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Roanu 台风中突然天气变化的自动气象站资料评估

摘要

以斯里兰卡南部 5.936 108° N、80.574 900°E 处的自动气象站(AWS)的气象时间序列观测数据为依据,对 2015 年 12 月至 2016 年 10 月大气边界层的变化进行了定量分析.结果表明,印度洋北部的季风、气温、气压、相对湿度、降水和向下短波辐射的扰动随着季风的逆转而变化.2016 年 5 月台风 Roanu 经过时,气压降低、相对湿度增大、降水增强和向下短波辐射减小,其特征是温度、相对湿度、降水和风速均迅速增加,之后气温和降水下降,而气压、向下短波辐射在急剧减小之后又急剧增大.自动气象站记录了台风到达前的气象条件,并自 2016 年 5 月 13 日起各个参数开始响应台风变化.从 2016 年 5 月 28 日开始,自动气象站记录台风通过后的气象条件,此时降水和向下辐射均减少.这些信号说明应用自动气象站可以持续观测台风条件.这项研究表明,斯里兰卡南部地区的气象数据可以用来进行天气评估,并可以对南部沿海地区的海气关系现象进行分析.此外,自动气象站的现场数据可以用作模型验证和参数化.

关键词

自动气象站;台风 Roanu;南斯里兰卡;风

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0　导读

本文原文为英文,希望感兴趣的读者进一步关注原文.

卫星数据、声学数据以及例如浮标、气象站等现场观测数据被广泛地作为模式输入数据,并用于模拟计算大气边界层过程以及用于天气预报.同时,准确、同步、连续和自洽的模拟结果对理解与空气-陆地/海气相互作用相关的气象和水文条件十分重要.由于在南印度洋缺乏观测数据,极大地影响了天气预报的准确性以及对海洋过程的认识.布设于斯里兰卡南部(5.936 108°N、80.574 900°E)的一个自动气象站(AWS),可以收集温度、湿度、风速、相对湿度、气压、降水和辐射等现场数据.

先将例如白噪声、仪器错误等异常数据人为剔除,再将 AWS 数据与欧洲中心数据进行比较.结果表明,通过 AWS 测量的气温、气压和相对湿度与欧洲中心 2 m 的气温、平均海表气压以及计算的相对湿度吻合较好.但是 AWS 测量的风速与欧洲中心数据的结果之间有较大的差别,这可能是因为欧洲中心数据为再分析数据,所有 10 m 以下的风速数据均被认为是 10 m 风速,因此引入了较多的误差.为了数据的可靠性,本文还分析了台风 Roanu 过境期间的观测数据.应用 2015 年 12 月到 2016 年 10 月 AWS 的数据进行季节分析,可以分辨出台风 Roanu,观测数据显示在台风过境时,温度、相对湿度、降水和风速快速增加,之后温度和降水下降但压力、向下短波辐射急剧下降之后急剧上升.对台风前后 AWS 的数据进行分析,在 AWS 数据的时空演化图中可以分辨出在 2016 年 5 月 13 日存在产生风暴的大气条件,到 5 月 18 日又发展为可以产生热带气旋的大气条件,并且根据 AWS 的观测,产生风暴的大气条件在 17 日后穿过了斯里兰卡南部地区.热带气旋通过时,AWS 记录了非常明显的大气参数扰动,观测到的向下短波辐射的减小并伴随降水过程显示了 AWS 对极端天气条件观测的可适用性.AWS 的现场观测数据完全可以分辨出极端天气过程.

本文验证了斯里兰卡南部区域布设的自动天气站数据的可靠性,并探讨了此数据对极端天气过程观测的准确性.这项研究表明,AWS 的观测数据可以用来进行天气预报,并可以用于分析斯里兰卡南部沿海地区海-气相互作用的过程.此外,AWS 的观测数据完全可以用作数值模拟的初始场数据并用于改进模式参数化过程.

Quality assessment of Automated Weather Station (AWS) data for abrupt weather changing during cyclone Roanu

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Abstract Meteorological time-series observations from the Automated Weather Station (AWS) located at 5.936 108°N,80.574 900°E south of Sri Lanka were used to quantify the variability in boundary layer from Dec 2015 to Oct 2016.The observations show the fluctuation of wind,temperature,pressure,relative humidity,precipitation,and downward shortwave radiation,accompanied by monsoon reversing over the northern Indian Ocean during this period of time.The episodic event has been noted by the low air pressure,high relative humidity,high precipitation and reduction of downward radiation during the passage of cyclone Roanu in May 2016.The event is characterized by the rapid increase in temperature,relative humidity,precipitation and wind speed followed by the decline of temperature and precipitation,and the abrupt decrease then dramatic increase in pressure and downward shortwave radiation.The reason behind these fluctuations is investigated using the dataset from AWS during May 2016.The analysis shows that AWS recorded pre-cyclone conditions which start to respond since 13th May,2016.The AWS also recorded post-cyclone conditions which are illustrated by reduction of downward radiation and precipitations after 28th May,2016.These signals are evident for the sustainability of AWS to the cyclone conditions.This study suggests that AWS dataset can be used for weather assessment in southern Sri Lanka region and analysis of air-sea relation phenomena in the southern coastal region.Furthermore,AWS can be used as in situ data source for model validation and parameterization.

