season or MJJAS and the wet or rainy season ONDJF over Indonesia (Aldrian 2002; Supari et al. 2018)). There will be a more evident impact during the dry season than the wet season. This is mainly due to some known fact (mainly due to the ocean surface streamflow overIndonesia) that is not discussed here (Wyrtki 1961).

One of the worst impacts will be El Nino during the dry condition when the actual dryer condition worsens the dry situation. The opposite of the La Nina during the wet or rainy season does not bother much; however, it is a normal perception that the excessive rainfall in the rainy season may be linked to the La Nina season. However, sometimes during the dry season, there is some flooding at some places, as the result of the combined impact of La Nina and wet Madden Julian Oscillation of the area. Usually, the MJO will be longer and wetter during La Nina and drier and shorter during El Nino. Thus in some cases, there will be excessive rainfall during La Nina year, which results in flooding.

On the other end, ENSO, especially El Nino, creates another extreme in the region's climate. The already dry condition is even more dryer in the dry season. The dry spell will increase up to more than 40% during June–July–August and September–October–November season of El Nino years compared to Neutral years (Supari et al. 2018). Hence, there is sometimes extreme dryness. Even worse, the situation is at the end of the dry season, when the dryness reaches its peak. There are many studies on this extreme and all consequences of this kind of extreme. This type of disturbance is pretty much known to scientists in this region. The knowledge of this is pretty much well understood in comparison with the effect on the other side of the extreme. The operational early warning for this case is pretty much better prepared since the timing is almost consistent and still have time for further preparation.

2.4.2 ITCZ Convergence

This is a common phenomenon in the tropics. The convergence occurs due to trade winds from the northern and southern hemispheres converging in the tropics. Sailors know the location as the doldrums or the calms because of its monotonous, windless weather, which is the area where the northeast and southeast trade winds converge. Since the Coriolis force and earth rotation that the trade wind flows to the west (in the northern hemisphere to the southwest and the southern hemisphere to the northwest), then the result of energy balance, the converge is the area where the wind stream flows to east. By definition, this is the definition of the tropical zone. The wind flows eastward, and clouds gather at this place and has lower pressure at the surface than the surrounding.

The Inter-Tropical Convergence Zone or ITCZ is where the extreme occurs, and this area changes position from north to south and back and forth (Pike 1971; Waliser and Sommerville 1994). The back and forth north–south movement is mainly controlled by the solar solstice or roughly corresponding with the thermal equator's location. The exact location is not defined and is mainly controlled by the changing pressure over the tropics. By definition, the solar solstice at a particular area below the solstice's edge around 23.5° latitude will pass twice the solstice. Then the equatorial type of climate will have twice the time where ITCZ passes over them. The other limitation to the twice occurrence will be the border between land and ocean and surface ocean current.

Fortunately, ITCZ is quite active, and is located in Indonesia, during the wet or rainy season. This condition is really in favor of extreme rainfall (Freitas et al. 2017). Combined with the warm sea surface temperature and other disturbances, it will make the ideal condition for extreme situations. Low surface pressure will attract water vapor from surrounding areas. Moreover, trade wind also contributes to the active sea surface temperature. The active or abnormal sea state will also contribute to the higher sea surface temperature. The most common indicator of ITCZ is the presence of eastward wind in the tropics. In most cases, it is not the lowest pressure level area in the tropics or near-equatorial trough, but they are surrounded by some lower pressure areas like vortices and wind saddle points. They are also places where clouds are usually gathered, which eventually create extreme weather conditions.

2.4.3 *Madden–Julian Oscillation*

The Madden–Julian oscillation is characterized by an eastward progression of large regions of both enhanced and suppressed tropical rainfall, observed mainly over the Indian and Pacific Ocean (Madden and Julian 1971). This phenomenon is one of the most persistent patterns in the tropics besides the ENSO (Zhang and Gottschalck 2002). It travels to the east or propagates eastward, at approximately 4–8 m/s. The anomalous rainfall is usually first evident over the western Indian Ocean. It remains evident as it propagates over the very warm ocean waters of the western and central tropical Pacific (Matthews and Li 2005). The MJO enhances and suppresses rainfall regions at the variability of 30–90 days periodically.

Over the tropics, none of the regions is more pronounced for MJO impact than Indonesia (Hidayat 2016). The enhanced rainfall and reduction are very clear. Furthermore, they are modulated with the presence of ENSO, the El Niño, and La Niña phenomenon. In the El Niño year, the dryer MJO will be extended and less enhanced rainfall during that year. While on the other hand, during La Niña year, the MJO will be much enhanced and sometimes leave with excessive rainfall and flood in some areas (Hidayat 2016). After all, we have for MJO the oscillation between 39 and 90 days oscillation. Although moving eastward, the MJO has different features during the rainy and dry seasons. In the dry season, after leaving the maritime continent, it will go northward, following where the ITCZ is, while in the wet season, MJO will mostly stay in the maritime continent because the ITCZ is in it. Another reason is that the maritime continent is the area with the most southland area, no more island, for example southward Java and Sumatra.

Right now, there is an excellent monitoring mechanism done by the Bureau of Meteorology Australia for MJO (Wheeler and McBride 2005). They measure the average Outgoing Longwave Radiation in the tropics (e.g., see Fig. 2.3). They are undoubtedly the average albedo or the cloud top height in the tropics. The OLR indicator is a nice indicator of how the MJO evolved in the tropics. Since MJO under a consistent movement to the east, we could easily predict by looking presently what is going on in the west of our present location. This is an accurate prediction yet

