Distribution features of meteorological parameters in Truong Sa archipelago area

Le Dinh Mau\textsuperscript{1,2}, Vlasova G. A.\textsuperscript{2}, Demenok M. N.\textsuperscript{2}, Pham Sy Hoan\textsuperscript{1}, Nguyen Van Tuan\textsuperscript{1}, Nguyen Duc Thinh\textsuperscript{1}, Pham Ba Trung\textsuperscript{1}, Tran Van Binh\textsuperscript{1}, Nguyen Thi Thuy Dung\textsuperscript{1}

\textsuperscript{1}Institute of Oceanography, VAST, Vietnam
\textsuperscript{2}V.I. Il'ichev Pacific Oceanological Institute, Far Eastern Branch, Russian Academy of Sciences (POI FEB RAS), Russia

E-mail: ledinhmau.vnio@gmail.com

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Abstract

This paper presents the distribution features of observed meteorological parameters in Truong Sa archipelago area including wind, tropical cyclone, and average values of solar radiation, air temperature, air humidity, rainfall. Observed data were collected from Truong Sa island hydro-meteorological station. In particular, data of tropical cyclones affecting Truong Sa archipelago area were collected from the websites http://www.jma.go.jp/jma/jma-center/(Japan). Study results show that the main meteorological parameters in Truong Sa archipelago area are affected by solar radiation and monsoon wind regimes in East Asia region which are Northeast monsoon occurring from November to April and Southwest monsoon occurring from June to September. Transition periods are May and October. Tropical cyclones occur mainly in November–December, maximum wind speed was 64 m/s in typhoon HAIYAN (November 2013). The highest average solar radiation occurs in April (277 hours), the lowest in January (181 hours). The highest average air temperature occurs in April (29.5°C), the lowest in January (26.6°C). The highest average rainfall occurs in November (341 mm), the lowest in March (62 mm). The highest average air humidity occurs in November–December (85%), the lowest in April–May (79%). The highest average water evaporation occurs in March (129 mm), the lowest in December (87 mm).

Keywords: Truong Sa archipelago, hydro-meteorological, wind, tropical cyclone.

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INTRODUCTION

The Truong Sa archipelago are one of the major archipelagos in the East Vietnam Sea, covering the area from 6°50'00"N to 12°00'00"N and from 111°30'00"E to 117°20'00"E (figure 1). This area has important strategic role in economy, environmental protection and national security of Vietnam. Observation and forecasting of meteorological parameters in the East Vietnam Sea region including the Truong Sa archipelago area have been carried out by several nations such as Vietnam, China, USA, Japan, Taiwan,... with main data taken from satellite source especially USA (National Oceanic and Atmospheric Administration - NOAA) which supplied many meteorological data with the best resolution and quality. At present, in Vietnam there are some study results related to meteorological conditions in the East Vietnam Sea region and Truong Sa archipelago area such as wind, wave, tropical cyclone,... which have been published by several authors, for example Le Dinh Mau and Nguyen Van Tuan (2014) [1], Le Dinh Mau et al., (2019) [2], Galina et al., (2020) [3]. In recent years, Vietnam National Center for Hydro-meteorological Forecasting (NCHMF) belonging to the Ministry of Natural Resources and Environment (MONRE) has been forecasting the meteorological parameters in the East Vietnam Sea region for different periods. In Truong Sa archipelago area, there are two main hydro-meteorological stations located at Southwest Cay island and Truong Sa island. The Truong Sa island station is equipped with modern observation equipment, and it is a partner of World Meteorological Organization (WMO) with number sign 48920. Observed data from Truong Sa island station were transmitted by frequency every three hours, and especially in emergency conditions it is every half hour [4].

This paper gives the distribution features of the observed meteorological parameters at the Truong Sa island station such as wind, tropical cyclone, and average values of solar radiation, air temperature, air humidity, rainfall. The study results should be the best scientific data for sustainable development of marine economy and national security.

