Article

Statistical Analysis of Tropical Cyclones in the Solomon Islands

Edward Maru [1,2], Taiga Shibata [2] and Kosuke Ito [2,*]

[1] Solomon Islands Meteorological Services; eddie.maru0@gmail.com
[2] University of the Ryukyus; itokosk@sci.u-ryukyu.ac.jp
* Correspondence: Department of Physics and Geosciences, Faculty of Science, University of the Ryukyus 1 Senbaru, Nishihara-cho, Nakagami-gun, Okinawa 903-0213, Japan
itokosk@sci.u-rykyu.ac.jp; Tel.: +81-98-895-8573

Abstract: This paper examines the tropical cyclone (TC) activity in Solomon Islands (SI) using the best track data from Tropical Cyclone Warning Centre Brisbane and Regional Specialized Meteorological Centre Nadi. The long-term trend analysis showed that the frequency of TCs has been decreasing in this region while average TC intensity becomes strong. Then, the datasets were classified according to the phase of Madden-Julian Oscillation (MJO) and the index of El Nino Southern Oscillation (ENSO) provided by Bureau of Meteorology. The MJO has sufficiently influenced TC activity in the SI region with more genesis occurring in phases 6-8, in which the lower outgoing longwave radiation indicates enhanced convective activity. In contrast, TC genesis occurs less frequently in phases 1, 2, and 5. As for the influence of ENSO, more TCs are generated in El Nino period. The TC genesis locations during El Nino (La Nina) period were significantly displaced to the north (south) over SI region. TCs generated during El Nino condition tended to be strong. This paper also argues the modulation in terms of seasonal climatic variability of large-scale environmental conditions such as sea surface temperature, low level relative vorticity, vertical wind shear, and upper level divergence.

Keywords: tropical cyclone; Madden-Julian Oscillation; El Nino Southern Oscillation; South Western Pacific; global warming

1. Introduction

Solomon Islands (SI) is the nation where tropical cyclones (TCs) are frequently generated in the South Pacific. National history showed SI region has been devastated by TCs where the people have lost their properties and its economy has been severely damaged due to extreme winds, torrential rain, and storm surges. The information on TCs is critically important to the public because this nation consists of many small scattered islands and people travel from an island to another island by hand-crafted small ships.

Considering the severity of disasters in the region, climate change and global warming have posted a great concern for the changes in the TC genesis and intensity. Recent studies [1] indicated that increasing rate of intense TCs in the south-western Pacific through the comparison between 1975-1989 and 1990-2004, may be related to the increasing sea surface temperature (SST) [2]. In addition to the climatology of TCs, it is also important to consider various natural variabilities relevant to TC activities. For example, Vincent et al. (2009) revealed that inter-annual variability of the South Pacific Convergence Zone (SPCZ) [3], which is strongly related to El Nino Southern Oscillation (ENSO), may have significance influence on TC genesis in the South Pacific. Chand and Walsh (2010) examined the impact of Madden-Julian Oscillation (MJO) on TC activities over Fiji region [4]. Iizuka and Matsuura (2012) investigated similar intra-seasonal and seasonal scale features impacting TCs over the southern hemisphere [5]. They concluded that in El Nino (La Nina) years, the natural frequency of TC increases (decreases) in the north-eastern quadrant of the south-western Pacific in which Solomon

Islands is located. Klotzbach (2014) showed that TCs in the south Pacific basin are also influenced by convective enhancement in phases 6-8 of the MJO [6]. The notable difference seen in cyclone displacements and frequency during El Nino and La Nina years can be explained by the SST and large-scale environmental conditions anomalies associated with the ENSO [7].

The above-mentioned studies basically address the basin-scale characteristics. However, considering the decision making in the SI region, it is important to make sure if these tendencies are robust for a nation-wide scale rather than a basin scale. However, the statistical characteristics of TCs around the SI region has never been investigated to the authors' knowledge. Therefore, it is important to investigate TC activity in the SI region. The main objectives of this study are (1) to clarify the long-term trend of TCs in the SI region and (2) to examine the modulation of TCs by ENSO and MJO regarding the TC genesis and intensity in consideration of large scale environmental conditions (e.g. sea surface temperature, low level relative vorticity, vertical wind shear, upper level divergence, outgoing longwave radiation (OLR), and 850 hPa wind vector). This work contributes to the disaster prevention and mitigation in SI from the perspective of nation-wide scale. The structure of this paper is as follows: Section 2 describes the data and methodology. In section 3, a long-term behaviour is described. The modulation of TCs to MJO and ENSO as well as physical parameters are described in section 4. Finally, a conclusion is summarized in section 5.

2. Data and Methodology

This study is based on the southern hemisphere TC season 30-year period starting 1986/1987–2015/2016. A season refers to the November 1st of a year to April 30th of the subsequent year. The best track of TC data used in this study is the same as used in the Solomon Islands Meteorological Services (SIMS), which are from Fiji Met Services (FMS) serving as the Regional Specialized Meteorological Centre (RSMC) Nadi and Bureau of Meteorology (BoM) serving as the Tropical Cyclone Warning Centre (TCWC) Brisbane. When a TC center is located to the east (west) of 160E, the dataset of RSMC Nadi (TCWC Brisbane) was used. This split follows the framework of World Weather Watch program of the World Meteorological organization. The study domain is defined as the area between 4°-20°S and 150°-175°E (Fig. 1). The time interval of the best track data record is six hours and a maximum wind speed refers to the average 10-minute sustained wind speed in this study. The definition of a TC is a tropical storm that achieved 34 knots (about 17.0 m/s) or above and the first appearance in the best track is used to define the TC genesis.

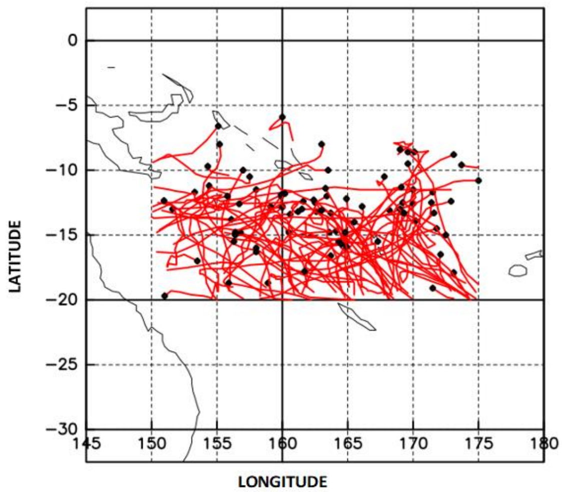


Figure 1. Genesis locations (black dots) and tracks (redlines) of all 81 TCs considered in the analysis.

