Aceh Int. J. Sci. Technol., 2 (3): 77-81
December 2013
doi: 10.13170/AIJST.0203.01

Aceh International Journal of Science and Technology

ISSN: 2088-9860

Contribution of Heat Fluxes on Cyclone Narelle as Simulated by a Mesoscale Model

[1*]Yopi Ilhamsyah, [2]Frinsa Lindiasfika, [2]Ahmad Bey, [1]Ichsan Setiawan, [3]Rizwan, and [3]Junaidi M. Affan
[1]Department of Marine Sciences, Syiah Kuala University, Banda Aceh; [2]Department of Geophysics and Meteorology, Bogor Agricultural University, Bogor; [3]Department of Capture Fisheries, Syiah Kuala University, Banda Aceh.
*Corresponding email: y.ilhamsyah@gmail.com

Received : November 22, 2013
Accepted : December 16, 2013

Abstract - Heat fluxes from oceanic evaporation particularly latent heat is important to drive the formation and intensification of Cyclone Narelle. The research was carried out by introducing a mesoscale model, namely Weather and Research Forecasting (WRF). One domain with spatial resolution at 10 km was utilized in the model. The model involved significant physical parameters, e.g., Kain-Fritsch in the cumulus scheme, Yonsei University in the Planetary Boundary Layer scheme, and WRF Single-Moment 3-class in the microphysics scheme. The analysis focused on January 8th to 14th upon all stages of Narelle. The result showed that Sea Surface Temperatures (SST) higher than 26°C was a favorable environment for Cylone Narelle to form. Surface sensible and latent heat fluxes have strong positive correlation with wind speed and SST. It can be concluded that these variables were highly correlated with surface heat flux that further lead to the formation and intensification of Cyclone Narelle in early January 2013 over South Indian Ocean. The tracks and stages of the model are nearly similar to the observations, the differences are found in late phases of Narelle.

Keywords: Latent heat; WRF; SST; Sensible heat; Wind speed

Introduction

Heat fluxes are the amount of heat transfer per unit area and time that is affected by rate of oceanic evaporation, surface air temperature, and aerodynamics resistance (Davies, 2010). Heat exchanges between ocean and atmosphere are indicated by sensible and latent heat transfer. Sensible heat flux mostly contributes to the increase or decrease of atmospheric temperature while latent heat flux from heat released during condensation processes becomes the main energy to drive Tropical Cyclone (TC) intensity over the ocean; the rise of intensity is presented by the increase of winds magnitudes and the decrease of surface pressure over certain areas (Raharjo *et al.*, 2010). Most TCs typically grow and develop over warm tropical and sub-tropical waters with high humidity, thus, TCs are commonly found over tropical region; a region where intensive solar radiation are abundant. High solar penetration over tropical ocean leads Sea Surface Temperatures (SST) to increase which affect to cause low pressure area; this could further drive the formation of TC, initiated by a tropical disturbance, tropical depression, and followed by tropical storm, and mature TC. The occurrences of TCs over the ocean vary. More than two-thirds of TCs occurred in the Northern Hemisphere (NH), of these about half of them occurred over Western North Pacific Ocean and about one-quarter over Eastern North Pacific Ocean, one-sixth over North Atlantic Ocean, and about one-eighth over North Indian Ocean. Of TCs that occurred over Southern Hemisphere (SH), almost half of them are formed over Northern Australia Waters, one-third over South Indonesian Waters, and one-quarter over South Pacific Ocean (Neiburger, 1995). Asrianti *et al.* (2013) studied some TCs, especially over Western North Pacific Ocean and found that the frequencies of TC occurrence over NH were about 320 events which were higher than the frequencies over SH which (i.e., 132 occasions).