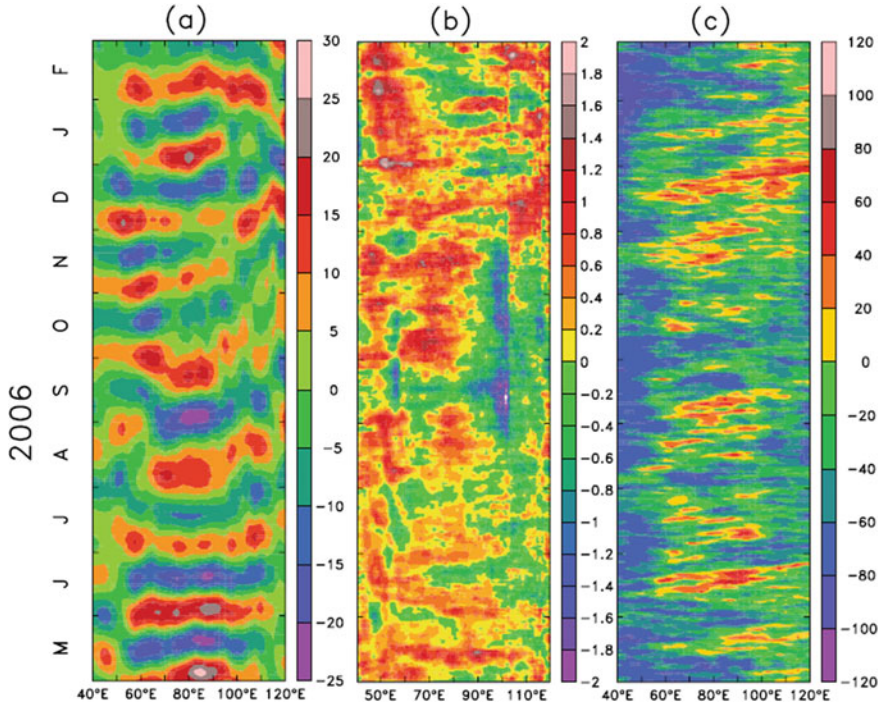


Fig. 2.3 Time–longitude plot of the 5S–5N averaged of **a** 30–60-day bandpass filtered OLR anomalies (Wm^2). The daily anomalies of OLR were filtered using a Lanczos filter with 121 weights. **b** Daily TMI SST anomaly (**c**) **c** The difference of the daily mean interpolated OLR from a value of 200 Wm^2 . Red indicates enhanced convective. *Source* Modified from Tangang et al. (2008)

so far. However, right now, there are also zonal or quadrant predictions based on the presence of MJO location so far. Nonetheless, the prediction of upcoming MJO phases, whether dry or wet, will be readily predicted. In the OLR analysis, the colder the number represents, the higher the cloud top height. Then it will represent the wet condition. Then, the higher the values, the OLR average will be the dryer situation with sometimes no cloud at all.

2.4.4 Cold Surge

Cold surge is a unique phenomenon of Southeast Asia. It originally began in the high latitude Siberia in the boreal winter (Chang and Hendon 2006). Sometimes the blocking over this high latitude occurs that stops the Ferrel cell that was originally supposed to move eastward in that latitude. The cold surge can reach equatorial latitudes where it manifests as strengthened northerly or northeasterly winds (Tangang et al. 2008). A corresponding temperature and dry signature may not be

present due to the influence warm seawater have on the surge. Depending on the thermodynamic characteristics of the pre-incurion environment, cold surges may also substantially impact convection and rainfall in the tropics (Chen et al. 2002). The cold and dry situations over there will push air moving to the East Asian coast-line down to Southeast Asia. Usually, high wind pressure accompanies cold and dry conditions. Sometimes in Hongkong, it occurs during the Chinese New Year Eve. It is a common phenomenon in the boreal winter which mostly occurs in November till March (Hattori et al. 2011). The indicator is the pressure and temperature drop in Hongkong by a few numbers in a short time. Occasionally, there will be snow blizzards in Hongkong. The ocean sea surface temperature that the ocean passes by will be cold and dry. Usually, this surge takes the path Hongkong, Vietnam, the Malaysian peninsula, and the northeast tip of Kalimantan or Borneo Island. Sometimes, the surge could reach the equator and push southward.

The path that the surge passes will be dry and cold. The air southward will be compressed because of that. In some areas in Sumatra, the phenomena leave forest fire conditions if it lasts longer than a week. What happened south of the dry area will be the extreme condition. Although it will be dry and cold in some areas, there will be a possibility that the compressed dry air will cause the wet air south of the area to create extreme rainfall. In some cases, there will be a flood; for example, if the surge could push up to the equatorial line in south Sumatra, then there will be extreme on the west Java, especially the capital city of Jakarta. Some high flood events in Jakarta are attributed to these surge activities. So this phenomenon could result in dry and forest fire and at the same time flood in other areas.

Depending on the strength, sometimes the surge creates more weather phenomena such as vortices along the way. The surge is a very short period event. Sometimes the presence could last several days and create a Mesoscale Convective System, which is even more extreme.

The surge has two stages (Chang et al. 2005):

- The edge, a pressure surge, travels at a speed of ~ 40 m/s, which is much faster than the advective speed and is therefore suggestive of a gravity wave-like propagation;
- The front, a significant drop in dew point that travels at speeds of only ~ 10 m/s.

2.4.5 Tropical Cyclone

Indonesia is not a tropical cyclone path, nor it is located in the cyclogenesis (Chang et al. 2003). The cyclone genesis area is usually an area located more than 10° latitude north and south. The weak earth Coriolis force is the main reason for that. Most locations in Indonesia are far below that number. The problem lies in the cyclone tail. Although not in their paths, the impact due to the presence of tails will create another extreme. In fact, every tropical cyclone induces two tails: the dry and wet tail. The wet tail usually comes with extreme rainfalls (Mulyana et al. 2018). With the impact of climate change, the tail of tropical cyclones is getting stronger, longer,

and far reaching, hence creating more severe problems. In some events, the cyclone tails bring a flood situation when it is high extreme enough.

Near Indonesia, there are three locations of tropical cyclone areas: the Philippine archipelago, the Bengal sea off the coast of Bangladesh, and southern Java between the Australian and Indonesia. There was one cyclone developed in the South China sea before at the degree of Singapore and additionally in the Banda sea eastern maritime continent. Both are located within a low latitude area, and the appearances were not common and only lasted a few hours. The appearance follows the cyclone's definition when it is declared by its name when they reach a certain threshold and demise when reaching another threshold.