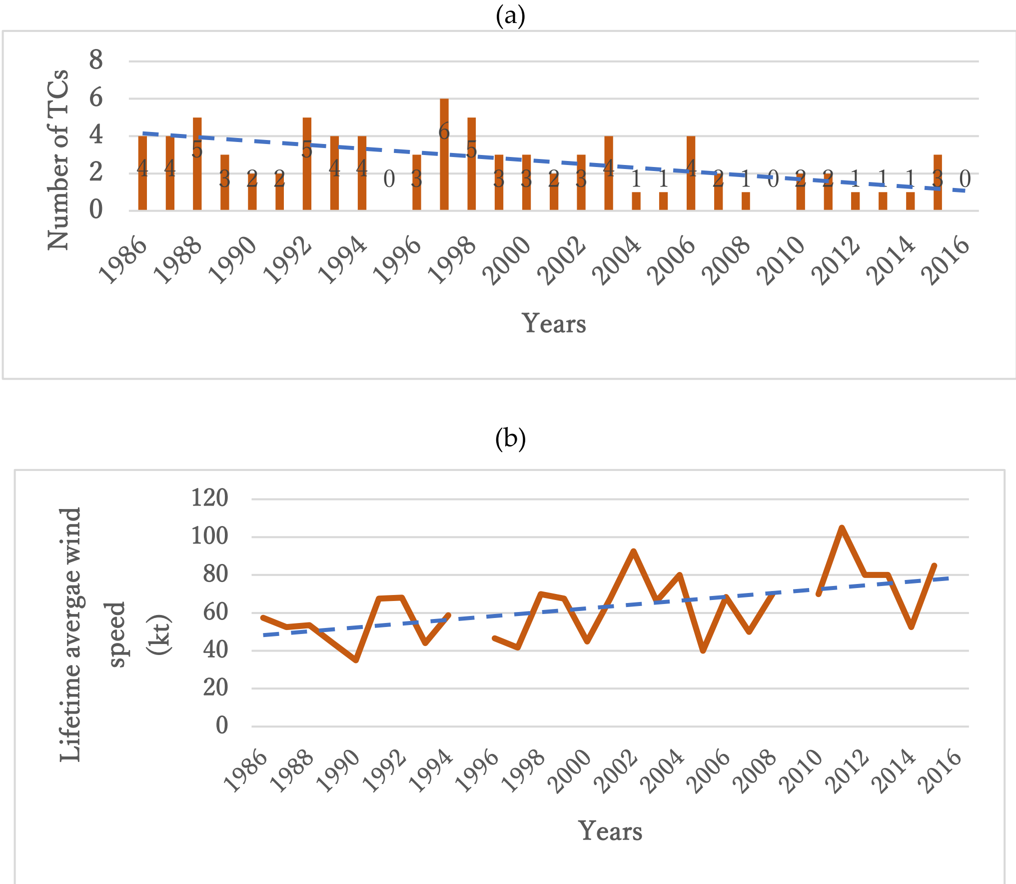
In total, 81 TCs were compiled for this research (Fig. 1). There is one TC that passed over the eastern boundary of the study domain as it was generated at the boundary. This treatment, however, does not substantially affect the main conclusions. Note that we do not investigate TCs outside of the above-mentioned domain, although a TC generated in the SI region sometimes travels to the south and devastates other nations after its intensification as illustrated by an example of TC pam (2015) in the light of the current scope.

The phase of MJO and ENSO indexes were obtained from BoM http://www.bom.gov.au/climate/mjo/graphics/rmm.74toRealtime.txt and http://www.bom.gov.au/climate/current/soihtm1.shtmlxx respectively. The air temperature, SST, OLR, zonal and meridional wind datasets were taken from National Centers for Environmental Prediction (NCEP) and the 850 relative vorticities and 200 hPa relative divergence are calculated from the wind data.

3. Long-term trend

We first focus on the long-term trend of number of TCs (NTC) and of average lifetime maximum wind speed. The analysis shows that the frequency of TCs has been decreasing (Fig. 2a) in this region, while average lifetime TC intensity becomes strong (Fig. 2b). The annual-mean number of TCs was 3.3 during 1986-1995, while it becomes 1.3 during 2007-2016. In contrast, the lifetime average wind speed was around 50 kt during 1986-1995 and it has increased by more than 40% in the last 10 years. The decreasing trend of numbers is a well-known feature and Sugi (2012) previously investigated this [8]. He argued that the significant warming of upper troposphere strengthens the atmospheric stability and reduction in the upward mass flux associated with the convective updrafts leads to reduction in global TC frequency. However, it is important to ensure that it is true for the SI regions because global TC tendencies is not necessarily same as regional TC tendencies [9].

(a)



(b)

Figure 2. (**a**) The number of TCs in each year during 1986-2016 and (**b**) the lifetime average wind speed in each year during 1986-2016. The regression lines are indicated in blue.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 8 May 2018 doi:10.20944/preprints201805.0132.v1

Peer-reviewed version available at *Atmosphere* **2018**, *9*, 227; doi:10.3390/atmos9060227