Key words automated weather station;cyclone Roanu;Southern Sri Lanka;wind

1 Introduction

Satellite data, sounding data, in situ station data such as buoy, weather station have been broadly used for model simulation[1-3].The station data which can be used to calculate land-atmosphere boundary layer processes and weather forecasting are needed to be pooled through data assimilation.These in situ data can be used to improve the weather forecast and model validation with highly reliable output. The lack of in situ data at the southern Indian Ocean affects the weather forecasting and understanding of the ocean processes. An Automated Weather Station (AWS) was established in southern Sri Lanka in March 2015 and has been maintained under the guidance of the South China Sea Institute of Oceanology (Fig.1).The weather station in this area can be of considerable support for gathering data in the boundary layer in southern Sri Lanka.Temperature,wind velocity,relative humidity,air pressure, precipitation, and radiation are the parameters which have been measured by this AWS.Accurate,simultaneous,continuous,and self-consistent time series of these parameters are critical for understanding meteorological and hydrological conditions related to air-land/air-sea interactions. In addition, Sri Lanka is located at a critical region between the Bay of Bengal and the Arabian Sea with seasonal reversal of surface and upper atmospheric wind[4-6].

Monsoon wind blowing away from Asian continent generates north-easterlies over the Bay of Bengal (BoB) and the Arabian Sea (AS) during winter,while it blowing toward Asian continent will generate southwesterlies during summer.The wind variation over the northern Indian Ocean has a unique feature[4-7]. The ocean circulation and climate over the Indian peninsula are directly impacted by the seasonal reversing monsoon. Southwest (May to September) and north-east (November-February) monsoon are the major monsoon seasons with two transition periods in between, namely pre-summer and post-summer[5]. Tropical cyclone is one impressive phenomenon occurred in this region, which has robust nature with harmful capability to mankind.

Tropical cyclones are introduced as intense and stable vortices which have lifetimes of two weeks or more[8] and usually develop in the northern Indian Ocean from 55°E to 90°E and 5°N to 20°N[9]. There are two cyclone seasons in the northern hemisphere during the two inter-monsoon seasons, pre-monsoon (May) and post-monsoon (October-November) with some being in June and September during the transitional period[10]. According to Singh et al.[11], May and November are known as cyclonic periods over the BoB and AS. Furthermore, they mentioned that the cyclone appearance over the BoB is four times higher than that over the AS. The cyclones undergo major changes in structure during their lifetimes. These changes cause variations in the distribution and intensity of wind and rain[8]. In detail, the wind speed increases between 18 and 33 m/s[11]. The sea surface temperature normally reaches or exceeds 27 ℃, the humidity (moisture content of air) increases, and the wind drifts in different directions that favors the rise of warm air and cloud formation. The multi-directional winds make difficulties to observe considerable wind difference with the higher area (known as low wind shear which facilitates clouds rising vertically). The aforementioned conditions should be fulfilled for cyclone formation in the tropics.

The parameters measured by AWS can be used to investigate the cyclone condition. To evaluate the ability of different measurement/observation systems under robust cyclone wind condition, we have carried out a case study for the Roanu cyclone (May 2016) which is originated from a low pressure area that formed south of Sri Lanka (according to IMD[12]). The parameter comparison with the ERA-Interim data was used for parameterization of AWS. Furthermore, mean state evaluation has been carried out to investigate the capability of AWS to capture the seasonal variations. The hypothesis built was, "how much accurate data can be generated by the AWS and how far can we use the AWS dataset for weather/climate assessment?" Additionally, the importance of AWS has been explored for model validation. In order to test our hypothesis, the description of data and methodology was carried out in section 2 and the comparative results and discussion have been presented in section 3. The concluding remarks have been highlighted in section 4.