DATA AND METHODS

The observation station at Truong Sa island is located at 8°38'30"N - 111°55'55"E (figure 1). The data on air temperature, relative air humidity, rainfall with observed frequency of 6 h/time (1 h, 7 h, 13 h, 19 h) were taken from the Southern Central Vietnam Center for Hydro-meteorological Forecasting from 1987 to 2015. In addition, the wind data were collected for the period from 1987 to 2013, monthly average solar radiation was collected for the period from 2003 to 2015. Furthermore, data of tropical cyclones affecting Truong Sa archipelago area from 1884 to 2018 were taken...
on websites: http://www.jma.go.jp/jma/jma
- eng/jma-center/(Japan). They include the wind
speed, central pressure, positions, radius of
maximum wind speed and track of tropical
cyclones..., The Saffir-Simpson hurricane scale
of the National Weather Service, USA was
used to classify tropical cyclone strength levels.

The standard method was used for data
processing and analysis of meteorological
parameters [5, 6] as follows:

The observed data series will be arranged
by years (t1–tn), months (x1–x12), days (xi–x31)
as matrices 1, 2:

\[ S_{i1}, S_{i2}, S_{i3}, \ldots, S_{i12} \]

\[ S_{11}, S_{12}, S_{13}, \ldots, S_{12} \]

\[ \ldots \]

\[ S_{n1}, S_{n2}, S_{n3}, \ldots, S_{n12} \]

And statistical functions are used to
estimate the necessary characteristic values in
equations 3, 4.

Monthly average value:

\[ \overline{S}(i) = \frac{1}{n} \sum_{j=1}^{n} S_{ij}, \quad i = 1, \ldots, 12 \]  

Yearly maximum value:

\[ S_{\text{max}}(\text{year}) = \max \{V_{\text{max1}}, V_{\text{max2}}, \ldots, V_{\text{max12}}\} \]  

Here, S is a characteristic of meteorological
elements.

**STUDY RESULTS**

**Wind regime**

Analysis of the observed wind data at
Truong Sa island station for the period from
1987 to 2015 shows that wind regime is
seasonally varied according to the East Asia
landmass wind regimes, which are Northeast
(NE) and Southwest (SW) monsoons. The
yearly and monthly distribution features are
presented in figures 2, 3.

The yearly distribution of wind (figure 2)
shows that the main wind directions are NE and
SW, the NE wind speed is greater than SW
wind speed. The monthly distribution of wind
(figure 3) shows that the NE monsoon is from
October to April and the predominant wind
directions are NE, ENE. Maximum occurrence
frequency of NE wind direction is 50% in
October. The SW monsoon is from June to
September with the predominant wind
directions of SW, WSW. Occurrence frequency
of SW wind direction is around 41% in August.
May and October are transition periods when
wind speed and direction are varied. Calm wind
frequency is low, during the NE monsoon the
calm wind frequency is 0%, during SW
monsoon the calm wind frequency is less than
10%. The data of occurrence frequency of
predominant wind directions at Spratly Island
are shown in table 1 and the data of monthly
average wind speed are shown in table 2. Also,
maximum monthly wind speed is shown in
table 3.

**Table 1.** Occurrence frequency of predominant wind directions at Truong Sa island station
for the period from 1987 to 2013

| Month | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. |
|-------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Direction | N | 50.0 | 33.1 | 28.8 | 17.8 | 29.6 | 40.8 | 36.6 | 29.5 | 11.2 | 32.3 | 36.6 |
| Occurrence frequency (%) | 46.3 | 50.0 | 33.1 | 28.8 | 17.8 | 17.8 | 40.8 | 36.6 | 29.5 | 11.2 | 32.3 | 36.6 |

**Table 2.** Monthly average wind speed (V_average) at Truong Sa island station
for the period from 1987 to 2013

| Month | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. | Average |
|-------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|--------|
| V_average (m/s) | 8.6 | 7.2 | 5.9 | 3.9 | 4.0 | 5.4 | 6.1 | 6.1 | 5.6 | 4.5 | 6.5 | 8.2 | 6.0 |
Table 3. Maximum monthly wind speed ($V_{\text{max}}$) at Truong Sa island station for the period from 1987 to 2013

| Month | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. | Max |
|-------|------|------|------|------|-----|------|------|------|------|------|------|------|-----|
| $V_{\text{max}}$ (m/s) | 20 | 20 | 18 | 19 | 28 | 28 | 34 | 24 | 32 | 40 | 32 | 40 |     |

