Impacts of the total solar eclipse of 9 March 2016 on meteorological parameters in Ternate

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Abstract. The total solar eclipse on 9th March 2016 has given a unique opportunity to assess impacts of the eclipse on various meteorological parameters in Ternate. A weather transmitter, a net radiometer, and a heat flux plate for measuring soil heat flux in bare soil were deployed during this special observation in Madaha, Ternate (0°51'17.5" N, 127°20'56.8" E). The measured meteorological parameters presented here are net radiation, air temperature, relative humidity, and soil heat flux. The results show that those parameters are significantly affected by the eclipse. The percentage of the observed decrease of net radiation during the eclipse was proportional to the obscuration percentage. The air temperature measured at 1.5 m declined around 1.9 °C with approximately 11 minutes lag between the mid-eclipse and minimum temperature during eclipse. Influences from the surrounding environment in the measurement site minimize the temperature response. As a consequence of temperature decrease, relative humidity increased. A drop in soil heat flux was also detected but its response was slower.

1. Introduction
Although eclipses are astronomical phenomena, they also draw considerable interest from atmospheric scientists because solar radiation is the main source of energy to the atmosphere. Solar eclipses provide a natural ‘laboratory’ for studying the Earth’s environment response to the abrupt change in radiation. The total solar eclipse event on 9th March 2016 started over the Indian Ocean, passed across the Indonesian region (Sumatra, Kalimantan, Sulawesi, North Maluku), and then ended near the Hawaiian islands. The greatest eclipse, the instance when the axis of the Moon's shadow cone passes closest to Earth's center, occurred over the Pacific Ocean. The variability of surface radiation during solar eclipses has been extensively studied [e.g. 1, 2, 3, 4, 5, and 6]. The results showed that all the radiation fluxes were significantly affected by eclipses. Zerefos et al. [2] and Kazadzis et al. [4] show that radiation decrease depends on its wavelength, which is more pronounced at the lower wavelength. There are a number of reports on impact of eclipse on meteorological parameters, such as air temperature, humidity, atmospheric pressure, and wind speed and direction [e.g. 1, 3, 6, 7, 8, 9, and literatures therein]. The range of temperature decrease during an eclipse varies from one location to the other. The existence of eclipse wind is debatable since for the same eclipse event, one location showed significant abrupt change in wind speed and direction, whereas others did not [9,10,11]. The fluctuation of relative humidity was largely reported as consequence of the temperature decrease.
Our measurements of meteorological parameters were carried out in Ternate (figure 1) before, during, and after the eclipse day. Ternate is one of the islands in the North Maluku region and lies in the vicinity to totality path of the total solar eclipse of 9th March 2016 and experienced 100% obscuration. This measurement was aimed to investigate how the abrupt change in radiation, when the Moon covered the face of the Sun, affects net radiation, air temperature, relative humidity, and soil heat flux (SHF).

Figure 1. The 9th March 2016 total solar eclipse path over the North Maluku region. Regions inside the red curves experienced the total solar eclipse while those outside the curve had partial solar eclipse. The blue line indicates the central line. Red square shows the location of our measurement site.

2. Measurement: site, weather condition, and instrumentation
Our measurement site was located in the north-east part of Ternate Island. The eclipse at this location started at 08:36:05 LT, with mid-eclipse at 09:53:00 LT, and ended at 11:20:51 LT (the eclipse lasted for 2h 44m 46s and the duration of totality was 2m 21s). The Local Time is UT+9h. The instruments were installed in Madaha, Ternate (0°51’17.5” N, 127°20’56.8” E). The land where the instruments deployed has sandy soil and only small parts of it were covered with short grass.

A weather transmitter was used to monitor six essential weather parameters. This instrument consists of ultrasound sensor to measure wind speed and direction; separate capacitive sensors for barometric pressure, temperature, and relative humidity measurement; and precipitation sensor. Net radiation measurement was carried out using a net radiometer with thermopile sensor. The weather transmitter and the net radiometer were mounted 1.5 m above the ground surface on horizontal pole protruding around 50 cm and 100 cm respectively from the mast. The heat flux plate for soil heat flux measurement was submerged around 5 cm from the soil surface. Only measurement for the bare soil will be reported in this paper. All data were recorded every 20 seconds and its acquisition is acquired by connecting the instruments to a data logger. The measurements were conducted from 7-10 March 2016. Unfortunately, due to a technical problem on 8 March 2016, the data logger could not record the measurements on that day until early morning on the following day. The sky was partially cloudy for most of the days of the observation, but during the eclipse the sky around the sun was clear.