Efforts in studying the effect of surface heat fluxes and the characteristics of TC formation have been intensively carried out, e.g., Gao and Chiu (2010) who investigated the connection between surface latent heat flux, precipitation, and TC intensity prediction over Western North Pacific Ocean. They developed a regression model which included some heat flux parameters to predict TC intensity. Therefore, it is necessary to study the relationship between heat fluxes and TC intensity with a case of Cyclone Narelle (CN) that lasted in early January 2013 over South Indian Ocean in order to recognize on how the impact of heat fluxes on TC intensity over the region. Based on Saffir-Simpson scale, CN is classified into category 4 Cyclone, the early genesis in a depression status are developed off the south coasts of East Nusa Tenggara. While travelling to the southwest of south coasts of Lombok, the status has been upgraded into a tropical storm and brings severe impact not only to the southern coasts of Indonesia but also to almost the entire Indonesian regions, some disasters in Indonesia are mostly related to CN, including big flood in Jakarta. Indonesian Agency of Meteorology, Climatology, and Geophysics release a warning for strong winds, heavy rains, and high ocean waves that possibly occurs due to the cyclone (National Geographic, 2013). The cyclone development and intensification, however, still remained questions. Beside its impact on Indonesia, fact that CN is not a subject of exploration yet motivates the present study. This study aims to analyze CN formation using a mesoscale model by obtaining the relationship between surface heat fluxes and CN intensity as well as obtaining tracks and stages of CN derived from model and observation.

Materials and Methods

The domain of study areas is between 11°S - 35°S and 105°E - 120°E for period of CN lifespan from January 8th to 14th, 2013. We simulate CN using Advanced Research of Weather and Research Forecasting version 3.3 (hereafter refer to simply WRF). WRF is a non-hydrostatic mesoscale model with terrain-following in the vertical-sigma coordinate. A review of mathematics, physics, dynamics, and thermodynamics of the model can be found in Skamarock *et al.* (2008). One domain with spatial resolution of 10-km is employed in the model with geographical coordinates covered the whole study domain as mentioned earlier. Besides, 28 pressure levels ranging from 1000-100 hPa are employed in the model. The model is also supported by the following physical parameterization: (a) surface and Planetary Boundary Layer (PBL) scheme, (b) cumulus scheme, and (c) microphysics scheme. Table 1 shows the physical parameterization used in the model. Osuri *et al.* (2012) implemented similar parameterization to simulate different TC over North Indian Ocean. A subroutine to calculate heat and moisture fluxes from the surface is included in the model. The initial boundary condition in the model are : (a) 2-minutes resolution of USGS terrain height data, (b) 2-minutes resolution of global 24-category USGS land use/cover data, and (c) 1.0° latitude x 1.0° longitude grids NCEP Final Analysis (FNL) data with grib2 format. The data is available in 6-hourly temporal resolution, i.e., 0000, 0600, 1200, and 1800 UTC and consists of meteorological variables, such as surface pressure, SLP, geopotential height, temperature, evaporation, relative and specific humidity, zonal and meridional velocity, vertical velocity, etc. Pressure levels are available from 1000 to 10 hPa. The information as well as the data is available online at http://rda.ucar.edu/datasets/ds083.2/#description. CN is simulated from January 7th to perform a warm-start at the first day of simulation in order to adjust the initial boundary condition as well as physical parameters in the model. Thus, analysis focuses on the second day of simulation on January 8th, 2013. The model output is presented by using VAPOR which is an attractive software to visualize the meteorological phenomena, e.g., TC.

The procedures of data analysis in the research are divided into three sections. Firstly, analysis of CN formation. Secondly, determining the relationship between surface heat fluxes and CN intensity, indicated by meteorological and oceanic variables, i.e., pressure, wind speed, and SST. SST data is available at http://iridl.ldeo.columbia.edu/SOURCES/NOAA/.NCDC/.ERSST/.version3b/.sst/dataselection.html. Thirdly, obtaining the tracks and stages of CN using model and its verification to the observation. Observation data is available at http://weather.unisys.com/hurricane/index.php which is six hourly data published by Joint Typhoon Warning Center (JTWC) based on ensemble models. Stages of CN intensity referred to Saffir-Simpson scale.

Table 1. Physical parameterization of the model.

Physical categories	Scheme
Surface layer	Monin-Obukhov with Carslon-Boland viscous sub-layer
Land surface	Noah land surface model
PBL	Yonsei University (YSU)
Cumulus parameterization	Kain-Fritsch scheme (KF)
Longwave radiation	Rapid Radiative Transfer Model (RRTM) scheme
Shortwave radiation	Dudhia scheme
Microphysics	WRF Single-Moment 3-class scheme