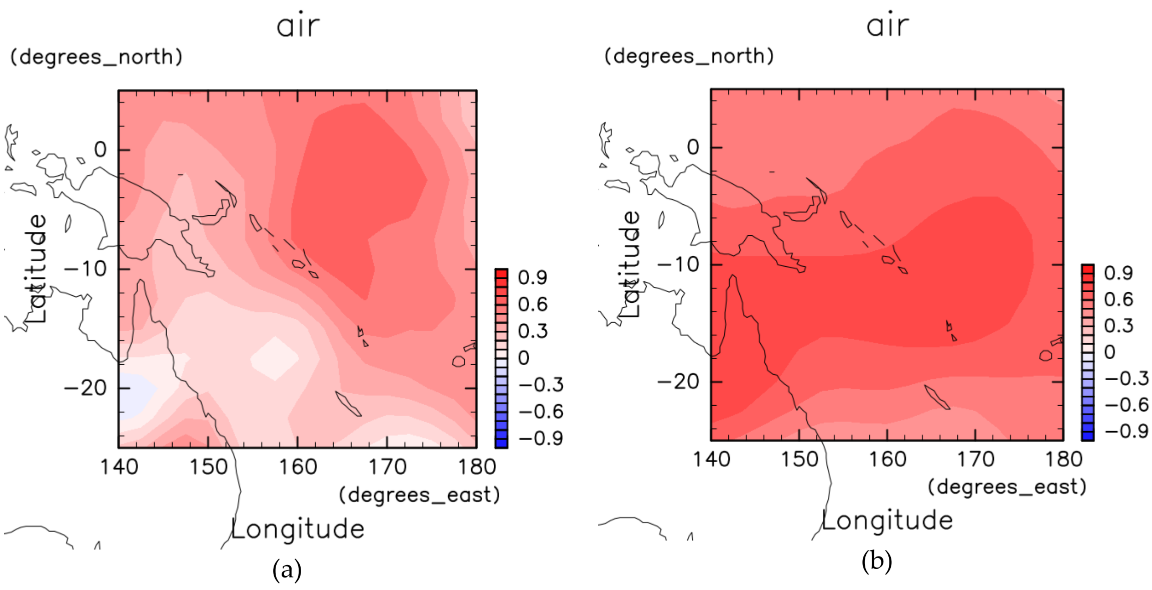


Figure 3. Temperature change between 2001—2015 and 1986—2000 at (**a)** 850 hPa and (**b**) 200 hPa.

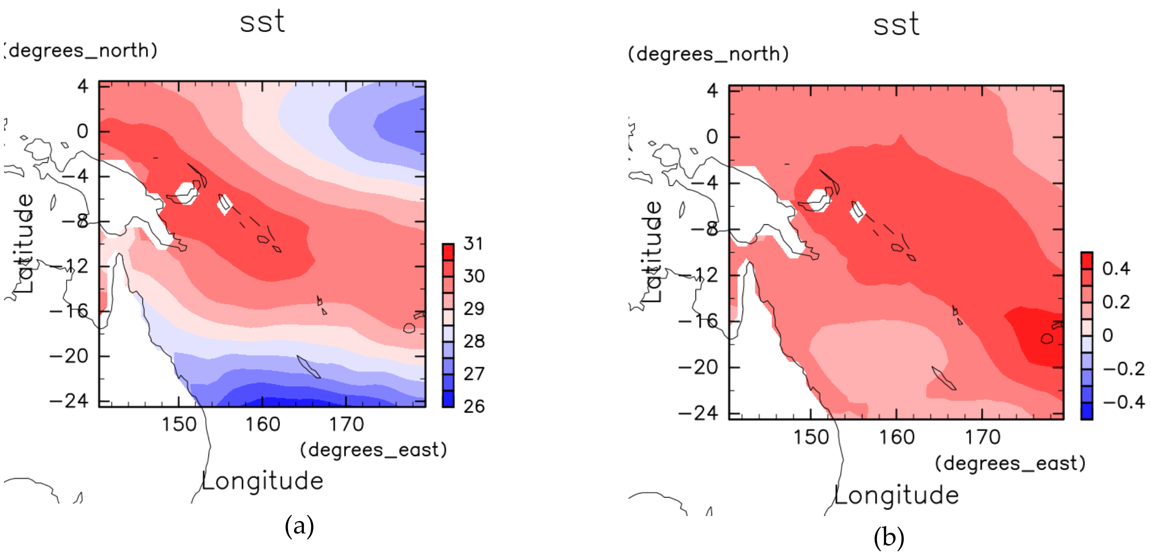
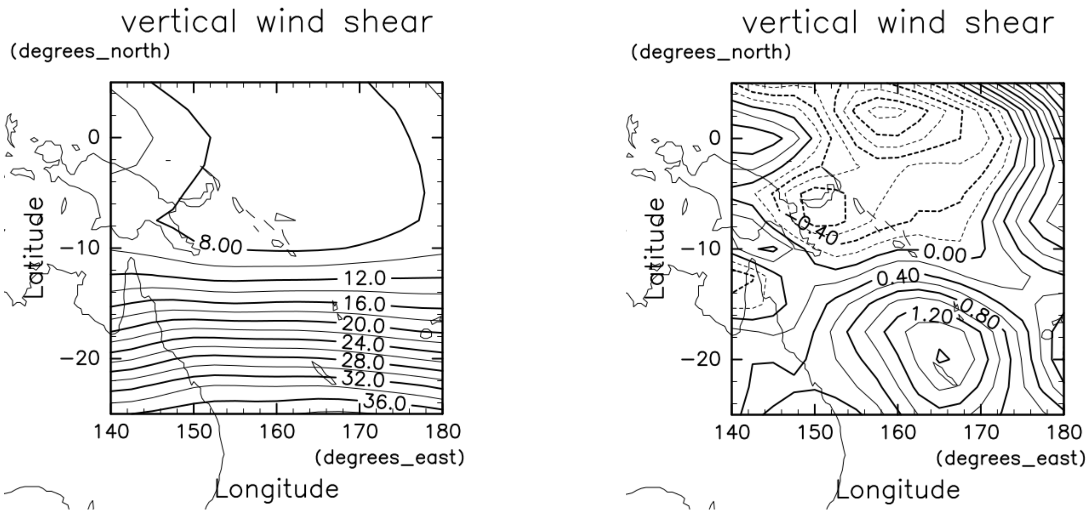


Figure 4. (**a**) Recent 15-seasons (2001/2002-2015/2016) average SST records and (**b**) SST change between recent 15-seasons (2001/2002-2015/2016) and earlier 15-seasons (1986/1987-2000/2001).

Therefore, changes in the 15-yr averaged temperature during 2001—2015 with respect to that during 1986-2000 at 850 hPa and 200 hPa were calculated (Figs. 3a and 3b). The upper tropospheric temperature increase is more significant than the lower tropospheric temperature increase. Particularly, the values south of 10°S indicates the enhanced static stability in recent years. It suppresses the deep convection and consistent with the studies addressing the number of TCs globally.

As for the TC intensity, the 15-yr averaged temperature during 2001—2015 is shown in Fig. 4a. The SST in the study domain (4°-20°S and 150°-175°E) is generally higher than the surrounding region and the highest value appears along the chain of islands from north-west to south-east. Comparing to the difference between recent 15-seasons (2001/2002-2015/2016) and the first 15-seasons (1986/1987-2000/2001). As demonstrated in Fig. 4b, it appears that the SST warming has provided the thermodynamically favorable condition that could lead to the increase of TC intensity. This result is in line with previous findings [1][2][10].

