AN INDICATION OF SEA-AIR INTERACTION THAT AFFECTS THE CLIMATE PATTERN OVER THE MOLUCCAN SEA

Edvin Aldrian[1]

Abstract

Starting with the regional annual cycle of rainfall over Molucca, which follow the sun eclipse movement instead of the common Inter Tropical Convergence Zone (ITCZ) movement, a suspicion of the sea-air interaction driven climate pattern comes up. The empirical study on rainfall – sea surface temperature (SST) relationship clarifies a function of rainfall accumulation to SST. A strong evident on the interaction comes from the result of Ocean General Circulation Model (OGCM). The model shows a surface water intrusion that comes from west Pacific into the north Molucca Sea before it enter the mainstream of the Indonesian throughflow in the north end of the Makasar strait. Most of the throughflow, as shown by the model, come from north Pacific, enter the Makasar strait southward and go into the Indian ocean through the Lombok strait (mostly) and a strait between Flores and Timor island. The intrusion of surface water in north Molucca conserves the warm sea surface temperature and keep a high convective area.

Intisari

Diawali dengan pembagian region berdasarkan pola hujan tahunan di Maluku, yang mengikuti pergerakan tahunan matahari dan bukannya yang biasa yaitu Inter Tropical Convergence Zone (ITCZ), kecurigaan akan adanya interaksi laut udara yang mendorong pola iklim timbul. Studi empiris mengenai hubungan hujan dan suhu permukaan laut menjelaskan fungsi akumulasi hujan terhadap suhu laut. Indikasi kuat adanya interaksi berasal dari keluaran model global sirkulasi laut. Model menunjukkan adanya intrusi arus permukaan dari pasifik barat ke Maluku utara sebelum masuk ke alur utama dari arus lintas Indonesia di ujung utara selat makasar. Sebagian besar arus lintas, sebagaimana dituntukkan oleh model, berasal dari utara, memasuki selat Makasar ke selatan dan menuju ke samudra Indonesia kebanyakan melalui selat Lombok dan sebagian kecil melalui selat antara pulau Flores dan Timor. Intrusi arus permukaan di utara Maluku menjaga kehangatan suhu muka laut dan menjaga daerah konvektif aktif.

Keyword: Indonesian throughflow, rainfall pattern, Molucca rainfall, ocean model, air-sea interaction

1. INTRODUCTION

This study was motivated by a need for an explanation of an uncommon annual rainfall cycle over the Moluccan Sea by Wyrtki (1956), Aldrian (1999, 2001). Most of the annual cycles of rainfall in Indonesia can be explained with the movement of the Inter Tropical Convergence Zone (ITCZ). Indonesia lies over the ITCZ passage that drives the Asian-Australian monsoons. Because of the ITCZ and these monsoons, most of the annual rainfall cycles over Indonesia has an annual peak in the Northern Hemisphere (NH) Winter or December – February (DJF) and an annual trough in the NH Summer or June – August (JJA). This is the common annual cycle, while the annual cycle over Molucca shows the inverse pattern.

1. Max Planck Institut für Meteorologie, Hamburg, Jerman

Ramage (1971) mentioned a possible pressure minimum in this region during April to June but did not relate that minimum to the throughflow.

There is a strong evidence of possibility of sea surface temperature influence in this region. Region C or Maluku lies over the eastern route of Indonesian throughflow. This flow regime passes Indonesian archipelago mostly through the Makasar Strait (Hirst and Godfrey, 1993; Godfrey et al., 1993) and Molucca (Rodgers et al., 2000). Godfrey et al. (1993) did not rule out the possibility that central Molucca holds a key to the remaining discrepancies between results of their model and measurements. During May–July (MJJ), the sea surface temperature in the West Pacific in the northeast of Indonesia is warmer than that of southern Indonesia. The South Pacific water infiltrates into the lower thermocline of the Banda Sea. When the throughflow reaches the deep Banda Sea of south Molucca (>5000 m deep) the warm current dominates the deeper layers through density driven overflow (Gordon et al., 1999).

Besides, there are two other backgrounds why we are pursuing this study. They are the location of the Molucca Sea around the Indonesian throughflow and an empirical relationship between sea surface temperature (SST) and rainfall over the tropics. In doing so the paper is divided as follow. Section 2 discusses data sources and follow by section 3 on the three approaches used here; regionalization, empirical study and ocean model, section 4 shows results of the above three approaches, follows by section 5 the discussion and section 6 concludes the paper.