The relationship between surface heat fluxes and CN intensity is determined by using correlation analysis, that is, between the surface heat fluxes as an ordinate variable (Y) and meteorological parameters that contribute to CN formation as an abscissa variable (X). Correlation coefficient (r) given in the below formula is used to measure the strengthen of linear relationship between independent variables (X) and dependent variables (Y), r values is ranging from $-1 \le r \le +1$ (Walpole, 1995). If r = -1, it shows a very strong negative correlation while r equal to 0 means no correlation, and r is equal to 1, implies a very strong positive correlation.

$$r = \left(\frac{\sum_{i=1}^{n} (X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum_{i=1}^{n} (X_i - \bar{X})^2} \sqrt{\sum_{i=1}^{n} (Y_i - \bar{Y})^2}} \right)$$

Results and Discussion

CN developed to become a mature stage in less than 7 days and at the end, it travelled farther away from tropical region. The result shows that the model is in agreement with the observation. Figure 1a shows that on January 8th, at 0000 UTC in the initial formation from a tropical depression to a tropical storm, surface latent, sensible heat fluxes, and wind speed continues to increase until reaching a mature stage, before it weakens into a tropical storm and finally turns into tropical depression on January 14th at 1800 UTC. Figure 1a shows that latent heat is higher than sensible heat flux. It was caused by the release of latent heat during condensation processes which subsequently form towering convective clouds that concentrated near the cyclone core and it plays a major role in driving CN intensity. Besides the heat fluxes, in the early stages of CN, the wind speed gradually increase until it reaches mature stage few days later. The wind speed starts to decrease after CN undergoes into a tropical storm and decaying stage on January 14th at 1800 UTC (see Fig. 1b). On the other hand, from the early stage of CN formation until it develops into mature stage, pressure slowly decreases. Meanwhile, when it weakened into a tropical storm on January 12th, the pressure increased until it changed into tropical depression on January 14th at 1800 UTC. Raharjo *et al.* (2010) explains when TC starts its strengthening phase, the pressure will continually decrease, accompanied by an increase in wind speed in the other side. Our simulation results also show a similar pattern in which at the beginning of the formation, wind speed increases and at the same time, pressure tends to decrease. While cyclone eases into decaying stage, the wind speed decreases but in the other hand, pressure increases.

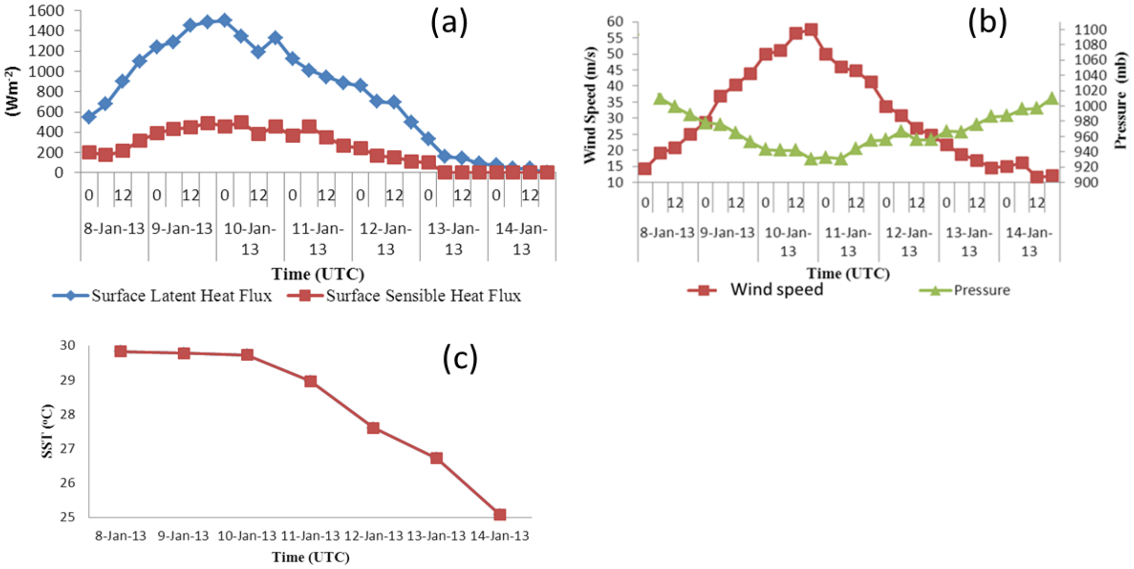


Figure 1. (a) Surface heat fluxes, (b) wind speed and pressure derived from model, and (c) SST during CN lifetime.