Peer-reviewed version available at *Atmosphere* **2018**, *9*, 227; doi:10.3390/atmos9060227



(a) (b)

Figure 5. Same as Fig. 4 but for the vertical shear of horizontal wind.

Another important factor is the vertical wind shear because it generally suppresses the TC genesis and intensity. Here we define the vertical wind shear as the magnitude of deep-layer horizontal wind vector difference between 850 hPa and 200 hPa. The vertical wind shear averaged over the 2001/2002-2015/2016 TC seasons is less than 10 m/s north of 10°S and becomes stronger toward the south due to the influence of midlatitude westerly jet (Fig. 5). Long-term change of the vertical wind shear in the study domain shows that the slight weakening (increasing) is seen north (south) of 10°S (Fig. 5b). Therefore, vertical wind shear provides an unfavourable condition for TC genesis and intensification in the southern part of the SI region in recent years.

4. Modulation of TCs by MJO and ENSO

4.1. MJO-TC relationship

The MJO is a large-scale mode of intra-seasonal atmospheric variability that propagates eastward along the equatorial region with the period around 30-60 days [6]. It is also widely known as an important mode for TC genesis. During the passage of an active phase with much convective activities, large-scale dynamic and thermodynamic fields can be modulated enhancing favorable conditions for TC genesis. The deep convection tends to be located near the SI region in phases 6-7, while it tends to be located at western hemisphere in phase 1, Indian ocean in phases 2-3, maritime continent in phase 4-5, Africa in phase 8 [11].

Figure 6 displays the frequency of TCs over the 30-year period (1986/1987-2015/2016) stratified according to the phase of the MJO. It shows that more TCs were generated in phases 6-8, with the largest number appearing in phase 6. Klotzbach (2014) indicated that TC activity in the south Pacific is associated with convective enhancement in phases 6-8 [6]. According to the daily chart of Wheeler and Hendon (2004), phases 6 and 7 are associated with convective enhancement in the south Pacific [11]. It is notable that very intense TCs can be generated even in phase 1—5. Figure 7 shows that very intense TC was generated at least once in all categories, although the frequent occurrence of very intense TCs is found in phase 6—8 in comparison with phase 1—3.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 8 May 2018 doi:10.20944/preprints201805.0132.v1

Peer-reviewed version available at *Atmosphere* **2018**, *9*, 227; doi:10.3390/atmos9060227

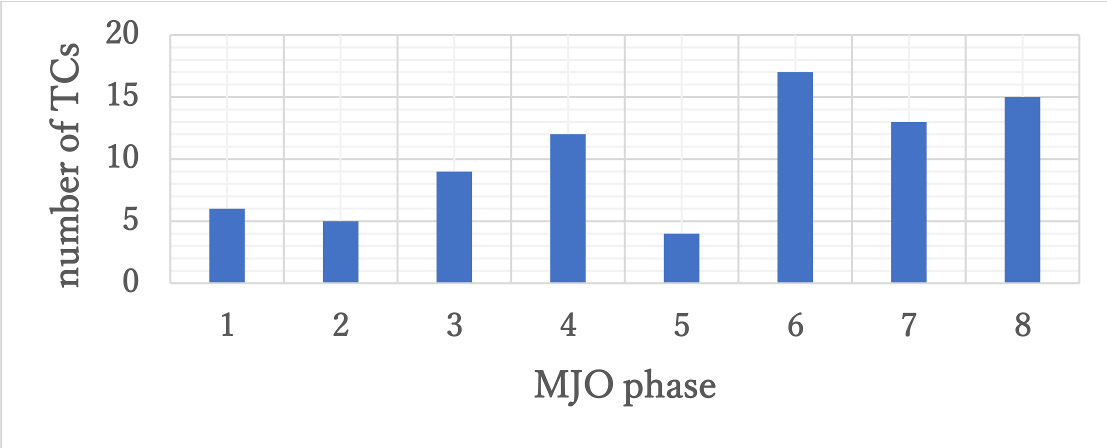


Figure 6. The number of TC genesis stratified according to the phase of MJO.

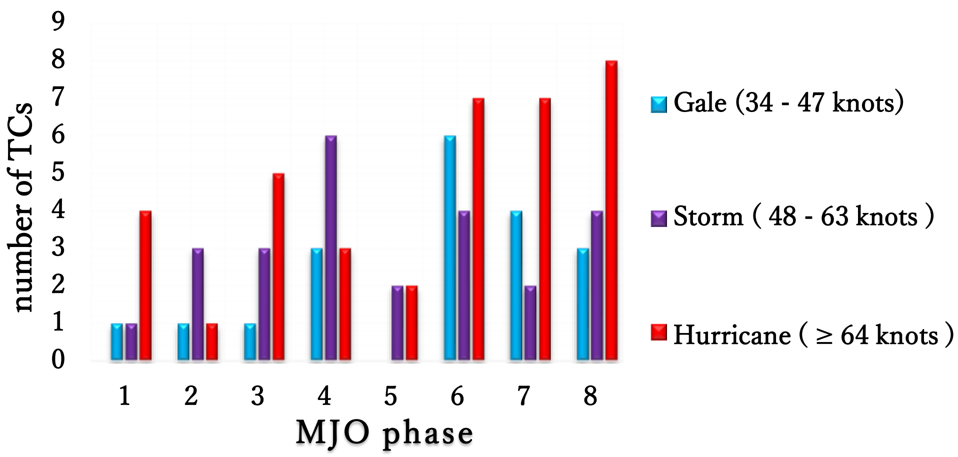


Figure 7. Number of TCs a categorized by the phase of MJO and the intensity class.