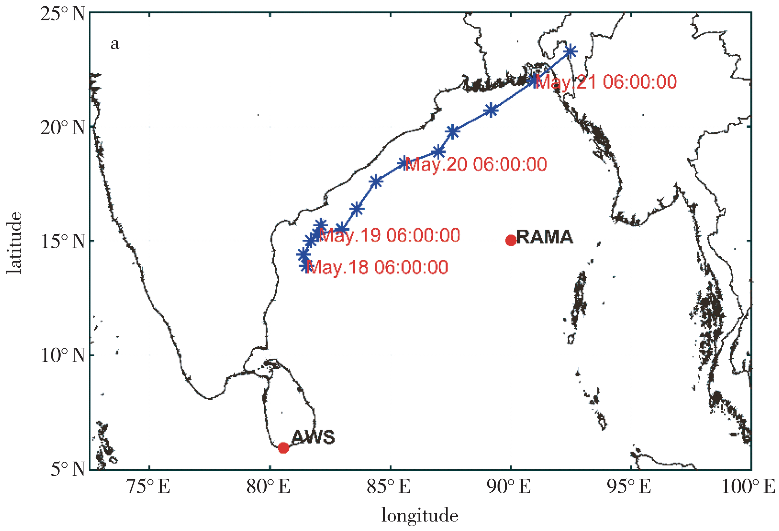

Fig. 1 (a) Location of the Automatic Weather Station (AWS) at (5.936 108°N, 80.574 900°E) and the track of cyclone Roanu from 18th to 21st May, 2016 (displayed by blue line), (b) the AWS

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2 Data and Methodology

2.1 ERA-Interim

ERA-Interim is a global atmosphere data assimilation system which is based on an Integrated Forecast System (IFS), extending back to 1979 and forward until the end of 2018[13]. The four-dimensional variation analysis included in the system has a 12-hour analysis window. The special resolution is approximately 80km with 60 vertical levels from the surface up to 0.1 hPa. This provides high resolution (0.125° × 0.125°) meteorological and hydrological data from 1979 to present, and is updated every month with a delay of two months. ERA-40 is the second generation atmospheric model and assimilation system. Due to some failures of ERA-40 in performing the high magnitude of precipitation over oceans from the early 1990s onwards and high magnitude of Brewer-Dobson circulation in the stratosphere, the ERA-Interim has been introduced as the third generation atmospheric and hydrological reanalysis data assimilation system, which could successfully eliminate or reduce the aforementioned failures in system ERA-40. The ERA-Interim has been strengthened with the completed high spatial and temporal resolution reanalysis data set of multiple variables with improved low-frequency variability and stratospheric circulation. However, there are several limitations including high intensity on water cycling such as precipitation and evaporation over the oceans and positive biases in temperature and humidity below 850 hPa compared to radiosondes in the Arctic region with less capability of capturing low-level inversions.

Accessible at: http://apps.ecmwf.int/datasets/data/interim-full-daily/levtype=sfc/.

2.2 Automated Weather Station (AWS)

The AWS is located at 5.936 108°N, 80.574 900°E south of Sri Lanka (Fig.1) and operationally conducted every minute of every day[14]. Temperature, wind velocity, relative humidity, air pressure, precipitation, and radiation are the factors which have been measured by AWS. To increase the reliability of the system, many of the crucial parameters are measured redundantly with duplicate sensors or sensors of different principle. Sensors are located at around 1.5–2.5 m above the ground level. Air temperature, relative humidity, and wind have been measured by two sensors which have been compared with each other to recognize the better sensor for the considered parameter (sensor comparison is not discussed here). Further analysis was carried out for the output obtained from selected sensors.

2.3 Methodology

Quality controlling process was necessary to maintain AWS data quality of all elements. Artifacts (considering the sensors specifications, upper and lower limits) which are recorded due to the noise, instrumental errors, etc. have been removed using quality control methods, and furthermore the days which have less than 60% recorded data (daily record is 1 440) have also been removed from the analyzing. The daily averaged dataset has been used for this study.

To answer the research questions, an exploratory comparison analysis, using linear regression statistics was performed for selected AWS dataset with ERA-Interim. If data are well correlated, the Root Mean Square Error (RMSE) and the Correlation Coefficient (CC), should be near to 0 and 1 respectively.

For the analysis, ERA-Interim data has been interpolated to AWS location to remove the distance barrier. All calculations were carried out for interpolated ERA-Interim data set and quality controlled AWS data. The measured parameters at different heights would be different from each other, even under identical atmospheric conditions. Comparing ERA-Interim wind (10 m) directly with the AWS-measured wind (2 m) could have therefore led to significant errors. For the comparison, the AWS-measured wind was transformed to a height of 10 m using the simple logarithmic profile approach. Lin and Wang[15] used a method to transform winds to a different height:

$$v(h_0) = v(h_i) \times (h_0/h_i)^{\alpha_i}. \quad (1)$$

Where h_0 and h_i are heights, $v(h_i)$ is the available wind speed at the height h_i, $v(h_0)$ is the unknown wind speed at the height h_0, and α_i is the wind shear coefficient which is equal to 1/7 associated with the heights h_0 and h_i (Lin and Wang[15]).