In Figure 1c, it is shown that SST in the early formation exceeds 26°C which is likely conducive for CN formation. According to early study by Gray (1968) and advance studies by Pasquero and Emanuel (2008), Zhou and Cui (2011), and Dare and McBride (2011), the formation of TC originates from warm waters about 26°C at the surface. Subsequently, following the changes in CN intensity during decaying stage, SST decreases. In table 2, we summarize that the pressure has a weak negative correlation to latent heat flux, while the wind speed and SST has a strong positive correlation to latent heat flux. The latter implies that SST is the main energy source for driving CN intensity. The relationship between sensible heat flux and pressure, wind speed, and SST are given in table 3. Surface sensible heat flux also has a weak negative correlation to pressure but has a strong positive correlation to the wind speed and SST, it implies that the wind speed has high correlation to surface sensible heat flux that contribute to the formation of CN by controlling air temperature of the atmosphere. Hence, two variables that have strong correlation to the surface heat fluxes leading to CN formation are wind speed and SST. It is also proved by Gray (1968) who revealed that the ideal sources of heat energy that contribute to TC formation could originate from warm surface ocean temperature above 26°C to a depth of 60 meters. Emanuel (1988) also stated that the strengthening TC intensity was associated with the increase of SST. Although SST plays an important role in the formation of TC, Evans (1993) and Ilhamsyah (2013a; 2013b) revealed that SST is not the only variable behind TC formation, but also some dynamical variables, such as wind speed and pressure need to be taken into consideration in furthering TC intensity.

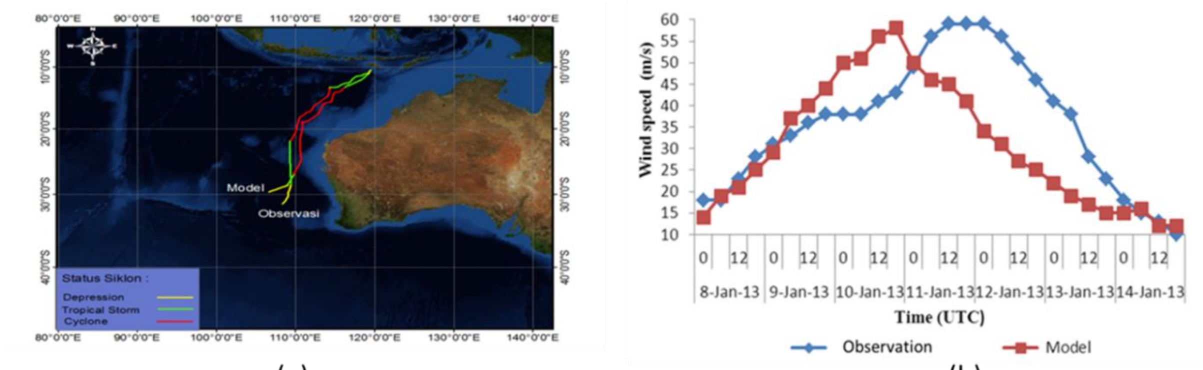
Table 2. Correlation coefficient (r) of surface latent heat flux with pressure, wind speed, and SST

Parameter	Surface latent heat flux
Pressure (mb)	-0.466
Wind speed (m/s)	0.842
SST (°C)	0.886

Table 3. Correlation coefficient (r) of surface sensible heat flux with pressure, wind speed, and SST

Parameter	Surface sensible heat flux
Pressure (mb)	-0.486
Wind speed (m/s)	0.876
SST (°C)	0.854

Comparison between observation and model in terms of tracks and stages of the cyclone are shown in figure 2a. Tracks and stages of the model show similarities with those of observations. At the early stage of CN formation, there are differences between model and observation. Model shows a tropical depression while observation exhibits a tropical storm. Nevertheless, the changing stages from tropical storm to mature cyclone shows similarities and occurs at the same time on January 9th, at 0600 UTC. Meanwhile, at the decaying stage, it shows no similarities between model and observation where model shows a delaying changes of CN stages. In spite of that, both model and observation eases into a tropical depression on January 14th at 1800 UTC. Figure 2b shows that the result of the model is nearly in agreement with the observation. In early and late formation during tropical depression stage, the model was well-coincided with the observation. However, at mature stage the peak of maximum wind speed of the model is quickly occurs compared to the observation.