2.4.6 Mesoscale Convective System

The Mesoscale Convective System (MCS) is a cloud system associated with a convective system complex that generates an adjacent rainfall area of about 100 km in at least one horizontal direction (Houze 2014), which is the life cycle has longer lifetime (greater than 3 h) than the individual convective element (Nuryanto et al. 2019). The majority of heavy rainfall events are triggered by these convective systems (Doswell et al. 1996; Choi et al. 2011; Jeong et al. 2016; Nuryanto et al. 2019). The development of convection over tropical regions is a key component of the global climate system as it vertically transports mass, momentum, and heat with large-scale atmospheric circulation patterns (Chen et al. 1996; Laing and Fritsch 2000; Moncrieff 2010). Interestingly, Indonesia is one of the tropical regions with extensive convective activity. So the attention should be more.

MCSs consist of convective cores and stratiform anvils, whose vertical and horizontal forms develop at different life cycle stages (Houze 1982). In particular, MCSs are embedded in tropical waves (Jakob and Tselioudis 2003), super-clusters of synoptic scale, and the Madden-Julian Oscillation (Nakazawa 1988), affecting the coupling of the atmosphere and atmosphere-ocean over a range of scales (Moncrieff 2010). For 100 years, scientists have been investigating the phenomenon of MCS, and it is still worth studying to this day.

Many MCS studies have been widely carried out in the tropics (e.g., Mohr and Zipser 1996; Zolman and Zipser 2000; Yuan and Houze 2010; Virts and Houze 2015; Putri et al. 2017, 2018; Nuryanto et al. 2017, 2018, 2019). However, there is still very limited research on MCS in Indonesia, i.e., the general life cycle of MCS in IMC (Putri et al. 2017); some cases of MCS events in Sumatra and Java (Putri et al. 2018); and the preliminary propagation study (Nuryanto et al. 2017); as well as MCS kinematic and thermodynamic structures (Nuryanto et al. 2018); also the case of the MCSs (Nuryanto et al. 2019) corresponding to the heavy rainfall event at Greater Jakarta area using satellite data.

The sea breeze merges to the center of the island during the daytime and enhances the inland convection, providing a favorable environment for MCS development over land. During the night, MCS formation is more concentrated over the sea, as the land

breeze converges from the surrounding islands to some straits (Qian 2008). Huang et al. (2018) discovered that MCSs occur more frequently over land than over oceans and are more intense. However, except in South America, India, and some parts of tropical Africa, ocean MCSs are usually larger and last longer than land.

Diurnal variation in the size of deep-convective systems over the western Pacific and maritime continent was observed by Chen and Houze (1997). The fractional area with cold TBB (< 208 K) reached a peak over the land in the afternoon, followed by a peak of moderate TBB (235–208 K) and a peak of warm TBB (260–235 K) at midnight. They also observed that the diurnal cycle amplitude was much more significant in the land than in the ocean.

For oceanic MCS, the rain fraction is also greater than for land MCS. In the developing and mature stages, the difference between land and oceanic MCS is especially noticeable, suggesting faster convection changes over land relative to the sea due to a strong diurnal cycle inhibited by the land area (Putri et al. 2017). Although the growth of land and oceanic MCSs varies at the beginning, at the end of their life span, both forms display similar characteristics as the dominant convections of the MCSs disappear.

The MCSs in Indonesia vary in the spatial distribution in different seasons according to different atmospheric conditions (Putri et al. 2017). The frequency of MCS is high across the entire area in December–January–February (DJF), associated with the movement of the wet monsoon from the north. In comparison, the distribution is usually sparser in June–July–August (JJA), with almost no MCS developing over Indonesia's southern part because most of the Indonesia's regions are affected by dry Australian monsoon. The MCS latitudinal distribution description in Fig. 2.4 shows that the hemisphere where the ITCZ resides is located with a high concentration of MCS. However, the maximum occurrence of MCSs persists at around 2° S irrespective of the season, likely due to the richest distribution of land–sea and more complex topography at this latitude over Indonesia (Putri et al. 2017).

The MCS seasonal variation amplitude varies regionally. With a frequency value of 1.5 months^{-1} ($10,000 \text{ km}^2$) $^{-1}$, Sulawesi has the most concentrated MCS. Due to its unique surface inhomogeneity, high concentrations of MCSs are likely in this region. Papua (1.4), Borneo (1.3), Sumatra (1.0), and Java (0.9) follow this value. During the dry monsoon season in JJAS, the small value of mean frequency in Java may be attributed to the strong suppression of MCS development (Putri et al. 2017).

Java Island exhibits a peak in seasonal rainfall in boreal winter. During this season, the highest occurrence of MCSs in Java also can be seen (Putri et al. 2017; Nuryanto et al. 2019). MJO's active phase also is well known for enhancing large-scale convective activities throughout the maritime continent of Indonesia (Hidayat and Kizu 2010). MJO, therefore, provided a more favorable atmospheric environment for the growth of the MCSs in this situation.

During the June–July–August (JJA) season, the Sumatra area has minimum MCS occurrence and rainfall peaks (Putri et al. 2017). Combined with a supporting topography and a strong vertical wind shear, the MCSs were initiated in favor of the warm SST around northern Sumatra (Putri et al. 2018). Although during the positive IOD, the convection is restricted to the northern part of Sumatra Island (Fujita et al. 2013),