2. DATA

The rainfall data used in this study are a monthly rainfall data set collected by the Indonesian Meteorological & Geophysical Agency (BMG) at 526 stations all over Indonesia from 1961 - 1993 and monthly rainfall data from a joint World Meteorological Organization and National Ocean and Atmosphere Administration (WMO-NOAA) project The Global Historical Climatology Network (GHCN). From both data sets along with the additional BMG data set, in total 5419 rain gauge stations over an area 20^0E - 180^0E and 25^0S - 25^0N are available. In our area of interest (19^0S – 8^0N and 90^0E – 140^0E), there are 884 rain gauges. Similar data set has been used by Aldrian (2001).
We also use SST data from the Global Ice and Sea Surface Temperature (GISST) dataset (Rayner *et al.* 1996) version 2.3b. This dataset is compiled from SST observations from 1871 until present, with a spatial resolution of 1^0. To have the same period as the rainfall data, we use data from 1961 to 1993 only.

3. METHODS

This study comprises three parts, the regionalization of the Indonesian climate based on the annual rainfall cycle, the empirical study of SST – rainfall relationship and a modeling study using an Ocean General Circulation Model (OGCM).

3.1. Regionalization

Rainfall data set was arranged into a gridded data set with a fixed resolution at T106 in the climate model standard. This horizontal resolution corresponds to 1.125^0 or about 110 km. Over our area of interest there are about 47 x 144 number of grids. Due to high spatial coherence in Indonesian rainfall (Haylock and McBride, 2001), there is a need to classify regions according to their annual rainfall patterns. This procedure is called the regionalization. All grids, which have similar annual rainfall patterns, belong to a region. The first regionalization attempt on Indonesia was done by Wyrtki (1956), when he divided the Indonesian waters into 9 subregions. This procedure is taken because grids with a homogenous annual pattern shall receive similar climatic effects. Aldrian (2001) did the regionalization with the double correlation method (Figure 1). The product of this method is comparable to another statistical method called the Empirical Orthogonal Function (EOF).

3.2. Empirical study

A simple empirical study is done to see the character of sea-air interaction over Indonesia. Previously Nicholls (1979) has developed the conceptual model of the air-sea interaction based on data from this region. Tropical sea-air relationship between SST and rainfall has been intensively investigated by Bony *et al*. (1997a, 1997b) and Lau *et al.* (1997). Following their works, we pick up an area in south Molucca (120E – 135E, 15S – 5S) and north Molucca (122E – 135E, 6S – 2N) and make a scatter plot of the SST and rainfall over those areas. There are limitations on the

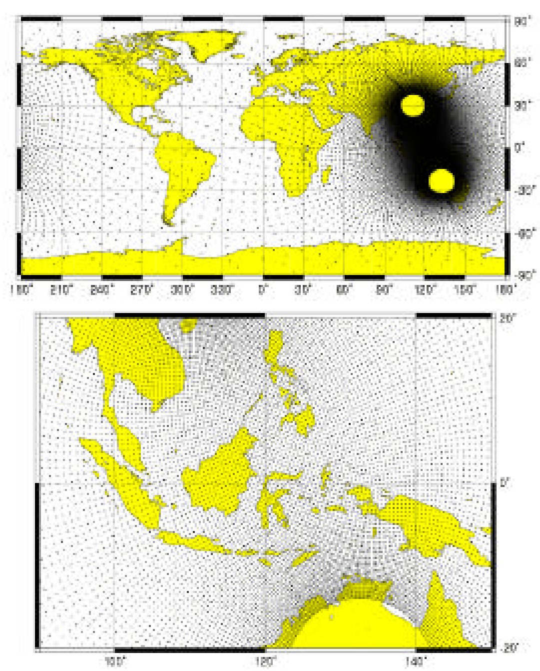

Figure 1. Grid system of the HOPE-C ocean model

interpretation of the rainfall over the sea as our main sources of data are inland data. However, considering the geography of this region where some stations are located in small islands, their

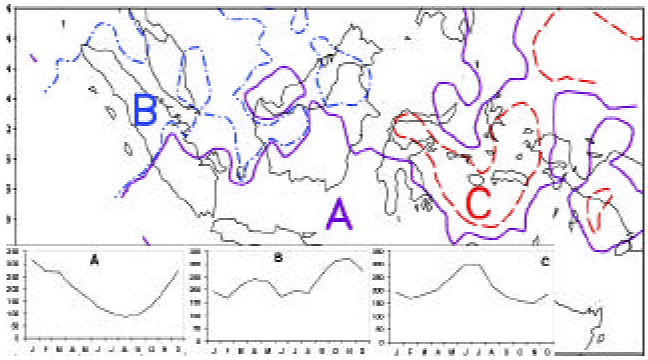

Figure 2 The three regions and their patterns as a result of the double correlation method. The three regions are region A or the south monsoonal region, region B or the northwest semi-monsoonal region and region C or the Molucca anti-monsoonal region.

data represents land as well as ocean data. There is a slight improvement on the empirical study done here in compare to those of Bony *et al.* (1997a, 1997b), where monthly analyses is added.