(a)

(b)

Figure 2. Comparison between model and observation in terms of (a) tracks and stages and (b) wind speed during CN lifetime.

Conclusions

The model has successfully simulated sensible and latent heat fluxes of CN. The fluxes are strongly associated with CN intensity as confirmed by the correlation analysis between the heat fluxes and ocean as well as meteorological parameters, e.g., SST, pressure, and wind speed. The wind magnitudes and SST have a strong positive correlation with surface latent heat flux. The fluxes are used as a primary energy to drive not only the formation but also the intensification of CN over South Indian Ocean. Comparison of tracks and stages between model and observation are nearly similar even though slight differences are found mostly during intensification stages of CN.

References

Asrianti, P, Bey, A. and Ilhamsyah, Y. (2013). Study of some tropical cyclones characteristics (Cases of Typhoon Choi-wan and Nida over Western North Pacific Ocean). Depik, 2(3): 154-161.

Dare, R.A. and McBride, J.L. (2011). The threshold sea surface temperature condition for tropical cyclogenesis. Journal of Climate, 24: 4570–4576.

Davies, J.H. (2010). Earth's surface heat flux. Solid Earth, 1: 5-24.

Emanuel, K.A. (1988). The maximum intensity of Hurricanes. Atmospheric Science, 45(7): 1143-1155.

Evans, J.L. (1993). Sensitivity of tropical cyclone intensity to sea surface temperature. Journal of Climate, 6(6): 1133-1140. doi:10.1175/1520-0442.

Gao, S. and Chiu, L.S. (2010). Surface latent heat flux and inner-core rainfall associated with rapidly intensifying tropical cyclone intensity prediction over western north pacific. International Archives of the Photogrammetry. Remote Sensing and Spatial Information Science, 38(8): 981-984.

Gray, W.M. (1968). Global view of the origin of the tropical disturbance and storms. Monthly Weather Review, 96(10): 669-700.

Ilhamsyah, Y. (2013a). Ocean-Atmosphere Analysis of Super Typhoon Songda 2011 over Western North Pacific Ocean. Proceedings of the 3rd Annual International Conference Syiah Kuala University (AIC Unsyiah) 2013 In conjunction with the 2nd International Conference on Multidisciplinary Research (ICMR) 2013, October 2-4, 2013. Banda Aceh, Indonesia: 139-145.

Ilhamsyah, Y. (2013b). Thermal characteristics and dynamics of tropical cyclone over Western North Pacific Ocean (A case study of Typhoon Songda (Chedeng) 2011). Master thesis, Bogor Agricultural University, Bogor.

National Geographic. (2013). Narelle masih berdampak besar untuk Indonesia. http://nationalgeographic.co.id/berita/2013/01/narelle-masih-berdampak-besar-untuk-indonesia. (Accessed on December 29th, 2013).

Neiburger, M. (1995). Memahami lingkungan atmosfer kita. *In*: Purbo, A (trans), Understanding our atmospheric environment. ITP Pr., Bandung.

Osuri, K.K., Mohanty, U.C., Routray, A., Kulkarki, M.A. and Mohapatra, M. (2012). Customization of WRF-ARW model with physical parameterization schemes for the simulation of tropical cyclones over north Indian ocean. Natural Hazards, 63: 1337–1359.

Pasquero, C. and Emanuel, K. (2008). Tropical cyclones and transient upper-ocean warming. Journal of Climate, 21: 149-162.

Raharjo, A., Radjawane, I.M. and Setiawan, A. (2010). Variabilitas kejadian Siklon Tropis di Samudra Hindia bagian Selatan. Ilmu Kelautan, 1: 1-8.

Skamarock, W.C., Klemp, J.B., Dudhia, J., Gill, D.O., Barker, D.M., Duda, M.G., Huang, X.Y., Wei, W., and Power, J.G. (2008). A description of the advanced research WRF version 3. NCAR Technical Note. Available at: http://www.mmm.ucar.edu/wrf/users/docs/arw_v3.pdf (Accessed on 10 January 2013).

Walpole, E.R. (1995). Pengantar statistika. PT Gramedia Pustaka Utama, Jakarta.

Zhou, B.T. and Cui, X. (2011). Sea surface temperature east of Australia: a predictor of tropical cyclone frequency over the Western North Pacific?. Chinese Science Bulletin, 56(2): 196-201.