Figure 2. Yearly wind rose diagram at Truong Sa island station (1987–2013)

Figure 3. Monthly wind rose diagram in Truong Sa island station (1987–2013)
Figure 3. Monthly wind rose diagram in Truong Sa island station (1987–2013) (next)
Tropical cyclone

During the period from 1884 to May 2018, there were 218 tropical cyclones that affected Truong Sa archipelago area. Some tropical cyclones went through the area, also others passed adjacent areas and affected this area. However, few typhoons took shape in the East Vietnam Sea and impacted on Truong Sa archipelago. Table 4 shows that there were 24 typhoons (11%) with maximum wind speed ($V_{\text{max}}$) > 33 m/s, 47 tropical storms (22.56%) with 17 m/s < $V_{\text{max}}$ < 33 m/s, and 147 subtropical storms (67.5%) with $V_{\text{max}}$ < 17 m/s. On average, there are 1.61 storms per year and this number is considerable.

**Table 4.** Statistics of tropical cyclones crossing the Truong Sa archipelago area and adjacent regions (1884–5/2018) based on Saffir-Simpson scale

|                      | Tropical depression | Tropical storm | Typhoon | Total |
|----------------------|---------------------|----------------|---------|-------|
| Number of occurrence | 147                 | 47             | 24      | 218   |
| Percentage (%)       | 67.43               | 21.56          | 11.01   | 100   |

**Table 5.** Monthly distribution of tropical cyclone in Truong Sa archipelago area during 1984–5/2018

| Month | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | April | May | Jun. | Jul. | Aug. | Sep. |
|-------|------|------|------|------|------|------|-------|-----|------|------|------|-----|
| Number of occurrence | 33   | 68   | 53   | 11   | 5    | 6    | 6     | 9   | 6    | 3    | 6    | 12  |
| Percentage (%) | 15.14 | 31.19 | 24.31 | 5.05 | 2.75 | 4.13 | 2.75  | 1.38| 2.75 | 5.50 |

**Table 6.** The maximum yearly wind speed of tropical cyclones affecting Truong Sa archipelago area during 1987–5/2018

| No. | Name | Time    | Maximum wind speed of tropical cyclones $V_{\text{max}}$ (m/s) | Maximum wind speed in Truong Sa archipelago area $V_{\text{max}}$ (m/s) |
|-----|------|---------|-------------------------------------------------------------|-------------------------------------------------------------|
| 1   | PHYLLIS | Dec. 1987 | 51                                                          | 18                                                          |
| 2   | TESS  | Nov. 1988 | 33                                                          | 33                                                          |
| 3   | NELL  | Nov. 1990 | 26                                                          | 23                                                          |
| 4   | THELMA | Nov. 1991 | 23                                                          | 23                                                          |
| 5   | ANGELA | Oct. 1992 | 46                                                          | 46                                                          |
| 6   | LOLA  | Dec. 1993 | 54                                                          | 46                                                          |
| 7   | TERESA | Oct. 1994 | 41                                                          | 33                                                          |
| 8   | ZACK  | Nov. 1995 | 62                                                          | 62                                                          |
| 9   | GREG  | Dec. 1996 | 23                                                          | 23                                                          |
| 10  | LINDA | Nov. 1997 | 33                                                          | 23                                                          |
| 11  | FAITH | Dec. 1998 | 46                                                          | 46                                                          |
| 12  | RUMBIA | Dec. 2000 | 28                                                          | 13                                                          |
| 13  | TD1121 | Nov. 2001 | 18                                                          | 18                                                          |
| 14  | MUIFA | Nov. 2004 | 59                                                          | 46                                                          |
| 15  | VICENTE | Sep. 2005 | 21                                                          | 18                                                          |
| 16  | HAGIBIS | Nov. 2007 | 44                                                          | 44                                                          |
| 17  | NEOGURI | Apr. 2008 | 51                                                          | 36                                                          |
| 18  | ONE  | Jan. 2010 | 15                                                          | 15                                                          |
| 19  | WASHI | Dec. 2011 | 28                                                          | 26                                                          |
| 20  | BOPHA | Dec. 2012 | 72                                                          | 41                                                          |
| 21  | HAIYAN | Nov. 2013 | 87                                                          | 64                                                          |
| 22  | SINLAKU | Nov. 2014 | 28                                                          | 23                                                          |
| 23  | DAMREY | Nov. 2017 | 46                                                          | 33                                                          |
| 24  | BOLAVEN | Jan. 2018 | 15                                                          | 15                                                          |
The yearly distributions of tropical cyclone in the study area were not regular. In the period from 1884 to 1944, there was a tropical cyclone per year on average, but from 1945 to May 2018, the trend rose rapidly with approximately 2.4 tropical cyclones per year. Especially, between the years 2013 and 2017 there were 6 tropical cyclones/year. In 2008, 1998, 1993, 1983, 1962, tropical cyclone occurred 5 times each year. In some years there was not tropical cyclone impacting on Truong Sa archipelago area. To sum up, the number of tropical cyclones more than 4 times higher than that in the second storm season (March–August). November is the month with the highest occurrence of 68 tropical cyclones (31.19%), followed by December with 53 tropical cyclones (24.31%), the third highest frequency occurring in October with 33 tropical cyclones (15.14%), January and September have the number of tropical cyclones of 11 and 12 respectively, the least stormy month is July (3 storms). Thus, it can be seen that tropical cyclone occurs frequently and in the study area, the main storm season coincides with the strong Northeast monsoon season. Therefore, when tropical cyclone comes, heavy rain, high winds and high waves cause even more hindrance to economic and defense activities in the region’s waters.