3. Results and discussion
The observed temporal variation of net radiation during 7-10 March 2016 is shown in figure 2a. On non-eclipse days, the net radiation started to increase in the morning, reached its peak around mid-day and decreased afterwards. During the night, as outgoing radiation leaving the Earth’s surface is larger than the incoming radiation, the value of net radiation is negative. Frequent sudden drop in net radiation pattern were due to varying cloud coverage. It can be noticed clearly in figure 2a that during the eclipse net radiation decreased. Moreover, near mid-eclipse the value of net radiation is negative, which resembled night time condition. Thus the decrease of net radiation during the eclipse time was virtually caused by the eclipse, instead of cloud coverage. During the eclipse, the net radiation dropped from 341.87 Wm⁻² to -40.21 Wm⁻². The net radiation reached its minimum shortly after the mid-eclipse.
Net radiation directly determines whether the surface temperature rises, falls, or remains the same. As the consequence, temperature pattern during the eclipse followed the net radiation pattern (figure 2b and 2d). A significant drop in from normal diurnal pattern for air temperature during the solar eclipse of 9th March 2016 is clearly seen. The temperature started to decrease from 30.2 °C at the beginning of the eclipse and reached its lowest temperature at 28.3 °C. This ~2 °C decrease is within the range already reported on other solar eclipse events [e.g. 8, 9, 10, 12, and 13]. However this decrease is lower than the temperature drop reported by Fernandez et al. [7] although both eclipses were total solar eclipses and occurred at similar time of day. Probably this is caused by the fact that the measurement site is located in an island surrounded by sea, which affected the temperature response (decrease) due to its larger heat capacity [10]. Figure 2d illustrates a comparison between net radiation and temperature during the eclipse. There was approximately 11 minutes lag between the net radiation and temperature minima during totality. The actual time lag is related to the thermal inertia of the surface layer [3].

The diurnal variation of relative humidity has opposite phase to that of temperature [14] during normal conditions as a consequence of temperature decrease during the eclipse, the relative humidity delayed its decrease until the temperature has reach its minima following the increase of net radiation
after totality (figure 2c and 2e). Following the temperature, shortly after the eclipse began, usual decrease in relative humidity at that time of day was halted and started to increase. Relative humidity increased from 66.7% and reached its maximum at 73.5%. The maximum relative humidity was lagging to mid-eclipse by 12 minutes, which is comparable to time lag between mid-eclipse and minimum temperature. The relative humidity resumed its normal decrease afterwards. The increase in relative humidity did not surpass the highest relative humidity at nighttime as the temperature remained above the nighttime lowest temperature. The latter indicates that the sudden darkening during short eclipse events does not result in cooling at the same magnitude as during sunset and night [15].

SHF is affected by the surface temperature, soil moisture, and vegetation [5]. Because the temperature significantly decreased during the eclipse, it is expected that SHF will respond to this decrease proportionally. Figure 2f shows that the SHF obviously decreased in response to the eclipse but in slower response. The SHF took around 23 minutes to decrease from 2.351 Wm$^{-2}$ after the eclipse started and the decrease persisted around 26 minutes after mid-eclipse until reaching a minimum value at -0.503 Wm$^{-2}$. A condition similar to night time during the eclipse is clearly seen in the SHF pattern, where the sign of the SHF values are negative.

4. Concluding remarks
Measurements of impact of the total solar eclipse of 9 March 2016 on net radiation, temperature, relative humidity, and soil heat flux showed that those parameters were significantly affected by the eclipse. The air temperature at 1.5 m declined 1.9 °C with around 11 minutes lag between the mid-eclipse and minimum temperature during eclipse. The percentage of the observed drop of net radiation during the eclipse was proportional to the obscuration percentage. The drop in temperature induced by the eclipse was initially expected to be even greater than the result of the measurements, since the eclipse occurred at late morning when temperature increases in normal days [10,13]. However the surrounding environment in the measurement site (particularly the sea) might affect in reducing the temperature response due to its larger heat capacity. Relative humidity increased from 66.7% and reached its maximum at 73.5% during the eclipse. The maximum relative humidity was lagging to mid-eclipse by 12 minutes. A drop in soil heat flux (SHF) was also detected although its response was much slower than other parameters.

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