Table 1. Composite 200 hPa horizontal divergence (s^{-1}), vertical wind shear ($m\ s^{-1}$), SST (℃), OLR (W/m^2), and 850 relative vorticity (s^{-1}) in each MJO phase. If the difference from the grand composite exceeded the standerd devitation, the value is marked in bold fonts.

phase	divergence	vertical wind shear	SST	OLR	850 hPa RV
1	1.05×10^{-6}	13.70	**28.65**	**237.99**	-2.84×10^{-6}
2	$\mathbf{0.79\times 10^{-6}}$	13.79	28.75	**237.44**	-2.02×10^{-6}
3	0.95×10^{-6}	15.02	28.82	232.29	-1.99×10^{-6}
4	1.20×10^{-6}	**15.64**	28.83	227.55	-1.97×10^{-6}
5	1.60×10^{-6}	14.96	**28.90**	223.62	-1.95×10^{-6}
6	$\mathbf{2.33\times 10^{-6}}$	14.10	**28.89**	**218.98**	-3.14×10^{-6}
7	$\mathbf{2.27\times 10^{-6}}$	13.59	28.82	**222.79**	$\mathbf{-4.14\times 10^{-6}}$
8	1.57×10^{-6}	**13.43**	28.77	232.96	$\mathbf{-3.58\times 10^{-6}}$

doi:10.20944/preprints201805.0132.v1

Peer-reviewed version available at Atmosphere 2018, 9, 227; doi:10.3390/atmos9060227

To clarify the environmental factors that can explain the variability, we calculated divergence at 200 hPa, vertical wind shear, SST, OLR and relative vorticity at 850 hPa averaged over our study area. Large-scale environmental conditions that is favourable condition for TC genesis and intensification in the Southern hemisphere are (1) large upper tropospheric divergence, (2) weaker vertical wind shear, (3) higher SST (4) lower OLR, and (5) stronger low-level negative vorticity (clockwise circulation). Table 1 summarizes these values, and they are marked in bold fonts if the difference with respect to the grand mean exceeds the standard deviation.

It shows several important differences among the different phases of MJO. The large number of genesis and strong TCs in phases 6 and 7 can be explained by large upper tropospheric divergence, lower OLR, and large negative vorticity field. Figure 8 shows the OLR becomes lower along the chain of islands and that horizontal wind field at 850 hPa yields the clockwise circulation in general. In contrast, phases 1-3 are characterized by the weaker upper tropospheric divergence, higher OLR, and weaker negative relative vorticity at 850 hPa. These features are generally consistent with the frequency of TC genesis and intensity. Although there are some differences of SST among the phases, the largest difference was only 0.25 K. It is interesting that the number of TCs was sufficiently small in phase 5. On a closer inspection, MJO phase 5 is characterized by the low OLR region centred at 150°E on the equator preceding the major low OLR region at 120°E and 15°S and the horizontal wind vector exhibits the anti-clockwise circulation in the SI region (see Fig. 8 of Wheeler and Hendon [11]). Although table 1 represents the environmental condition over the months when TCs were generated, the negative vorticity is relatively weak in phase 5. It suggests that convection is relatively active but the low-level circulation is not favourable for the initiation of the vortex in phase 5. Of course, care should be taken for the fact that the number of TCs investigated is not so large. In other words, the small number in phase 5 might be merely a statistical artefact .

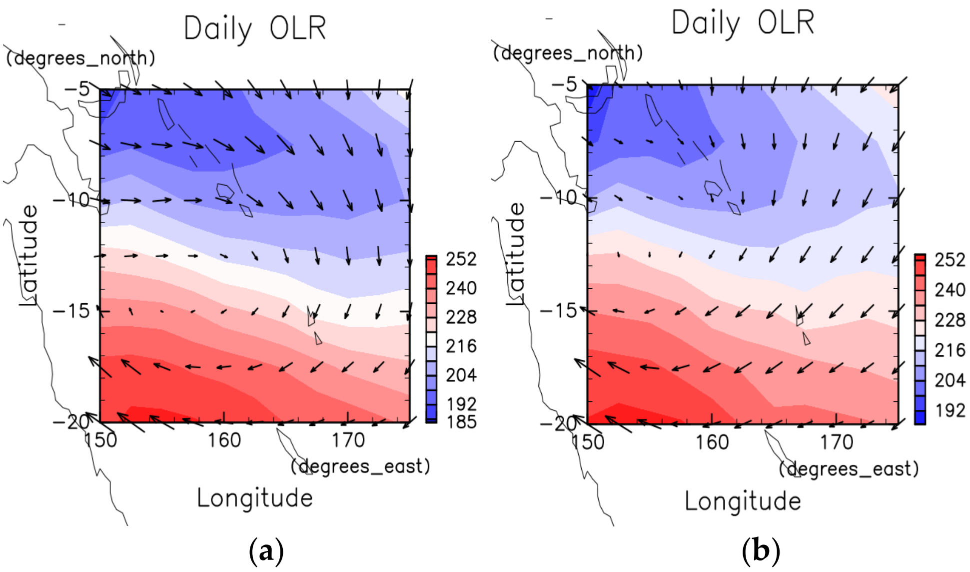


Figure 8. Composite of OLR over-plotted by the wind vector at 850 hPa for (**a**) phase 6 and (**b**) phase 5.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 8 May 2018 doi:10.20944/preprints201805.0132.v1

Peer-reviewed version available at Atmosphere 2018, 9, 227; doi:10.3390/atmos9060227

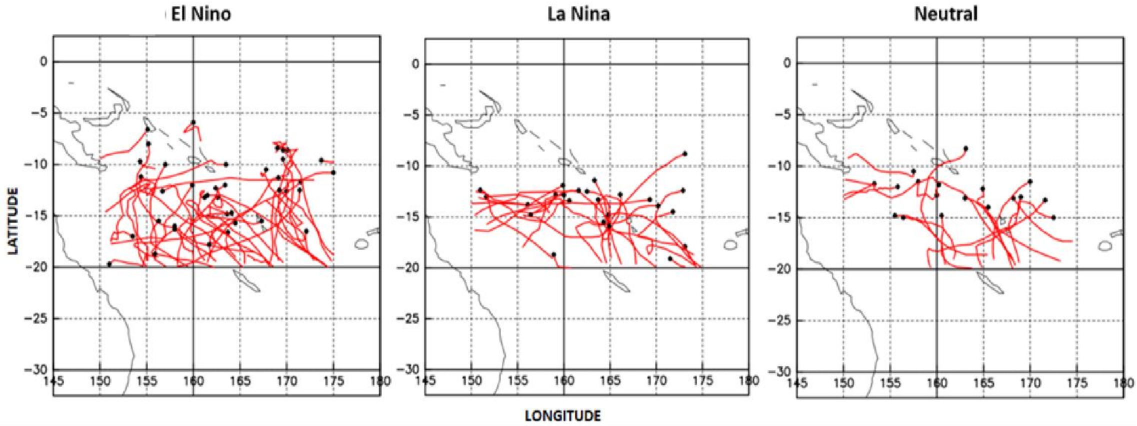


Figure 9. TC genesis locations in black dots for El Nino (left), La Nina (middle), and neutral (right) period, respectively. Associated TC tracks are denoted in red lines.