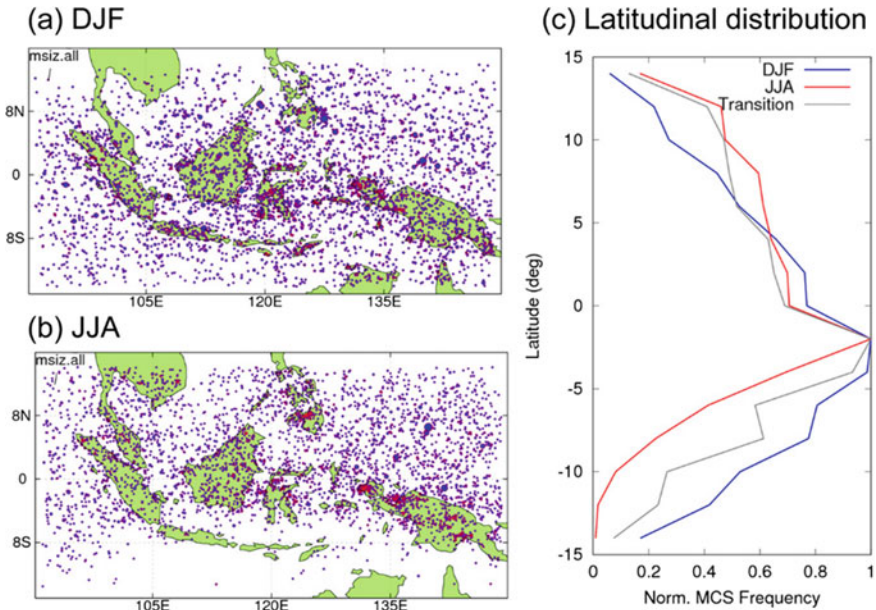


Fig. 2.4 Frequency of MCS in the study area in **a** December–January–February (DJF) and **b** June–July–August (JJA). **c** Latitudinal variation of MCS occurrence in DJF, JJA, and transitional seasons (SON and MAM), normalized by maximum latitudinal frequency in each season. *Source* Modified from Putri et al. (2017)

and the sheer magnitude was between two and three times greater than that around Java (Putri et al. 2018).

2.4.7 Vortices

This is a smaller version of the cyclone. Usually, in Indonesia, it is like a twister version. Local people name it the “puting beliung”. They are the size of water sprouts or smaller twisters. On the mesoscale version, the vortices could last several days. The cold surge can inhibit such a version called a Borneo vortex. In some other places, similar conditions may occur. The area is the location of many coasts and mountains, where this combination is perfect for a small twister. This happens when cold air from the hilly mountain meets the warm air from the coast. When there are changes in the local and regional winds, this is usually happening. Although small, the period of its lifetime is less than an hour. It is still dangerous, and the extreme it creates is sometimes devastating. Many of this kind occur in the transition time between two monsoonal periods when the local wind usually in the form of land and sea breeze meets the regional wind usually in the form of mountain wind.

Additionally, the presence of a land–sea breeze will favor the warm uphill breeze from the sea coast. In the blogger scale or mesoscale, the wind changing direction, such as trade wind and surface pressure change, also contributes to the Borneo vortex in the presence of cold surges (Tangang et al. 2008). With the presence of trade wind and ITCZ, sometimes vortices form during the saddle point at the surface pressure level. The combination of this phenomenon with others such as the cold surge or tail of a tropical cyclone will sometimes favor extreme conditions for extreme weather.

2.4.8 *Air Quality Extreme*

Air quality extreme is the condition whenever the ambient air quality drops to a certain level that causes ambient air to be unable to fulfill its function due to the entry of substances, energy, and/or other components into the air ambient by human activities (President of Indonesia Regulation 41 1999). Air quality extremes are associated with air pollution events. Air pollutant standard index (ISPU), which is a unitless number, is calculated to describe the condition of ambient air quality in a particular location based on the impact on human health, aesthetic value, and other living things (Indonesian Minister of Environment P.14 2020). ISPU established by the Indonesian Ministry of Environment is based on seven major air pollutants as particulate matter (PM10), PM2.5, carbon monoxide (CO), ozone (O₃), sulfur dioxide (SO₂), nitrogen dioxide (NO₂), and total hydrocarbon (HC) (Indonesian Minister of Environment P.14 2020). Each of these pollutants has a national air quality standard set by the Indonesian Ministry of Environment following the World Health Organization (WHO) Air Quality Guidelines (AQGs) to protect public health and is a pivotal component of national risk management and environmental policies. These standards may vary with other countries according to the approach adopted for balancing health risks, technological feasibility, economic considerations, and various other political and social factors, which in turn will depend on, among other things, the level of development and national capability in air quality management (WHO 2006).

Air quality extreme occurs if the concentration of the atmosphere's pollutants is above the national air quality threshold. The increase of pollutants concentration is mainly due to human activities and natural phenomena. Nowadays, Indonesia's population is concentrated in urban areas like Jakarta Greater City and exposed to air pollution (Kusumaningtyas et al. 2021; Permadi and Kim Oanh 2008; Suhadi et al. 2005; Wasi'ah and Drijeana 2017). Rapid economic growth coupled with transportation and industrial facilities in urban areas become the crucial sources of pollutants emission such as CO, NO₂, volatile organic compounds (VOCs), and other secondary pollutants (Permadi et al. 2017; Lestari et al. 2020). Meanwhile, recurrent forest and land fires in some parts of Sumatra and Kalimantan also contribute to the worst air pollution due to the release of very high concentrations of greenhouse gasses and aerosols (Eck et al. 2019; Gaveau et al. 2014; Hayasaka et al. 2014). Air quality extreme due to emission from peatland fire in Sumatra and Kalimantan

has profoundly perturbed the chemical composition of the atmosphere and proven impacted the regional air quality around neighborhood countries (Kusumaningtyas and Aldrian 2016; Koplitz et al. 2018). The impact of emissions from peatland fires on air quality and livelihood is much higher several orders of magnitude compared to other sources of emissions.