The relative humidity has been calculated using the below equation considering temperature and dew point for ERA-Interim (relative humidity for AWS is directly recorded):

$$H_R = 100 \frac{e^{\left(\frac{aT_d}{b+T_d}\right)}}{e^{\left(\frac{aT}{b+T}\right)}}. \quad (2)$$

Where a is 17.625 and b is 243.04 which are the constants of temperature T (℃), T_d is the dew point (℃), and H_R is the relative humidity in %. Based on the August-Roche-Magnus approximation, it is considered valid for: 0 ℃ $<T<$ 60 ℃, 1 % $<H_R<$ 100%, and 0 ℃ $<T_d<$ 50 ℃ (Alduchov and Eskridge[16]).

3 Result and discussion

3.1 Mean state comparison between AWS and ERA-Interim

It is essential to compare the satellite and model analysis with observations and in situ data. In this section, we report the detailed comparison of ERA-Interim data with the AWS data. The comparison of ERA-Interim with in situ measurements from AWS data is shown in Figure 2. ERA-Interim has given sea surface temperature (SST) and 2 m air temperature (T_{2m}) and is being compared with AWS temperature to figure out the best companion either T_{2m} or SST of ERA-Interim. The scatter diagram and graph show the comparison of temperature at 2 m elevation of ERA-Interim with AWS temperature (Fig. 2a). The 2 m elevation temperature shows good correlation with Root Mean Square Error (RMSE) and Correlation Coefficient (CC) being 0.746 44 ℃ and 0.856 04 respectively.

Similar to temperature, ERA-Interim has two pressure levels as surface pressure and mean sea level pressure. The mean sea level pressure of ERA-Interim shows high correlation with 0.990 53 (CC) and 25.460 43 Pa (RMSE). Thus the air pressure of AWS is similar to the mean sea level pressures (Fig. 2b). The calculated ERA-Interim relative humidity has a small deviation from the AWS measured relative humidity with CC and RMSE equal to 0.737 04 and 9.630 61% respectively (Fig. 2c).

Space-based data collecting systems such as satellite or reanalysis data system consider the ground level/ lowest elevation level as 10 m. Thus, all analysis output below the 10 m height is considered as a similar result as at 10 m level. However, the noise, buildings, trees or any other obstacles cause the effects on the at-

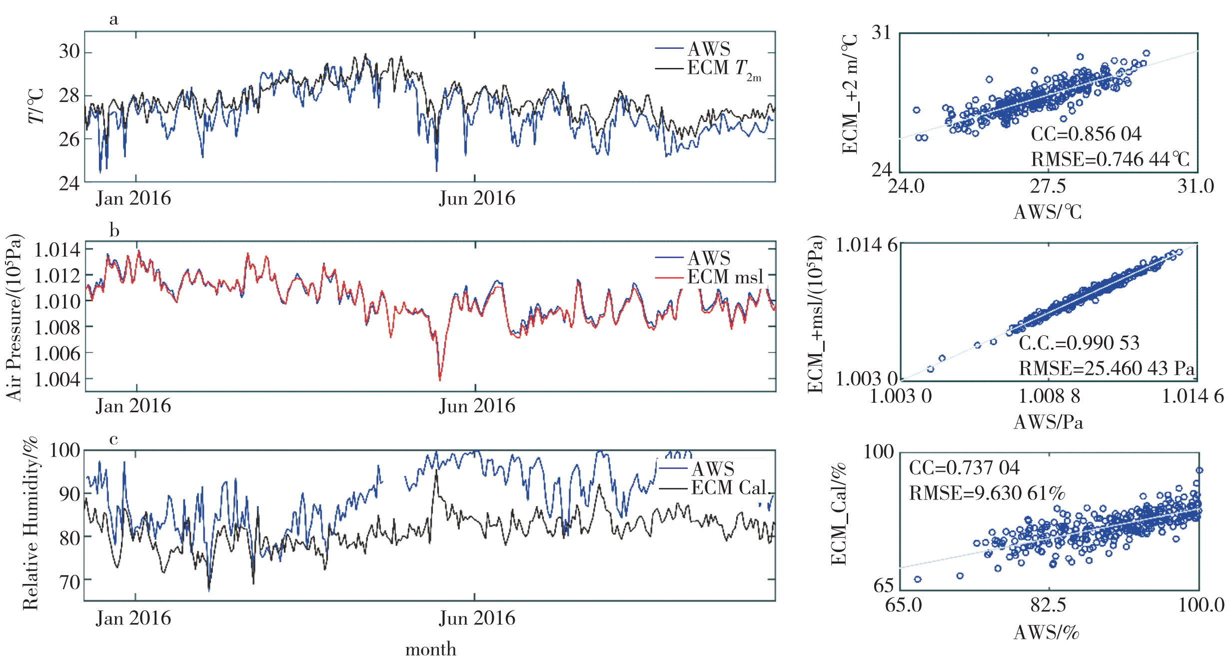

Fig. 2 Time series and scatter diagram of (a) air temperature (℃) at 2 m elevation, (b) air pressure (Pa) (mean sea level pressure of ERA-Interim) and (c) relative humidity (%), measured by AWS and calculated by ERA-Interim from 9th December, 2015 to 14th October, 2016

mospheric and hydrological parameters within this level. According to Satheesan et al.[1], Pensieri et al.[2], Pickett et al.[17] and Parekh et al.[18], the wind data shows considerable errors in comparison between space-based data and buoy data. Furthermore, they have reasoned the moisture content around buoy landed in the ocean. The buoy also gives around the 2-3 m height wind data. The wind comparison between AWS and ERA-interim also didn't show considerably enough correlation.