3.3. Ocean model

The ocean model used in this study is the Max Planck Institute's the Hamburg Ocean Primitive Equation model version C (HOPE-C) ocean model (Wollf *et al*., 1997). This model is an OGCM and works on the global scale. The coordinate system is the Arakawa-C conformal grid, which depend on the location of two poles (Figure 1). These poles, due to the ocean model constrain, must lie over land grids. In a common use, these poles are located in north and south poles with an imaginary land grid over the north pole. Since our main focus is the Molucca Sea, we shifted the location of those poles to over China and Australia. In doing so, we will have denser grids over Molucca and coarser grids for other parts of the globe. With this setup, the highest resolution over Molucca is about 0.4^0. With such a conformal grid, the global ocean circulation is also simulated, while the local processes over the Moluccan Sea are also considered. The simulation works only based on the ocean boundary or the prescribed ocean topology and was forced with climatological surface winds and frictions from NCEP reanalyses (Kalnay *et al*. 1996). Initial subsurface condition of salinity and temperature has been prescribed by Levitus ocean data. Ocean ground topology was calculated from the 2 minutes ocean topology data from US Navy. Then the model is run for 10 years using Julian day calendar to reach a stable condition free of model spin-off and initial conditions.

4. RESULTS

4.1. Regionalization

The result of the "double correlation method" is illustrated in Fig. 2, which shows three main climate regions. The procedures and the result of this regionalization has been extensively discussed in Aldrian (2001). Region A occupies most of the area especially south Indonesia, south Sumatera, part of Kalimantan, Sulawesi and Irian Jaya. This region is much affected by the dry southeast monsoon. Region B is located in northwest Indonesia around North Sumatera, Aceh, parts of Kalimantan and the Malaysian Peninsula. This region is mainly affected

Table 1. Ocean model descriptions

y-axis (meridional)	105
x-axis (zonal)	182
no. of layer	20
layer depths (m)	10,30,50,75,110,155,215,295, 400,535,700,895,1125,1400, 1750,2200,2750,3400,4200,5350
North Pole	112E 29N
South Pole	132E 22S
Time step interval	3200 s
Output	Monthly
Input forcing (climatological NCEP)	• 2m air temperature • short wave radiation forcing • precipitation rate • cloud cover • dew point temperature • zonal (u) surface flux • meridional (v) surface flux • 10 m wind in u and v

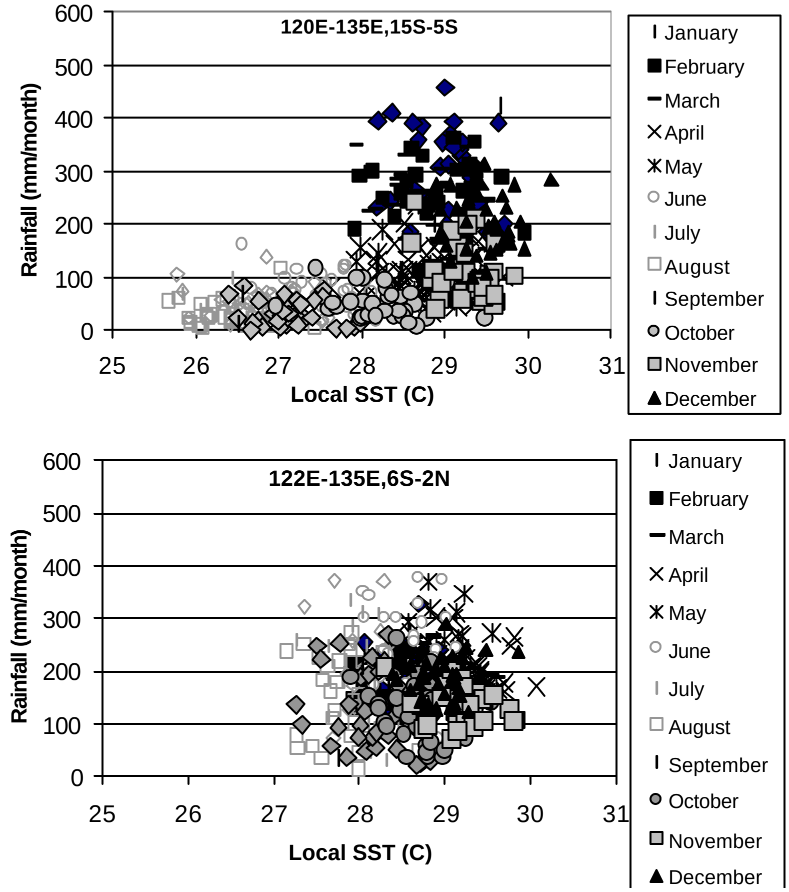

Figure 3. SST-rainfall relationship in south Molucca (top) and north Molucca (bottom)