The alteration of atmospheric composition (in terms of physical and chemical properties of gaseous and aerosol) can lead to climate changes. A perturbation to the atmospheric concentration of meaningful greenhouse gas and or aerosols induces a radiative forcing that can affect climate (Brasseur et al. 2003). As commonly known from the Intergovernmental Panel on Climate Change (IPCC), greenhouse gasses have a positive radiative forcing, meaning that they tend to warm the surface due to the absorption of solar radiation. Black carbon emitted from biomass burning is also a strong absorbing aerosol. On the other hand, aerosols in the form of sulfate, nitrate, and carbonaceous aerosols scatter solar radiation, thus cooling the surface. The scattering of solar radiation produces a negative radiative forcing (IPCC 2007; Seinfeld and Pandis 2006; Brasseur et al. 2003). Aerosols from forest/land fires could also affect the climate system by modulating cloud microphysical processes resulting in large perturbations in the regional water cycle and circulation of entire Southeast Asia, including the South China Sea, southern China, and Taiwan (Tsay et al. 2013; Lin et al. 2014). The aerosol burden is strongly influenced by meteorological parameters such as humidity, wind speed and direction, and rainfall. These parameters could be changed in response to El Niño–Southern Oscillation (ENSO) (Yu et al. 2019). During strong El Niño, the drought increases more intensely and extends to more expansive spatial areas. Drought reduces humidity and the absence of precipitation, leaving a drier condition that ease of drained peatland is burned by humans, such as Sumatera and Kalimantan. Therefore, aerosol effects provide positive feedback to ENSO's evolution or the meteorological response to ENSO.

Worst air pollution due to smoke from peatland fires in Sumatera and Kalimantan leaves giant consequences to many sectors. This event impacts the economic, public health, environmental, and political situation among Indonesia and neighboring countries. During the fire in Riau 2013, the air quality index reached 1084, categorized as hazardous. The smoke haze led to the disruption of transportation facilities and airport closure with an estimated loss of ~ 108 thousand USD due to delays and cancellation of domestic and international flights (Kusumaningtyas and Aldrian 2016). An extreme El Niño event coupled with a positive phase Indian Ocean Dipole in 2015 triggered severe drought and eventually inducing peatland burning to spread farther than in typical rainfall years (Eck et al. 2019). Very high aerosol loading as indicated from aerosol optical depth (AOD) value at 550 nm was estimated to reach ~ 11 to ~ 13 during prominent peat burning in Central Kalimantan as presented in Fig. 2.5 (Eck et al. 2019). According to Eck et al. (2019), this AOD value was the highest, and they have no knowledge of such high smoke AOD values having been previously reported in the scientific literature. Recent forest and land fires that coincided with El Niño also reoccurred in Sumatera and Kalimantan in 2019. BMKG recorded the daily average concentration of PM10 in Palembang (South Sumatera) and Pekanbaru site (Riau Province) reached almost 500 $\mu\text{g}/\text{m}^3$ as presented in Fig. 2.6. This number is

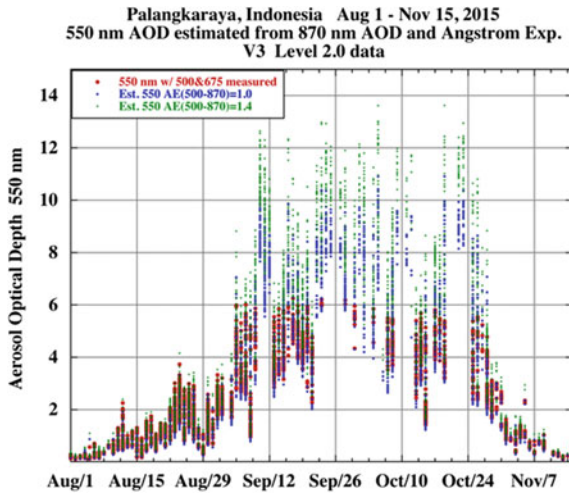


Fig. 2.5 Time series of AOD at 550 nm at the Palangkaraya, Indonesia, site from August 01 through November 15, 2015. Shown in red are AOD at 550 nm computed when measured values at 500 and 675 nm were available. Also shown are estimates of 550 nm AOD, utilizing the measured 870 nm AOD in conjunction with assumed Angstrom exponents (500–870 nm) of 1.0 (blue) and 1.4 (green). *Source* Eck et al. (2019)

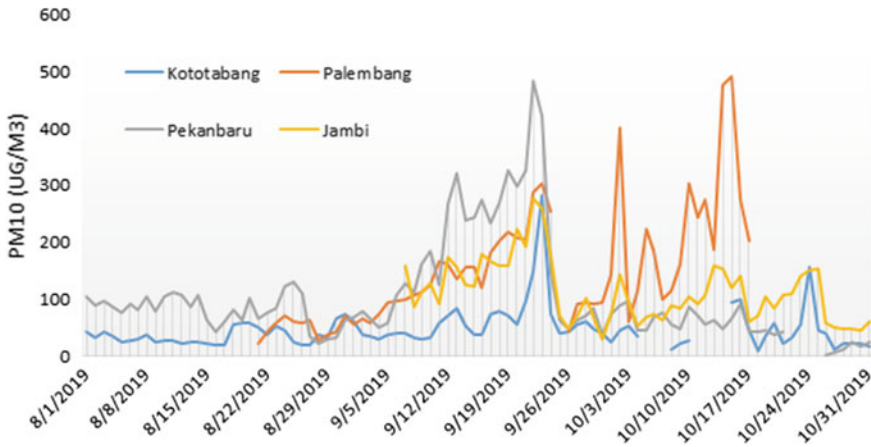


Fig. 2.6 Daily average of PM10 concentration during the burning period in August–October 2019 in several fire-prone areas in Sumatera

three times above the national threshold ($150 \mu\text{g}/\text{m}^3$). Uda et al. (2019) estimated the long-term exposure of PM2.5 from recurrent peat fires and smoke events in Central Kalimantan. They found that there were 648 premature mortality cases per year, which include 55 mortality cases due to chronic respiratory diseases, 266 mortality cases due to cardiovascular diseases, and 95 mortality cases due to lung cancer.

Another event of extreme air quality was the volcanic eruption. The emission plume from Mount Agung eruption in Bali 2017 headed to Denpasar, the capital city, and caused several flights to be delayed and canceled. Economics and tourism sectors were lost. However, due to a lack of air quality monitoring in the field, we could not retrieve information on the concentration of air pollutants.