ERA-Interim is a long-term dataset which is used to study the impact of over ocean/land. However, the limitations of reanalysis data can be overcome using the observational data. The accuracy of reanalysis data can be assured by the comparison of ERA-Interim data with observational data. The considerable errors in wind data could be caused by nearshore geometry or the spatial resolution of ERA-Interim model for selected AWS region.

3.2 Seasonal variation of AWS data

Temperature, precipitation, wind speed, relative humidity, pressure, and radiation have been examined to show the seasonal variation of AWS data. The seasonally reversing winds force two distinct monsoon seasons in the Northern Indian Ocean[4-5,7]. The South-West Monsoon (SWM) winds are much stronger than during the North-East Monsoon (NEM)[5]. The Figure 3f has shown the high wind speed during May to September which is the SWM period in Sri Lanka. Relative humidity is lower during the NEM than SWM, which usually shows a high peak during September-November due to the peak of precipitation and the high wind speed. According to the AWS data, the peak of relative humidity is shown during May and September, which is gradually increasing from March to May and reaches its maximum level during May (Fig. 3c). The increasing humidity is related to the high precipitation during this period of time (Fig.3d). Fluctuation of downward radiation shows its clear relation with precipitation (Fig. 3b), and the temperature has increased gradually since December 2015 and reached the maximum during April then starts to drop and gives lowest point during September (Fig.3a). The increasing air temperature is one

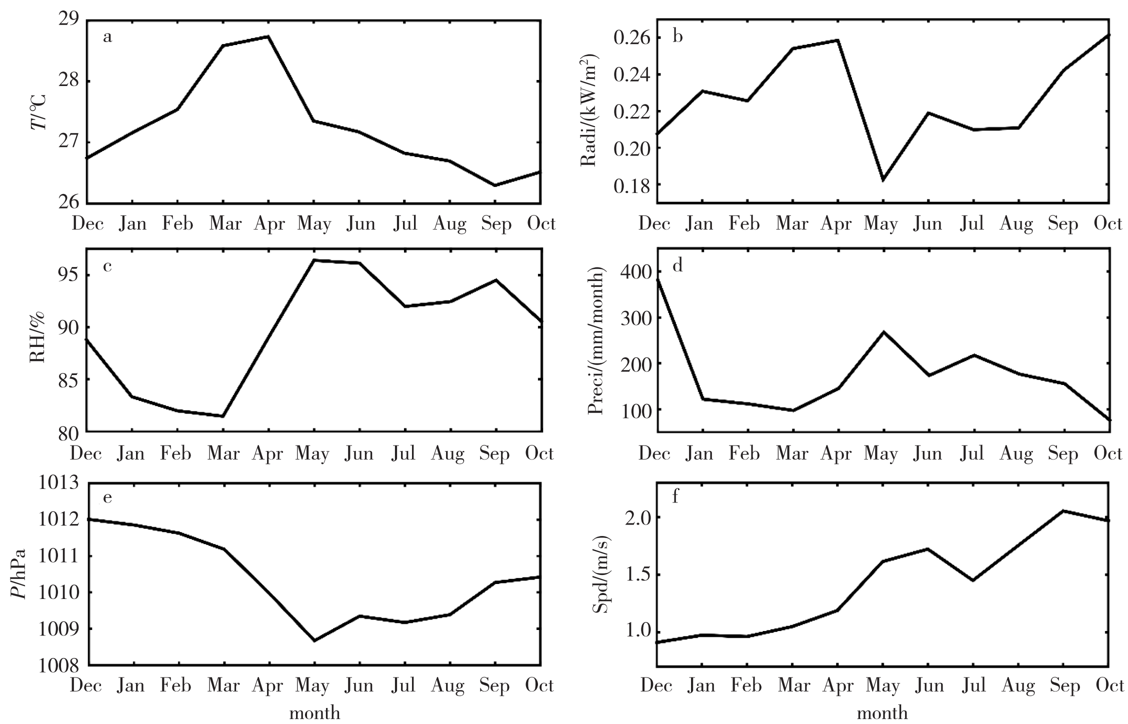

Fig. 3 The seasonal variation of (a) temperature (℃), (b) downward radiation (kW/m^2), (c) relative humidity (%), (d) precipitation (mm/month), (e) pressure (hPa) and (f) wind speed (m/s) from December 2015 to October 2016 from AWS at about 2 m elevation