The maximum yearly wind speed of tropical cyclones affecting Truong Sa archipelago area during 1987–5/2018 (table 6) shows that the maximum wind speeds of 62 m/s and 64 m/s occurred in 1995 and 2013 induced by typhoons ZACK and HAIYAN, respectively.

**Solar radiation**

Distribution features of monthly average solar radiation at Truong Sa island are shown in table 7. The data illustrate that the maximum solar radiation occurs 2 times each year, in April (277 h) and August (233 h). The minimum value is in December (132 h). This phenomenon depends on the solar trajectory in the year.

**Table 7. Monthly average solar radiation at Truong Sa island station during 2003–2015**

| Year | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. |
|------|------|------|------|------|-----|------|------|------|------|------|------|------|
| 2003 | 232  | 235  | 272  | 304  | 235 | 181  | 232  | 242  | 159  | 191  | 216  | 113  |
| 2004 | 260  | 265  | 302  | 306  | 274 | 197  | 188  | 235  | 177  | 226  | 171  | 127  |
| 2005 | 191  | 238  | 277  | 274  | 259 | 203  | 257  | 224  | 176  | 257  | 229  | 122  |
| 2006 | 129  | 259  | 292  | 273  | 267 | 159  | 78   | 238  | 145  | 226  | 139  | 133  |
| 2007 | 199  | 143  | 224  | 244  | 223 | 241  | 213  | 205  | 136  | 215  | 137  | 95   |
| 2008 | 87   | 212  | 290  | 249  | 206 | 215  | 183  | 250  | 153  | 229  | 175  | 195  |
| 2009 | 228  | 286  | 305  | 302  | 310 | 212  | 171  | 203  | 228  | 130  | 181  | 72   |
| 2010 | 121  | 203  | 170  | 255  | 239 | 202  | 230  | 251  | 192  | 236  | 177  | 79   |
| 2011 | 185  | 200  | 200  | 263  | 250 | 215  | 193  | 260  | 138  | 223  | 196  | 201  |
| 2012 | 205  | 229  | 310  | 257  | 280 | 163  | 166  | 226  | 193  | 243  | 161  | 48   |
| 2013 | 199  | 236  | 302  | 287  | 311 | 146  | 135  | 268  | 208  | 244  | 194  | 156  |
| 2014 | 136  | 258  | 311  | 304  | 321 | 214  | 250  | 198  | 197  | 237  | 201  | 239  |
| Mean | 181  | 230  | 277  | 265  | 196 | 191  | 233  | 183  | 222  | 185  | 132  |      |