2.5 Works for Extremes

As for the task and function of BMKG to provide data services for extreme warnings from their observed stations, currently, in 2021, BMKG has 22 climatology stations, more than 120 meteorological stations, and 31 geophysics stations that all supply climate data and more than 5000 meteorological network posts. Additionally, there are automatic weather networks, automatic rain gauge networks, and agricultural automatic weather stations. Currently, there are 697 online instrument networks with more than 120 agricultural automatic weather stations. The BMKG stations usually monitor rainfall, evaporation, wind, relative humidity, and surface pressure.

BMKG also operates more than 40 weather radar networks. Almost all radar networks have been integrated and can be used for the public using their mobile devices. The public may know exactly using their location about the presence of weather conditions, especially rainfall from one hour ago, up to 30 min ahead. The one and half hour animation of the current weather will give the public enough options for their action. The animation also gives a clear situation of the threat of extreme danger for the public.

At the center of the BMKG office, satellite monitoring is also conducted. Satellite images provide information for future warnings and give indicators for the next analysis of extreme. Information on fronts, wet atmosphere condition, and wind direction locally and regionally can be derived from the satellite information. With the help of applications such as windy, the warning can be done easily and faster. BMKG also operates some weather modeling for weather prediction. The model runs from European Center for Medium-Range Weather Forecast or ECMWF, and BMKG obtains only the extreme indicator for analysis from ECMWF. BMKG subscribes to the service of ECMWF. Regularly, BMKG could provide parameter analysis of extremes such as information on probabilistic extreme precipitation.

Several indicators on extremes are derived from services of other meteorological and climatological agencies outside the country. The primary information for El Nino–Southern Oscillation comes from ocean observation in the Pacific Ocean. The Toga COARE (Tropical Ocean Global Atmosphere—Coupled Ocean—Atmosphere Research Experiment) deployed an array of buoys to monitor sea surface and subsurface temperature on the Pacific. From this array of buoys, we derived the ENSO indicators. For ENSO prediction, we produce our BMKG indicators and information from other agencies such as NOAA, JAXA, BoM Australia, and NCEP. Other extreme indicators all also derived from international cooperation, such as the MJO, cold surge, and tropical cyclones. For MJO indicators, usually people follow

the BoM Australia MJO monitoring that is now readily available on the Internet. BMKG operates its own Tropical Cyclone Warning Center (TCWC) after being given the authority and operation area for cyclone monitoring.

For forest fire and volcano observation usually, BMKG works in cooperations with other agencies such as the National Agency for Space and Aeronautics and the Ministry for Forestry and Environment. The Volcanic Agency under the Ministry for Energy and Mineral Resources is the last important agency for cooperation.

2.6 Future Extremes

Climate change is characterized by changes in the mean and changes in variability and extremes (Tank 2003). It has been reported that temperature and precipitation extremes will likely be changing due to global warming, which is “extremely likely” influenced by anthropogenic factors (IPCC 2014). Experimental studies using both global and regional models indicated that the temperature increases could increase extreme rainfall events (e.g., Watterson and Dix 2003; Wehner 2004). For the Indonesia case, there are several kinds of literature reporting experiments on the projection of extremes over Indonesia using either statistical (Karlina 2016; Daksiya et al. 2017) or dynamical approach (Jadmiko and Faqih 2014; Chandrasa and Montenegro 2020; Supari et al. 2019).

Karlina (2016) downscaled the global model of HadCM3 using a statistical approach to estimate the future drought over Wonogiri District. She found that the number of drought events at the end of the twenty-first century is projected to be less than that in the historical period. Daksiya et al. (2017) document their study on the possible impact of changing climate on the frequency of daily rainfall extremes in Jakarta. A total of 15 GCMs were involved in their statistical downscaling process. Two statistical methods were applied, i.e., the Long Ashton Research Station-Weather Generator (LARS-WG) and the Statistical Downscaling Model (SDSM). Outputs of those two methods were compared with data from NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP), the downscaling product which is freely available. They found that the annual maximum daily rainfall may significantly change in the future, with an average increase as high as 20% in the 100-year return period daily rainfall (see Fig. 2.7). The seasonal daily rainfall maximum increases for the wet season. However, the dry season did not exhibit a consistent increase or decrease across the models suggesting that the annual scale changes are mostly due to changes in the wet season.

Additionally, some dynamical downscaling experiments also contribute to our insight on the future extremes of Indonesia. Jadmiko and Faqih (2014) dynamically downscaled the GCM EH5OM using RegCM3 over Indramayu District. They found that extreme rainfall (rainfall > third quartile) may not change in the future. In a larger experiment, Chandrasa and Montenegro (2020) investigate the potential impact of climate change on rainfall over the whole country. They downscaled the Max Planck’s Institute Earth System Model with Medium Resolution (MPI-ESM)