by the ITCZ and by the northeast passat wind. While region C is located over the Molucca, a part of Irian and north of Irian. Most scientists believe that this region and the Makasar strait are main passages of the throughflow.

The annual cycles of those three regions are described in Fig. 1 from Aldrian (2001). Region A has one peak (trough) in Northern Hemisphere winter (summer) or in DJF (JJA). While Region B have two peaks in ND and MAM. The peak of MAM is lower than that of DJ. Region A, which covers most of the areas, has an annual cycle, which represents the existence of ITCZ or the Asian monsoon in Indonesia. Thus Region A is regarded as the monsoonal type region, while Region B with two peaks is regarded as the semi monsoonal type region. Almost similar to this, the peaks in Region B are consistent with the annual march in the latitude of the ITCZ.

Region C, on the other hand, has the inverse pattern or the anti monsoonal type, its peak in MJJ and its trough in NDJ. Actually this pattern follows the movement of the sun eclipse from the Southern to the Northern Hemisphere back and forth. There is one possible mechanism that drives this kind of climatic pattern. It is from the sea air interaction, but how the interaction comes into action. A small significant part of Region C located north of Irian Island suggests a clue of possible sea-air interaction from the west Pacific. This region is located in the Indonesian throughflow that brings surface water from Pacific to Indian Ocean. Most scientists believe that the throughflow is originated from Northwestern Pacific not from equatorial west Pacific. There must be a mechanism that drives surface water from equatorial west Pacific as well. This is the topic that we would like to explore with the OGCM.

4.2. Empirical study

The scatter plot of SST – rainfall relation on Fig. 3 agrees well with previous works. The scatter plot shows the relation or functionality between SST and rainfall in south Molucca for region A and north Molucca for region C. Thus, the plot depicts a mechanism of the local sea-air interaction. As the SST reduces, so does the maximum rainfall amount. However the reduction is not linear. A significant increase happens as the SST was raised above 28^{0}C. According to Bony *et al.* (1997) this increase is not infinite. The critical point is around 29.4^{0}C, where the increase of temperature does not give higher rainfall amount. In fact, the rainfall amount starts to decrease. Other interesting point from the