factor which determines the storing water vapor content in the air. At the peak of air temperature, sudden increase of relative humidity is observed (Figs.3a,3c). During the transition period from NEM to SWM, the air pressure decreases around the southeast Arabian Sea[19]. This pressure drop shows the lowest point during May (Fig.3e). The high air temperature and high wind speed facilitate storing more water vapor which leads to the sudden drop in air pressure. The aforementioned mechanism has clearly been illustrated by Figure 3. As a summary of Figure 3, the low pressure, high wind speed, high precipitation, low downward radiation and peak of relative humidity indicate the special phenomena such as cyclone of northern Indian Ocean, e.g. cyclone Roanu has passed through the Bay of Bengal during May 2016[12]. This one year example is strong enough to explain the value of AWS for reanalysis data validation, for study about seasonal variation and special climatic events like a cyclone. For further explanation, the cyclone Roanu has been investigated using AWS data during May 2016.

3.3 Cyclone Roanu case study

Cyclone Roanu was the first tropical cyclone of annual cyclone cycle in 2016 (See Fig.1 for track). Cyclone Roanu originated at south of Sri Lanka following the low-pressure area and gradually drifted northward with intensifying cyclone storm by 19th May of 2016. The low-pressure area had been generated over the Bay of Bengal on 14th May and consolidated around the east coast of Sri Lanka. The storm reached to cyclone level on 19th May, 2016 with a maximum wind speed of 110 km/h and lowest pressure of 983 hPa[12]. Figure 4 has illustrated the wind vector overlaid over pressure from ERA-Interim reanalysis data to explore the stormed condition in Sri Lanka region.

Temporal evolution of atmospheric variables obtained from AWS data has been used to examine the onset of the cyclone at southern Sri Lanka and shown in Figure 5. During pre-cyclone period of Roanu (1st to 10th May), the tropical pre-monsoon conditions were prevailing at AWS. Average sea level pressure was around 1009 hPa with moderate north-easterly winds speed in the range of less than 1.5 m/s. Rainfall has recorded the AWS maximum of 14 mm/d to 0mm/day and the air temperature was between 26 ℃ to 28 ℃. Average relative humidity during this time period was in the range of 90%−96% and the downward radiation was between 0.025−0.27 kW/m^2.

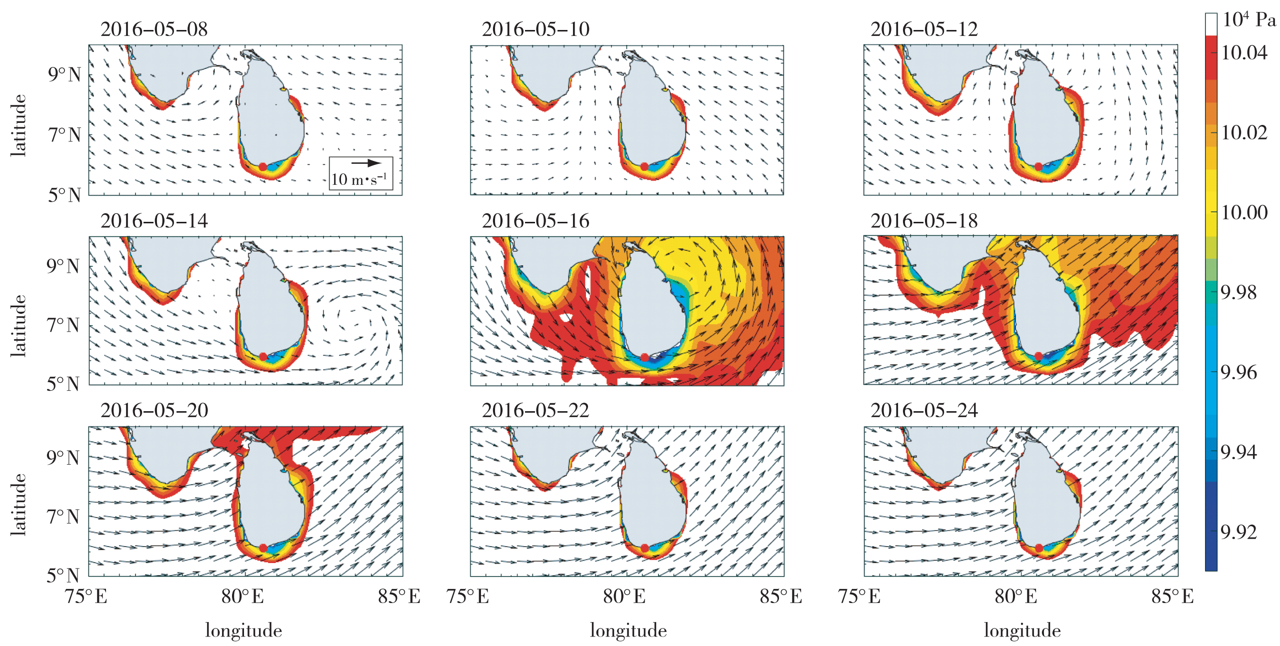

Fig. 4 Wind vector overlaid by the ERA-Interim surface pressure (in 10^4 Pa) from 5th to 29th May, 2016 (red dot indicates the location of AWS, vector scale is 10 m/s)