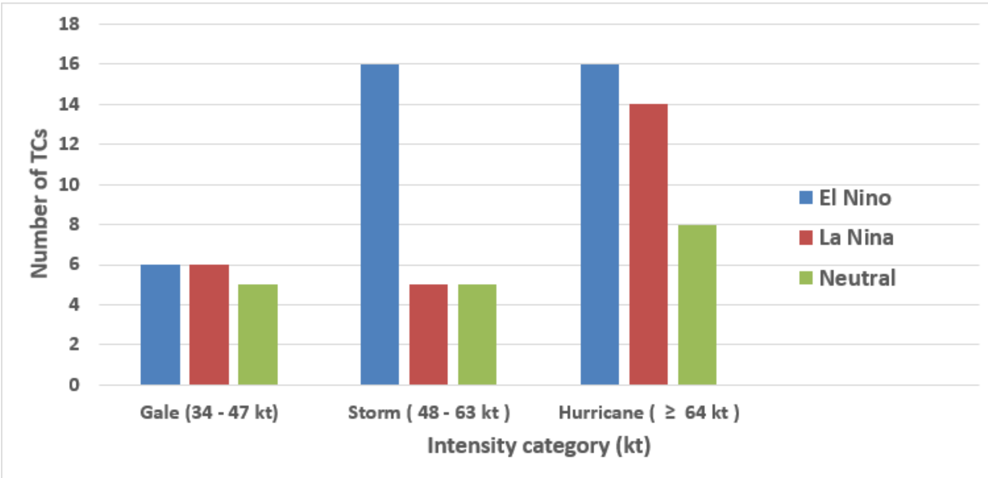


Figure 10. Intensity categories according to ENSO conditions and number of TCs.

4.2. ENSO-TC relationship

ENSO is regarded as the most prominent atmospheric and oceanic interannual variability with a different time-scale longer than MJO [12]. Several previous studies revealed that ENSO has influenced on inter annual variability of TC activity in most basins [5]. Lander (1994) also highlighted that the displacements of TC genesis location is robustly associated with ENSO [13]. Therefore, we classified the dataset according to the category of El Nino, neutral, and La Nina period.

Figure 9 shows that the genesis location of TCs tends to be shifted to the south during La Nina period in comparison with El Nino period. During La Nina period, it is very rare to observe the TC genesis between 0-10°S. The number of TCs is also different according to the ENSO index. TCs are observed more frequently during the El Nino period, while they are less frequently observed during the La Nina period. As for neutral years the displacement and number of TC formations seems to be between the two. As for TC intensity, the number of storm category TCs (maximum wind speed of 48—63 kt) is larger in El Nino period (Fig.10). However, the number of strong TCs is comparable between El Nino and La Nina in the SI region.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 8 May 2018 doi:10.20944/preprints201805.0132.v1

Peer-reviewed version available at Atmosphere 2018, 9, 227; doi:10.3390/atmos9060227

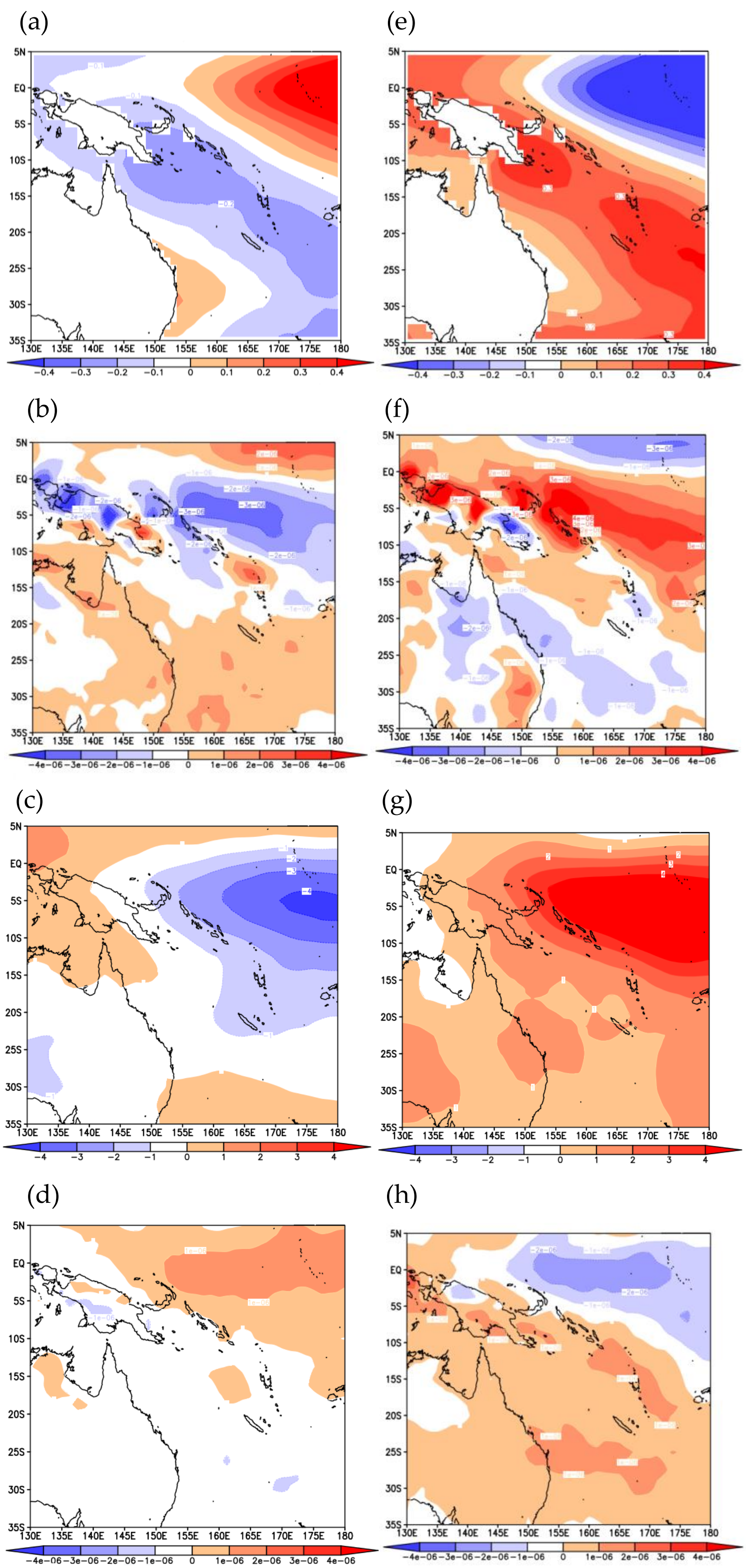


Figure 11. The anomaly in large scale environmental conditions for El Nino period: (a) SST (°C), (b) 850 hPa relative vorticity (s^{-1}), (c) vertical wind shear (m/s) and (d) 200hPa divergence (s^{-1}),. (e)-(h) Same as (a)-(d) but for La Nina period.