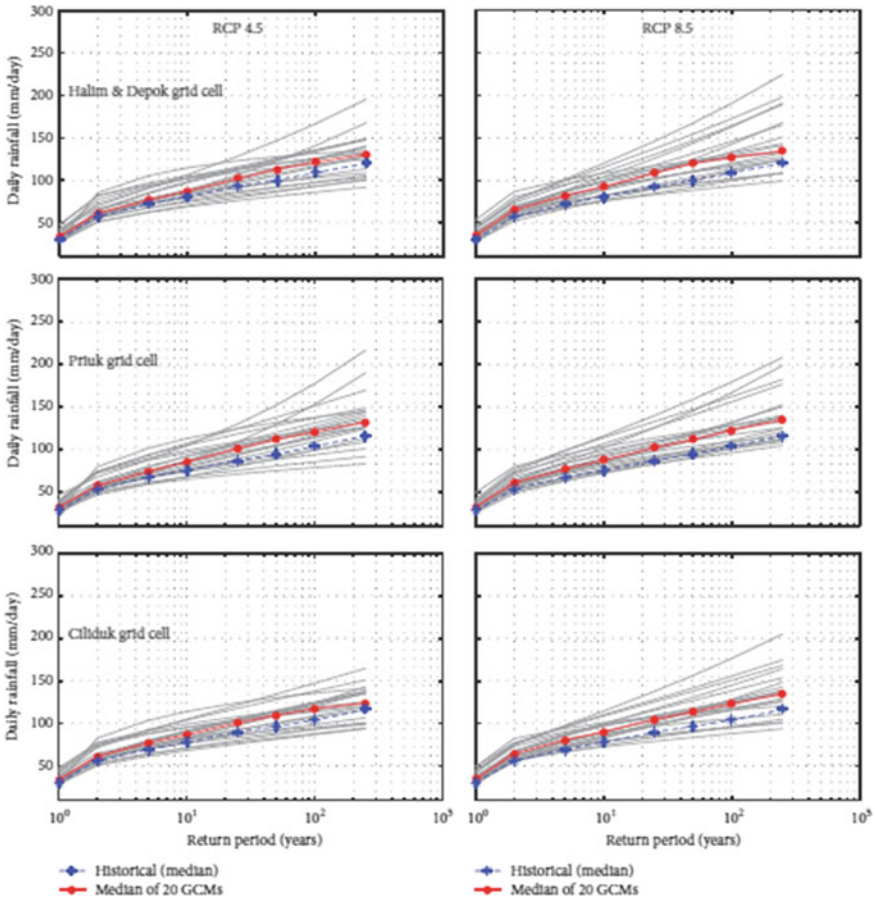


Fig. 2.7 Estimated value of daily rainfall for several return periods under RCP 4.5 (left) and RCP8.5 (right) for locations around Jakarta city. The 20GCM predictions for the period of 2041–2070 are indicated with thick gray lines. *Source* Modified from Daksiya et al. (2017)

using WRF regional model under RCP8.5. Four cumulus schemes were tested to find the best option in simulating the Indonesian climate. Two time intervals were selected to represent the future, the near future (2036–2040), and the far future (2096–2100). They found that during the monsoonal wet season, the number of rainy days and consecutive wet days (CWD) increases in most regions, and contrast, consecutive dry days (CDD) decrease. Additionally, Sumatra may have a higher risk of drought because of the future decreases in soil moisture projected in most of its area for all seasons. Supari et al. (2019) explore the output of downscaling data produced by BMKG to investigate precipitation extremes’ possible response under global warming of 2 and 4 °C. They use the Regional Climate Model system RegCM4 to downscale CSIRO Mk3.6. It is reported from their study that under

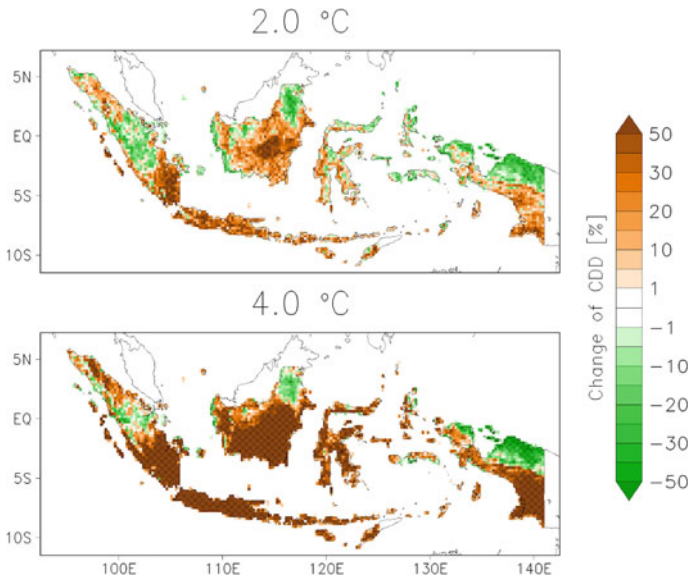


Fig. 2.8 Possible changes in CDD, under two global warming thresholds (2 and 4 °C). *Source* Supari et al. (2019)

these two global warming levels, there will be a decrease in total annual precipitation (PRCPTOT) in most parts of the country. Consistently, the dry spell duration is projected to increase as represented by the CDD index (consecutive dry days, see Fig. 2.8). On the other hand, a mixed increase and decreased tendency is found for the projection of the frequency and precipitation extremes. Seasonally, PRCPTOT tends to decrease during the dry season (June–July–August, JJ) and tends to increase during the wet season (December–January–February, DJF).

A more complex experiment on the future extremes using multi-GCMs, multi-RCMs, and multi-scenarios is documented in Supari et al. (2020) under the CORDEX-SEA Project. The project was run by a collaboration of institutions from countries within the South East Asia region. An ensemble of regional climate simulations consisting of eight members taking from a subset of archived CORDEX-SEA simulations at 25 km spatial resolution was used for their study covering the South East Asia domain, including Indonesia. The assessment of changes was done by comparing precipitation indices during the end of the century (2081–2100) relative to the reference period (1986–2005) under RCP4.5 and RCP8.5 scenarios. They selected four ETCCDI indices, i.e., PRCPTOT, CDD, R50mm, and RX1day, to represent precipitation extremes. They conclude that substantial changes in the characteristics of precipitation extremes may occur over the domain in the future, where changes under RCP8.5 are generally in greater magnitude compared to that under RCP4.5. Those changes include a decrease in PRCPTOT over most countries and consistently an increase of dry spell duration (CDD). In general, the southern part of SEA region will experience a greater magnitude of drying signal in PRCPTOT