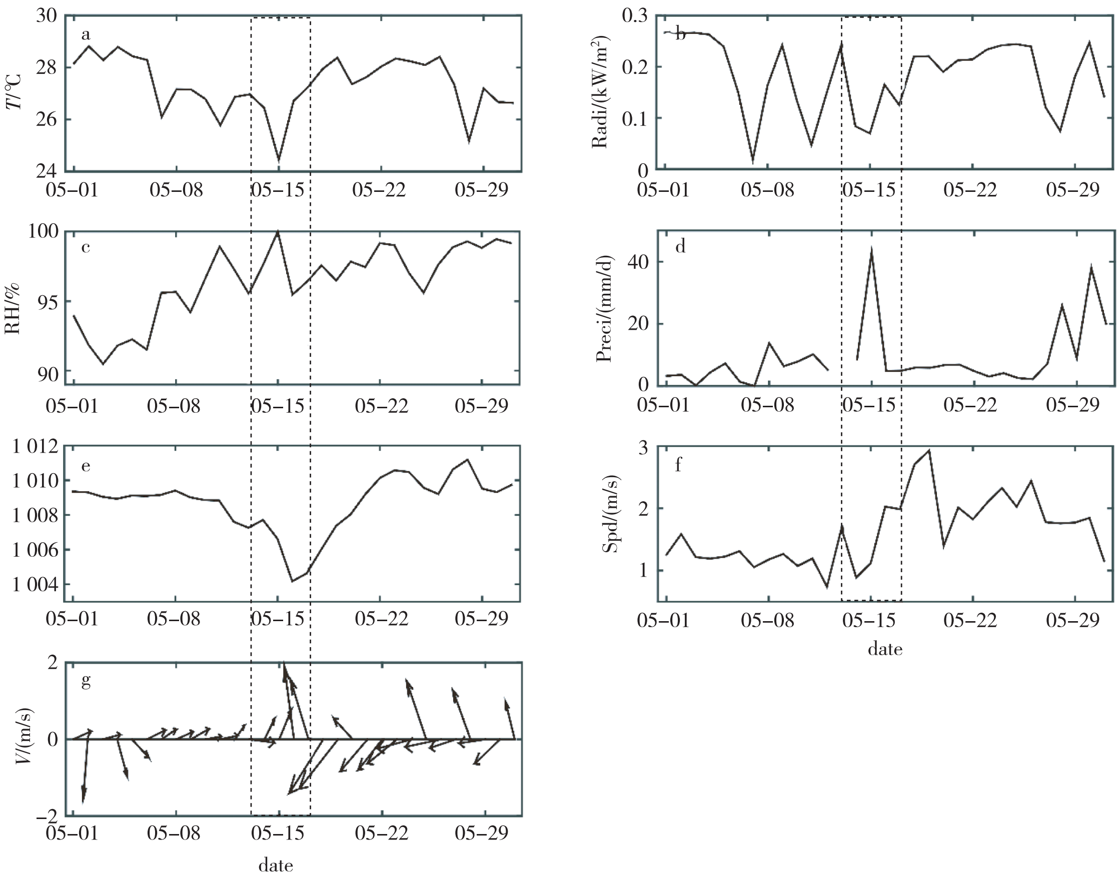

Fig. 5 Temporal evaluation of (a) temperature (℃),(b) downward radiation (kW/m^2), (c) relative humidity (%),(d) precipitation (mm/d),(e) pressure (hPa),(f) wind speed (m/s and (g) wind vector (m/s) measured by AWS from 1st to 31st May at about 2 m elevation

When cyclone approached, the AWS air pressure started to drop from 1 009 hPa to 1 004 hPa from 11th May to 16th May and the wind direction changed from northeast to southeast (due to cyclone circulation of wind). During the cyclone period, the maximum AWS wind speed reaches 3 m/s on 19th May (Fig.5f). The drifting wind to different direction is the considerable factor which can be observed during the cyclone period. This is clearly shown in this cyclone activated period (Fig. 5g). AWS recorded the highest precipitation (50mm/day) on 15th May with lowest air temperature of 24.5 ℃. With the cyclone onset, the intense cloud cover which reflects the incoming shortwave radiation was indicated by the reduced AWS downward radiation from 0.25 kW/m^2 to 0.075 kW/m^2 (Fig. 5b). High wind speed increased the evaporation which reasoned the increase of moisture content in the atmosphere and resulted in relative humidity approximating to 99.98% and almost nearest to saturation. Intense rainfall resulted in a sharp decrease in the air temperature (3 ℃) and the recorded minimum temperature was 24.5 ℃. The SST (Fig.6) and air temperature (Fig.5a) shows relatively large differences.