**Air temperature**

Table 8 gives the information about distribution features of monthly average air temperature at Truong Sa island station. The data show that maximum air temperature occurred in May (29.3°C), minimum value in January (26.4°C).
Table 8. Monthly average air temperature at Truong Sa island station during 1987–2015

| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 1987 | 26.4| 26.4| 27.9| 29.0| 30.0| 29.2| 28.4| 28.6| 28.6| 28.9| 28.3| 27.1|
| 1988 | 26.9| 27.1| 28.4| 29.1| 29.4| 28.5| 28.1| 28.4| 28.3| 27.3| 26.9| 25.8|
| 1989 | 26.7| 25.9| 26.7| 28.7| 28.9| 28.3| 28.0| 27.8| 28.0| 27.7| 27.8| 26.4|
| 1990 | 26.6| 27.3| 28.0| 29.1| 29.3| 28.6| 28.2| 28.0| 27.6| 27.2| 26.9| 26.4|
| 1991 | 27.1| 27.0| 27.7| 28.9| 29.6| 28.7| 28.4| 28.2| 28.0| 27.7| 27.4| 27.0|
| 1992 | 26.4| 27.1| 28.0| 29.2| 29.9| 28.6| 28.4| 28.0| 28.2| 27.9| 26.7| 26.7|
| 1993 | 26.5| 26.2| 27.3| 28.5| 29.8| 29.5| 28.0| 28.2| 27.8| 27.6| 27.7| 26.9|
| 1994 | 26.3| 26.9| 27.9| 28.7| 28.7| 28.5| 27.8| 28.1| 28.1| 28.2| 27.8| 27.0|
| 1995 | 27.0| 26.7| 27.4| 28.9| 29.4| 29.0| 28.5| 28.5| 27.6| 28.4| 27.7| 26.0|
| 1996 | 25.8| 26.0| 27.5| 28.7| 28.9| 29.1| 28.4| 28.4| 28.1| 28.2| 27.7| 26.4|
| 1997 | 26.4| 26.8| 27.4| 29.2| 29.4| 29.4| 28.0| 28.6| 28.9| 28.5| 28.1| 28.3|
| 1998 | 28.4| 28.4| 28.6| 29.4| 30.3| 29.4| 29.3| 29.1| 28.6| 28.4| 27.8| 26.9|
| 1999 | 26.4| 26.8| 28.6| 29.0| 28.5| 28.2| 27.7| 28.0| 28.3| 28.3| 28.1| 26.7|
| 2000 | 26.1| 26.4| 27.3| 28.3| 29.2| 28.3| 28.3| 27.9| 28.4| 26.8| 27.8| 26.6|
| 2001 | 25.8| 27.1| 27.3| 29.1| 28.7| 27.6| 28.2| 27.1| 28.3| 27.4| 27.1| 26.1|
| 2002 | 25.8| 26.1| 27.4| 28.1| 29.1| 27.7| 26.8| 26.5| 26.6| 25.6| 25.2| 24.8|
| 2003 | 23.4| 24.6| 23.6| 26.5| 27.8| 28.6| 25.0| 28.8| 27.9| 27.5| 27.8| 26.5|
| 2004 | 26.4| 26.1| 27.2| 29.0| 28.4| 27.7| 28.1| 28.1| 28.6| 28.1| 28.0| 26.7|
| 2005 | 26.3| 27.4| 27.9| 29.2| 29.3| 28.7| 27.8| 28.5| 28.1| 28.4| 27.5| 26.4|
| 2006 | 26.1| 27.6| 28.3| 29.0| 29.0| 28.5| 28.7| 28.3| 27.9| 28.4| 28.4| 27.3|
| 2007 | 26.4| 27.2| 28.4| 29.1| 29.0| 28.8| 28.2| 28.0| 27.9| 28.2| 27.0| 26.9|
| 2008 | 26.7| 26.3| 27.2| 29.1| 28.4| 28.9| 28.2| 28.3| 27.9| 28.1| 27.6| 26.7|
| 2009 | 25.5| 24.5| 28.4| 28.2| 28.3| 28.3| 28.5| 28.8| 27.4| 28.2| 27.2| 27.4|
| 2010 | 27.3| 25.5| 28.7| 28.7| 30.8| 28.9| 28.6| 28.6| 28.9| 28.1| 28.0| 26.7|
| 2011 | 26.0| 26.4| 26.8| 27.7| 29.0| 28.7| 28.4| 28.7| 28.4| 28.5| 27.9| 26.7|
| 2012 | 26.8| 27.0| 27.8| 28.4| 29.1| 28.9| 28.1| 28.9| 27.7| 28.1| 28.5| 28.4|
| 2013 | 27.2| 27.6| 28.7| 29.6| 29.7| 29.0| 28.0| 28.4| 28.2| 28.2| 27.9| 26.7|
| 2014 | 25.8| 26.4| 27.7| 29.6| 30.4| 29.4| 28.5| 28.8| 28.7| 28.6| 28.4| 27.8|
| 2015 | 26.0| 26.8| 28.2| 29.7| 30.6| 29.6| 29.1| 28.6| 28.8| 28.9| 28.3| 28.5|
| Mean | 26.4| 26.6| 27.7| 28.8| 29.3| 28.7| 28.1| 28.3| 28.2| 28.0| 27.7| 26.8|