Figure 11 shows the anomaly of physical parameters during El Nino and La Nina periods. The southerly shift of TC genesis during La Nina period is consistent with lower SST, stronger vertical wind shear, weaker negative vorticity and weaker upper tropospheric divergence in the northern part of the SI region. All these conditions help suppress the active convection in the northern part of the SI region. In particular, the mean SST is relatively low near the equator (Fig. 4a) so that the cold anomaly of SST during La Nina shuts down the energy supply to sustain the active convection. Furthermore, because SST anomaly significantly drives surface wind anomalies, the north-easterly and south-easterly trade winds enhances moisture convergence triggering low-level vorticities and high moisture content during El Nino events. This is well-known feature of the SPCZ pattern [3].

4.3. Interplay of MJO and ENSO on TCs

To assess the interplay of MJO and ENSO, the number of TC genesis was divided into both MJO phase and ENSO index (Fig. 12). It can be noted that there is increasing number of TCs associated with MJO-El Nino relationship compared to La Nina and neutral years. In general, the combination of an amplified phase of the MJO traversing over the SI region together with large-scale fields as displayed supports enhancement of convective activity for TC generation.

The positive anomalous SST during El Nino could be a possible clarification for the intensification and enhancement of TCs. In addition, a convectively enhanced phase of the MJO coexistence with the El Nino condition (warming SST anomalies) influences low-level westerlies and large-scale fields robustly impacting more intense frequency as seen in phases 6-8 (Fig.12). It is notable that the very intense TC Pam (2015) was generated during the active MJO phase 6 and El Nino [7]. Due to the limitation of the number of cases, we could not address this issue further. However, we should be cautious about the very intense TC in case of the phase 6-8 and El Nino phase.

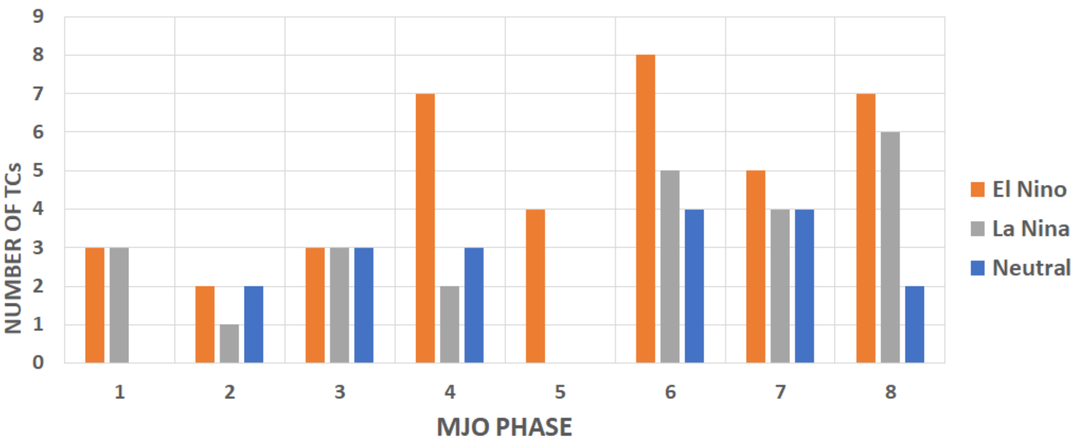


Figure 12. As in Fig. 6, but for each ENSO conditions.

5. Conclusions

This study documents the long-term trend of TCs in the SI regions and how tropical cyclone activity in the SI region is influenced by the MJO and the ENSO using statistical analysis with best track dataset. Firstly, we clarify the long-term trends over 30-year period (1986/87-2015/16). The frequency of TCs has been decreased but maximum average intensity becomes strong. The reduction of TC frequency is consistent with the increase of atmospheric stability, as explained by strong warming in the upper troposphere than in the lower troposphere. In contrast, the increase in intensity may be attributed to the large sensitivity to SST. Although this work is done for investigating nation-wide characteristics, this is consistent with previous studies which addressed the issue of global TC

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 8 May 2018 doi:10.20944/preprints201805.0132.v1

Peer-reviewed version available at *Atmosphere* **2018**, *9*, 227; doi:10.3390/atmos9060227

frequency and intensity changes under conceptual understanding of rising SSTs in a warming environment.

There were significant TC genesis patterns associated with the MJO. Statistically significant genesis increase is seen in phases 6-8, with most genesis occurring in phase 6. In contrast, phases 1, 2, and 5 tend to be associated with less TC genesis while the least occurred in phase 5. The least genesis in phase 5 is an unexpected result because MJO phase 5 is characterized by the active convection over the maritime continent close to the SI region. It may be explained by the weaker negative vorticity anomaly. The most TC genesis in phase 6 is presumably associated with low OLR and low-level negative background relative vorticity, which are known as favourable conditions for the TC genesis. Another notable feature is that even in phase 1-4 there are a lot of violent TCs generated over the SI region. As for the influence of ENSO, more (less) TCs are generated during El Nino (La Nina) periods. The increase (decrease) and northerly (southerly) shift of TC genesis during El Nino (La Nina) periods is presumably due to SST anomaly and large negative (positive) low-level relative vorticity anomalies and decrease (increase) of vertical wind shear. Therefore, it is concluded that both MJO phase and ENSO are vital for the frequency and distribution of TC genesis in the SI region.