The effect of Roanu started to disappear from the southern Sri Lanka region after 17th May and conditions started to become normal. A notable difference is that the relative humidity increased to 96%-99% as compared with pre-cyclone period of 90%-96% (Fig.5c). AWS data show two rainfall events after cyclone during 28th May and 31st May (Fig.5d). Signal of these two events are evident in the AWS measurements, with reduction in magnitude of downward radiation due to cloudy conditions. Here cyclone conditions are referred with respect to the surface winds, thus it is appropriate to consider SST variation. SST would increase with the high solar radiation which facilitates evaporation to gen-

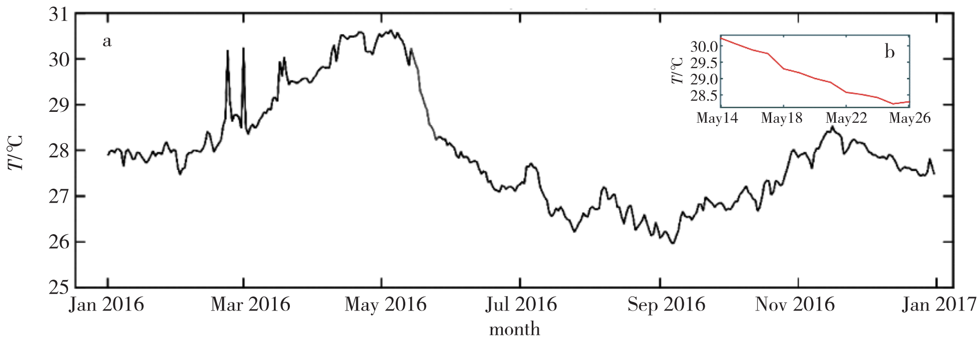

Fig. 6 Time series of sea surface temperature (℃) measured by ERA-Interim (a) from 1st Jan to 31st Dec, 2016, and (b) from 14th to 26th May, 2016, the red line indicates the period of cyclone Roanu

erate the cyclone condition over the region then would decrease with the onset of cyclone. According to Figure 6, the SST has started to increase in March and reached its maximum in May, then starts to gradually decrease and the ocean surface becomes cooler. The low pressure area has formed in southern Sri Lanka during 16th May as impact of Roanu and AWS shows the variation of atmospheric parameters at southern Sri Lanka during the cyclone period.

4 Summary and conclusions

The position of Sri Lanka is unique as the region which faces the special climatic phenomenon and monsoon reversing. For the understanding of these climatic/weather events and the monsoon patterns of northern Indian Ocean, it is important to have reliable data source. For the purpose of this, the AWS was established near to southern coast of Sri Lanka and continues gathering data up to now. The air temperature, pressure, wind, relative humidity, precipitation and downward radiation are the parameters which have been collected by AWS daily. Several comparisons with different data sources were carried out to explore the quality of AWS data. The AWS data comparison with ERA-Interim was discussed here and has shown good correlation. This comparison revealed that the AWS air pressure can be used as the mean sea level pressure. This is clear enough to prove the AWS as a reliable in situ data source for model validation and parameterization. The one-year data were examined to understand the annual seasonal variation during 2016. According to the results, AWS can detect the seasonal variation of the northern Indian Ocean monsoon reversing and special weather changing events such as cyclone. The cyclone Roanu has passed through Bay of Bengal during May of 2016 and the low pressure area which favored Roanu was originated south of Sri Lanka. The AWS could capture the pressure drop since 13th May and the atmospheric elements changes before and during the cyclone passage. Thus, the temporal evaluation of cyclone Roanu has been explored using the AWS data. The pre-cyclonic period, cyclonic period and post-cyclonic period were clearly evident from the fluctuations of atmospheric parameters. The unusual increase of air temperature since February and reaching its maximum in April are indicated in seasonal cycle. The sudden drop of air pressure on 16th of May shows the capability of AWS to capture the abnormal atmospheric behavior before it turns to bad weather condition. According to the satellite observations, the low pressure area was observed at south of Sri Lanka during 14th of May[12]. However, AWS started to respond on 13th May and could capture this stormed conditions before it turns to cyclone on 18th of May. Thus, this real-time automated system can be used to capture the abrupt weather changes. Furthermore, it reveals its capability to be an in situ data source for model parameterization and validation and for the seasonal event evaluation.

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