**Air humidity**

Distribution features of monthly average air humidity at Truong Sa island are shown in table 9. The data show that the monthly average air humidity is 83%. The maximum of monthly average air humidity was 86% occurring in October and November. The minimum of monthly average air humidity was 79% occurring in April and May. The absolute minimum value of air humidity was 54%. 

412
Table 9. Monthly average air humidity at Truong Sa island station during 1987–2015

| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 1987 | 86  | 84  | 80  | 78  | 74  | 80  | 84  | 80  | 83  | 79  | 84  | 87  |
| 1988 | 89  | 87  | 80  | 79  | 80  | 82  | 81  | 81  | 79  | 84  | 87  | 84  |
| 1989 | 85  | 82  | 83  | 77  | 80  | 80  | 81  | 84  | 81  | 83  | 84  | 85  |
| 1990 | 83  | 83  | 78  | 80  | 82  | 84  | 82  | 83  | 83  | 86  |     |     |
| 1991 | 83  | 84  | 77  | 78  | 76  | 81  | 82  | 84  | 85  | 79  | 83  | 87  |
| 1992 | 81  | 81  | 81  | 75  | 76  | 83  | 82  | 85  | 82  | 82  | 87  | 87  |
| 1993 | 81  | 83  | 80  | 78  | 74  | 76  | 85  | 85  | 85  | 79  | 86  | 87  |
| 1994 | 88  | 89  | 86  | 79  | 83  | 82  | 85  | 83  | 85  | 78  | 83  | 85  |
| 1995 | 86  | 86  | 84  | 78  | 77  | 81  | 81  | 80  | 85  | 81  | 86  | 89  |
| 1996 | 88  | 87  | 84  | 80  | 82  | 78  | 82  | 82  | 83  | 82  | 84  | 88  |
| 1997 | 83  | 87  | 80  | 75  | 80  | 77  | 84  | 83  | 80  | 81  | 84  | 81  |
| 1998 | 78  | 77  | 77  | 77  | 78  | 79  | 77  | 79  | 82  | 83  | 85  | 88  |
| 1999 | 90  | 86  | 79  | 80  | 80  | 83  | 82  | 83  | 81  | 81  | 83  | 88  |
| 2000 | 88  | 89  | 87  | 80  | 80  | 83  | 83  | 84  | 82  | 86  | 86  | 87  |
| 2001 | 88  | 85  | 86  | 79  | 79  | 82  | 83  | 85  | 82  | 83  | 85  | 86  |
| 2002 | 84  | 83  | 79  | 78  | 79  | 83  | 83  | 83  | 83  | 83  | 88  | 84  |
| 2003 | 84  | 81  | 81  | 69  | 83  | 81  | 84  | 84  | 86  | 86  | 84  | 87  |
| 2004 | 85  | 84  | 81  | 77  | 83  | 84  | 82  | 83  | 82  | 85  | 87  | 89  |
| 2005 | 83  | 82  | 72  | 79  | 82  | 83  | 86  | 83  | 85  | 83  | 88  | 91  |
| 2006 | 92  | 89  | 84  | 83  | 82  | 84  | 83  | 83  | 83  | 83  | 83  | 85  |
| 2007 | 87  | 83  | 79  | 80  | 82  | 82  | 84  | 83  | 84  | 85  | 88  |     |
| 2008 | 86  | 84  | 86  | 80  | 81  | 79  | 81  | 82  | 83  | 86  | 90  |     |
| 2009 | 88  | 85  | 83  | 83  | 86  | 83  | 84  | 84  | 85  | 84  | 86  | 85  |
| 2010 | 85  | 81  | 82  | 82  | 78  | 78  | 82  | 83  | 82  | 86  | 85  | 89  |
| 2011 | 89  | 84  | 88  | 85  | 82  | 84  | 83  | 82  | 84  | 87  | 90  |     |
| 2012 | 90  | 89  | 86  | 86  | 83  | 84  | 86  | 83  | 87  | 84  | 85  | 83  |
| 2013 | 83  | 85  | 81  | 79  | 81  | 83  | 85  | 84  | 83  | 85  | 89  |     |
| 2014 | 83  | 82  | 82  | 77  | 78  | 83  | 85  | 83  | 84  | 85  | 86  |     |
| 2015 | 86  | 83  | 80  | 80  | 76  | 80  | 82  | 84  | 82  | 81  | 85  | 83  |
| Mean | 86  | 84  | 82  | 79  | 80  | 81  | 83  | 83  | 83  | 83  | 85  | 87  |