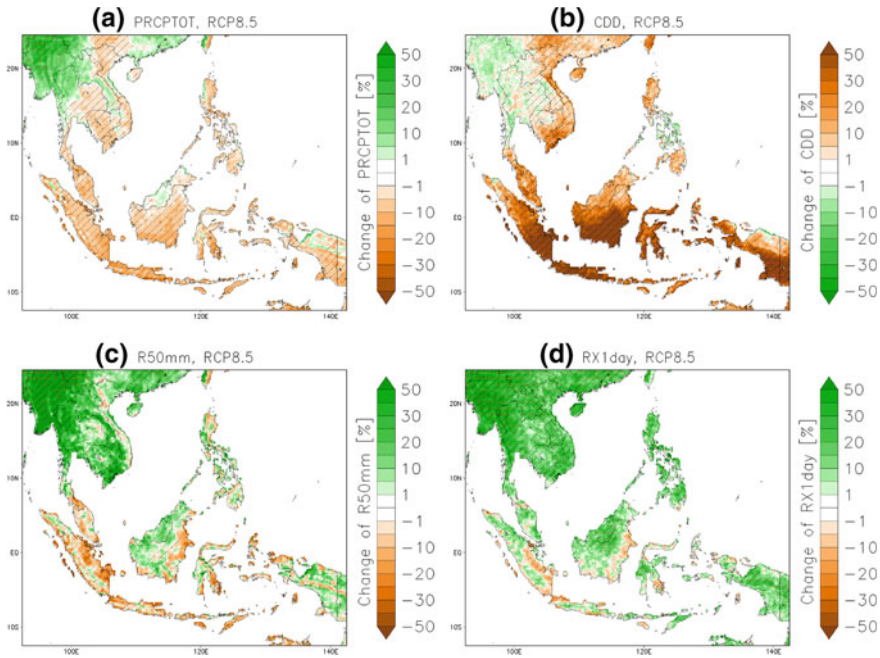


Fig. 2.9 Projected changes in precipitation indices during the end of the century, under RCP8.5. Source Supari et al. (2020)

and CDD compared to the northern part (see Fig. 2.9). In contrast, for the index of R50mm and RX1day, they reported a strong significant wetting signal over the northern part, while in the southern part those indices show a mixed weak wetting and drying tendency.

2.7 Institutions for Disaster in Indonesia

After understanding Indonesia's extreme situation and the corresponding climate and air quality phenomena, we now introduce institutions responsible for managing and administering the disaster analysis for climate and air quality.

2.7.1 *BMKG or the Agency for MeteorologyClimatology and Geophysics*

BMKG has the authority to issue early warnings for future weather and climate. BMKG is like the NOAA version for Indonesia. From this agency, the public will

receive extreme warnings. This agency should also issue multiple hazards related to extreme weather and climate and air quality. This agency also provides extreme weather for air navigation and sea state. It provides the meteorological early warning, climate early warning, and air quality. BMKG is part of the World Meteorological Organization or WMO a UN specialized agency for meteorological and climate early warning. BMKG operates many instruments and models to observe and analyze the current weather and climate information. It includes the upper air, surface, and means states of the ocean. For weather prediction, two dynamical numerical models are used by BMKG, i.e., the ECMWF model and the CFS model which is downscaled using WRF.

The chance of extreme weather and climate events is quantified based on the probability forecast of rainfall exceeding certain threshold with the minimum probability to release warning as 70%.

2.7.2 BNPB or the National Disaster Management Authority

BNPB is the specialized agency for disaster management, primarily when a disaster occurs. It also provides disaster management for disaster prevention and precaution if possible. As the BMKG prepares the early warning system, BMNP provides information on the impact and risk level of a disaster. Together they provide the risk-based warning and impact-based forecast, as proposed by the International Strategy for Disaster Risk ISDR by the UN and endorsed by World Meteorological Organization WMO in their Congress.

2.7.3 BPPT or the Agency for Assessment and Application of Technology

BPPT is the clearing technology, audit technology, and technology innovation needed by assessing and applying technologies. One of the products under collaboration with BMKG is the Fire Danger Rating System or FDRS, an early warning system developed for forest fires. BPPT also develops the ASEAN Coordinating Centre for Humanitarian Assistance on Disaster Management (AHA Center and the NeoNet is another version of WMO GEOS (Global Earth Observation) for Indonesia.

2.7.4 LAPAN or the Agency for Space and Aeronautics

LAPAN is an agency like NASA for the USA or JAXA for Japan. LAPAN has the authority for remote sensing services by law in Indonesia. However, some of the

remote sensing satellites are also done within BMKG. Precipitation, cloud coverage, and remote sensing analysis for wind direction and water content level are done separately in BMKG. Many remote sensing businesses are similar to the one in BMKG. The information on hotspots for a forest fire is also legally by LAPAN. However, BMKG and the Ministry for Forest and Environment also derived their information using outside satellite observation.

2.7.5 Ministry for Forestry and Environment

This Ministry is vital for the forest fire and the peatland restoration business. Peatland restoration keeps the water level for peatland, which is vital to maintain the capacity not to increase hotspots associated with a forest fire.

2.7.6 Ministry for Energy and Mineral Resources

This Ministry holds the Volcanology Agency, a critical agency for monitoring and declaring the airport operation's air quality index.

2.7.7 Ministry for Public Work and Housing

This Ministry is essential for catchment water management. It is essential for surface water management and control flood and inundation in housing areas.

2.8 Conclusions

This chapter depicts the extremes of climate phenomena in Indonesia. The purpose will be for education and general public information on how the country manages the extreme information. It discusses the climate phenomena that attribute to some extremes and modalities to handle the extreme in Indonesia. The situation might be different from country to country. The definition of extreme and the future extreme type is also discussed here. Then the chapter also introduces institutions for climate extremes. Extreme phenomena described here are not exhaustive, but there are some more. However, major climate extremes phenomena presented here are enough for most causes of extremes. The final section also introduces some works for future extremes based on the model projections. This chapter also discusses one of the notable extremes in air quality, especially during the dry season.

The studies of the extreme in Indonesia monsoon over Indonesia have progressed extensively for the past years. The broad spectrum of spatiotemporal occurrences of extreme phenomena and the interrelations between the strong diurnal cycle in the combined land–sea breeze, subseasonal weather types such as the MJO, and ENSO-related interannual variability. Not to mention the timing and frequency of the tropical cyclones, surges, and small scale and mesoscale vortices. The unique feature also includes the influence of the upper ocean streamflow that also controls the climate type (Wyrski 1961), a feature that may not exist in other regions of the world.

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