The current work is meaningful because it generally exhibits that a nation-wide scale feature around the SI region is consistent with the global-scale and/or basin-scale feature. One may think that this looks trivial. In fact, it is very important to make sure the existing findings are generally valid for the society because the activity and preparedness are formed by the nation-wide scale typically. In particular, it is important to note the local climatological feature such as the smaller number of TCs in MJO phase 5. We believe this work will help mitigate and prevent the TC-related disasters in the SI region, through arising the preparedness of the society. Although we focus on the SI region alone, it might be important to be cautious about very intense TC outside the SI region in case of the phase 6-8 and El Nino phase such as TC Pam (2015) that devastated Vanuatu was generated very close to the SI region. It might contribute to other countries and will be one of our future research topics.

Acknowledgments: We thank the helpful comments from Profs. Hiroyuki Yamada and Toshiki Iwasaki. This work was supported by JICA Pacific Leaders' Educational Assistance for Development of State and MEXT KAKENHI 15K05294 and 18H01283.

Author Contributions: Funding acquisition, Kosuke Ito; Investigation, Edward Maru; Project administration, Kosuke Ito; Software, Taiga Shibata; Supervision, Kosuke Ito; Visualization, Taiga Shibata; Writing – original draft, Edward Maru and Kosuke Ito.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Webster. P. J., G. J. Holland, J. A, J. A. Curry, and H. -R. Chang. Changes in tropical cyclone number, duration, and intensity in a warming environment. *Science* **2005**, *309*, 1844-1846, DOI: 10.1126/science.1116448.
2. Emanuel. K., Increasing destructiveness of tropical cyclone over the past 30 years. *Nature* **2005**, *436*, 686-688, doi:10.1038/nature03906.
3. Vincent. E. M., M. Lengaigne, C. E. Menkes, N. C. Jourrdain, P. Marchesiello, and G. Madec. Interannual variability of the South Pacific convergence zone and implications for tropical cyclone genesis. *Climate dynamics* **2009**, *36*, 1881-1896, https://doi.org/10.1007/s00382-009-0716-3.
4. Chand. S.S., K.J. Walsh. The Influence of the Madden–Julian Oscillation on Tropical Cyclone Activity in the Fiji Region. *J. Climate* **2010**, *23*, 868–886, https://doi.org/10.1175/2009JCLI3316.1.
5. Iizuka. S., Matsuura. T, 2012. Analysis of Tropical Cyclone Activity in the Southern Hemisphere using Observation and CGCM Simulation. *Cyclones: Formation, Triggers, and Control, 1st ed.*, Oouchi. K, Fudeyasu. H., Nova Science Publishes, Inc: New York, USA, **2012**; *Volume 1*, pp. 37-59, ISBN 978-1-61942-975-5.
6. Klotzbach. P.J. The Madden–Julian Oscillation's Impacts on Worldwide Tropical Cyclone Activity. *J. Climate* **2014**, *27*, 2317–2330, https://doi.org/10.1175/JCLI-D-13-00483.1.

Peer-reviewed version available at *Atmosphere* **2018**, *9*, 227; doi:10.3390/atmos9060227

7. Nakano. M., H. Kubota, T. Miyakawa, T. Nasuno, and M. Satoh. Genesis of Super Cyclone Pam (2015): Modulation of Low-Frequency Large-Scale Circulations and the Madden–Julian Oscillation by Sea Surface Temperature Anomalies. *Mon. Wea. Rev.* **2017**, *145*, 3143–3159, https://doi.org/10.1175/MWR-D-16-0208.1.
8. Sugi. M. Reduction of Global Tropical Cyclone Frequency Due to Global Warming. *Cyclones: Formation, Triggers, and Control, 1st ed.*, Oouchi. K, Fudeyasu. H., Nova Science Publishes, Inc: New York, USA, **2012**; *Volume 1*, pp. 115-123, ISBN 78-1-61942-975-5.
9. Tsutsui. S., J. Estimation of changes in tropical cyclone intensities and associated precipitation extremes due to anthropogenic climate change. *Cyclones: Formation, Triggers, and Control, 1st ed.*, Oouchi. K, Fudeyasu. H., Nova Science Publishes, Inc: New York, USA, **2012**; *Volume 1*, pp. 125-141, ISBN 978-1-61942-975-5.
10. Lin. I., C. Wu, I. Pun, D. Ko. Upper-Ocean Thermal Structure and the Western North Pacific Category 5 Typhoons. Part I: Ocean Features and the Category 5 Typhoons' Intensification. *Mon. Wea. Rev*. **2008**, *136*, 3288–3306, https://doi.org/10.1175/2008MWR2277.1.
11. Wheeler. M.C., H.H. Hendon. An All-Season Real-Time Multivariate MJO Index: Development of an Index for Monitoring and Prediction. *Mon. Wea. Rev.* **2004**, *132*, 1917–1932, https://doi.org/10.1175/1520-0493(2004)132<1917:AARMMI>2.0.CO;2
12. Kubota. H., 2012: Variability of typhoon tracks and genesis over the Western North Pacific. *Cyclones: Formation, Triggers, and Control, 1st ed.*, Oouchi. K, Fudeyasu. H., Nova Science Publishes, Inc: New York, USA, **2012**; *Volume 1*, pp. 95-114, 978-1-61942-975-5.
13. Lander. M.A. An Exploratory Analysis of the Relationship between Tropical Storm Formation in the Western North Pacific and ENSO. *Mon. Wea. Rev.* **1994**, *122*, 636–651, https://doi.org/10.1175/1520-0493(1994)122<0636:AEAOTR>2.0.CO;2.
14. NOAA. International Best Track Archive for Climate Stewardship (IBTrACS). Available online: https://www.ncdc.noaa.gov/ibtracs/index.php?name=wmo-data (accessed 16th January 2017).
15. Bureau of Meteorology (BoM) Tropical cyclone plotting information/ intensity scale comparison. Available online: https://www.australiasevereweather.com/cyclones/tropical_cyclone_intensity_scale.htm (accessed 20th February 2017).
16. Bureau of Meteorology (BoM) RMM Data. Available online: http://www.bom.gov.au/climate/mjo/graphics/rmm.74toRealtime.txt (accessed 06th April 2017).
17. Bureau of Meteorology (BoM) RMM Data. Available online: http://www.bom.gov.au/climate/current/soihtm1.shtml (accessed 07th April 2017).
18. Pacific Climate Change Science. Available online: https://www.pacificclimatechangescience.org/wp-content/uploads/2013/06/PCCSP-_ClimateVariabilityChange.pdf