Rainfall

Distribution features of monthly average rainfall at Truong Sa island are shown in table 10. Yearly rainfall was from 2,000 mm to 2,300 mm and the rainy duration was 170–190 days. It is relatively high value compared to other areas with similar latitude. The rainy season starts in May and finishes in December (about 8 months). During the period from October to December, the rainfall was around 250–300 mm/month. During February–March the rainfall was low at 40 mm/month and 6–7 days/month.
Water evaporation

Distribution features of monthly average water evaporation at Truong Sa island are shown in Table 11. The data show that from March to May the maximum value of water evaporation was 120 mm/month. From November to December the minimum value of water evaporation was 80 mm/month.
Table 11. Monthly average water evaporation at Truong Sa island station during 1987–2015

| Year | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. |
|------|------|------|------|------|-----|------|------|------|------|------|------|------|
| 1987 | 74   | 138  | 196  | 189  | 177 | 162  | 146  | 147  | 151  | 146  | 113  | 104  |
| 1988 | 71   | 132  | 150  | 152  | 137 | 150  | 162  | 162  | 153  | 133  | 163  | 163  |
| 1989 | 151  | 184  | 237  | 164  | 145 | 143  | 162  | 113  | 107  | 152  | 122  | 52   |
| 1990 | 160  | 100  | 241  | 201  | 214 | 163  | 156  | 158  | 132  | 126  | 138  | 130  |
| 1991 | 172  | 182  | 178  | 159  | 179 | 153  | 160  | 156  | 150  | 138  | 121  | 124  |
| 1992 | 184  | 219  | 228  | 150  | 163 | 168  | 133  | 166  | 129  | 118  | 110  | 109  |
| 1993 | 124  | 113  | 152  | 117  | 110 | 145  | 160  | 137  | 149  | 160  | 147  |      |
| 1994 | 150  | 123  | 143  | 166  | 152 | 127  | 124  | 118  | 109  | 110  | 108  | 88   |
| 1995 | 121  | 93   | 126  | 145  | 151 | 127  | 103  | 132  | 120  | 110  | 99   | 134  |
| 1996 | 104  | 111  | 128  | 122  | 123 | 129  | 142  | 138  | 137  | 105  | 102  | 84   |
| 1997 | 148  | 149  | 177  | 152  | 140 | 69   | 107  | 104  | 102  | 85   | 70   | 61   |
| 1998 | 45   | 68   | 107  | 89   | 112 | 94   | 93   | 75   | 81   | 87   | 54   |      |
| 2000 | 81   | 57   | 66   | 82   | 105 | 84   | 93   | 88   | 103  | 80   | 74   | 67   |
| 2001 | 71   | 61   | 69   | 87   | 96  | 91   | 91   | 83   | 90   | 68   | 73   | 70   |
| 2002 | 101  | 89   | 116  | 111  | 110 | 86   | 109  | 107  | 87   | 93   | 57   | 83   |
| 2003 | 92   | 107  | 111  | 149  | 90  | 91   | 84   | 91   | 85   | 71   | 76   | 113  |
| 2004 | 88   | 96   | 120  | 131  | 95  | 84   | 88   | 97   | 89   | 93   | 81   | 60   |
| 2005 | 98   | 90   | 119  | 121  | 98  | 92   | 82   | 101  | 93   | 85   | 59   | 46   |
| 2006 | 47   | 66   | 81   | 83   | 87  | 91   | 119  | 96   | 85   | 94   | 68   | 61   |
| 2007 | 58   | 70   | 94   | 92   | 79  | 69   | 79   | 90   | 81   | 69   | 72   | 66   |
| 2008 | 67   | 77   | 59   | 83   | 92  | 95   | 89   | 92   | 91   | 68   | 59   | 60   |
| 2009 | 76   | 74   | 95   | 89   | 77  | 97   | 90   | 107  | 110  | 100  | 66   | 80   |
| 2010 | 80   | 85   | 94   | 88   | 110 | 102  | 104  | 83   | 74   | 69   | 63   | 65   |
| 2011 | 55   | 68   | 51   | 64   | 83  | 76   | 85   | 79   | 73   | 72   | 56   | 44   |
| 2012 | 41   | 45   | 68   | 53   | 75  | 91   | 81   | 93   | 83   | 81   | 71   | 94   |
| 2013 | 98   | 81   | 99   | 90   | 86  | 71   | 72   | 79   | 79   | 82   | 60   | 44   |
| 2014 | 98   | 86   | 99   | 99   | 107 | 94   | 88   | 89   | 90   | 85   | 69   | 67   |
| 2015 | 73   | 97   | 119  | 106  | 110 | 102  | 102  | 92   | 98   | 91   | 68   | 97   |
| Mean | 100  | 105  | 129  | 122  | 120 | 111  | 112  | 111  | 106  | 100  | 88   | 87   |

Statistical characteristics of main station are shown in Table 12.

Table 12. Statistical characteristics of main meteorological parameters at Truong Sa island station (1987–2015)

| Parameters | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. |
|------------|------|------|------|------|-----|------|------|------|------|------|------|------|
| Mean       |      |      |      |      |     |      |      |      |      |      |      |      |

**Notes:** $T_{av}$: Average air temperature ($^\circ$C); $T_m$: Maximum air temperature ($^\circ$C); $T_{min}$: Minimum air temperature ($^\circ$C); $R$: Average rainfall (mm); $R_n$: Average rainy days; $U_{av}$: Average air humidity (%).

**CONCLUSIONS**

The main meteorological parameters in Truong Sa archipelago area are affected by solar radiation and monsoonal wind regimes in the East Asia region. The NE monsoon occurs from November to April, the SW monsoon occurs from June to September, transition periods are May and October. Tropical...
Cyclones occur mainly during November–December, the maximum wind speed was 64 m/s in typhoon HAIYAN (November 2013). The highest average solar radiation occurs in April (277 hours), the lowest in January (181 hours). The highest average air temperature occurs in April (29.5°C), the lowest in January (26.6°C). The highest average rainfall occurs in November (341 mm), the lowest in March (62 mm). The highest average air humidity occurs in November–December (85%), the lowest in April–May (79%). The highest average water evaporation occurs in March (129 mm), the lowest in December (87 mm).

In conclusion, the Truong Sa archipelago area has harmonious meteorological conditions except the effect of tropical cyclone activity.

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