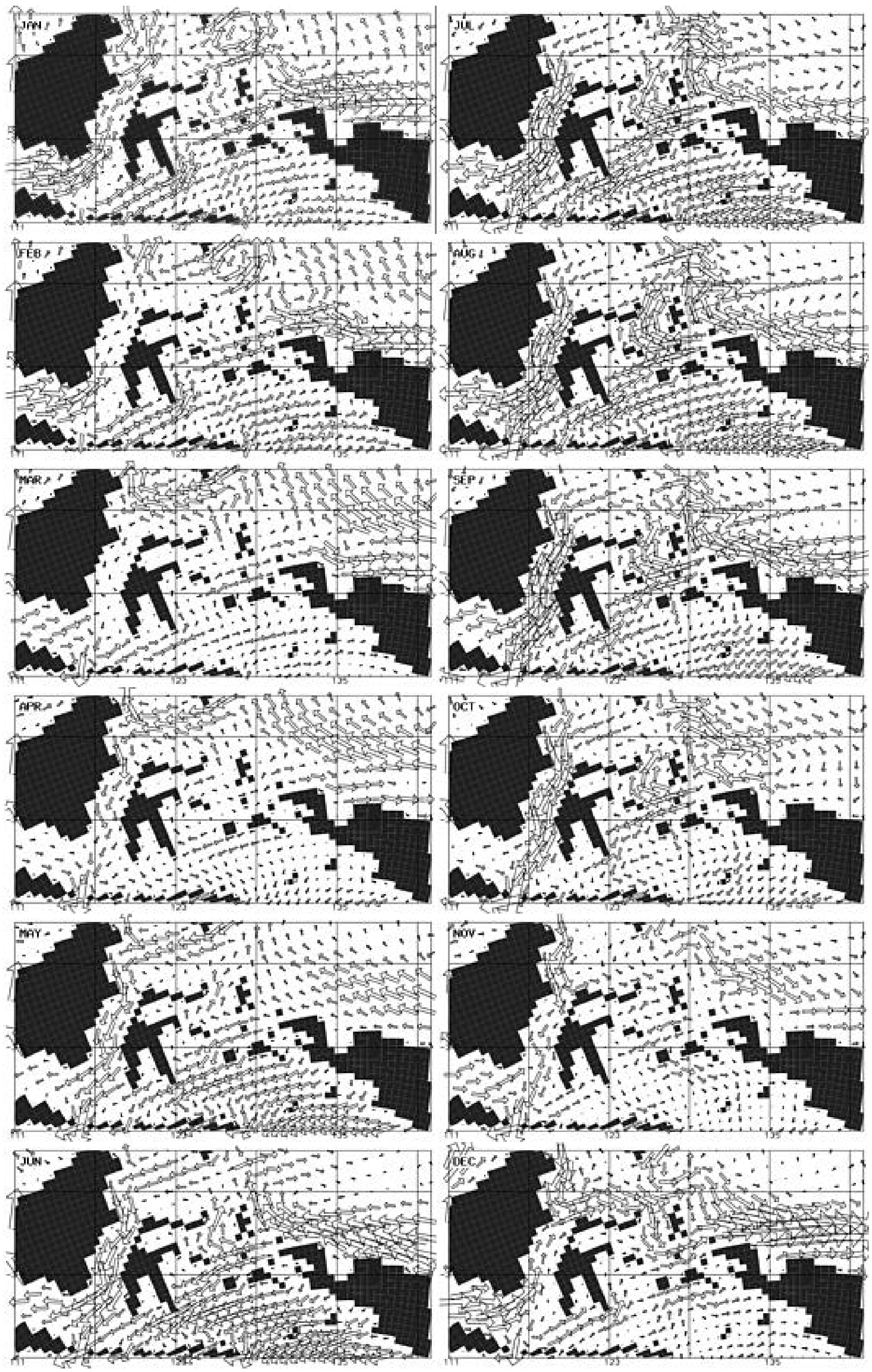

Figure 4. Annual march of ocean streamflow from the surface to 20m depth, shown without unit of scale around east Indonesian.

figure is clusters of rainfall accumulation as we march from January to December. These clusters represent the annual rainfall cycle described in Fig. 2 for region A and C, because the sample of SST and rainfall are derived from these regions. As we notice from that figure, months with similar SST value do not always produce similar rainfall ranges, for example January and November. There must be other mechanisms that control this or some contributions outside SST. This question needs further researches and is beyond the scope of this study. The main lesson here is the consistent feature in the SST – rainfall relationship as shown previously by other scientists.

The major differences between those scattered plots are narrow distribution for SST and rainfall in region C in comparison to those of region A The narrow range of SST in region C lies in high rainfall region according to works by Bony *et al*. (1997). Thus, we should look for the cause of this maintained high SST values by the ocean model.

4.3. Ocean model

The result of CHOPE model (Fig. 4 and 5) shows the anatomy of the Indonesian throughflow. Figure 4 shows the annual march of surface flow around eastern islands. The flow are monsoonal with a reverse direction in every half year. Most of the throughflow pass through the Makasar strait and come from the north Pacific. The throughflow passes the Lombok strait and some make a detour to the east and flow through a strait between Flores and Timor Islands before it goes to the Indian Ocean. There is some intrusion of the flow from west Pacific and most of this source flow to the Molucca Sea first before they are collected in the north end of the Makasar strait. The peak of the intrusion into the north Molucca Sea coincides with the peak of the Indonesian throughflow in the middle of the year or when the rainfall cycle reaches its peak in this region (Region C).

Figure 5 show the vertical profiles of the intrusion in July when the peak of the intrusion occurs. The intrusion of the sea current into the Molucca Sea reaches a depth of 90 m or at layer between 60 – 90m depth. The intrusion is not detected anymore below that layer. The intrusion goes south up to the Seram Island or circulating only in north Molucca. After a long integration (10 years), the simulation shows a change of SST distribution, which follows the intrusion of surface water from west Pacific. The annual march of the intrusion follows the annual cycle of Region C with its peak in MJJ.

In order to see the effect of this intrusion to the local SST, we take the area average of the SST in similar area to those of the empirical section above and compare the model result with an independent SST observation from the GISST2.3 data set. Furthermore, to understand the effect of the amount of the intrusion water flowing into the north Molucca sea, we did a small sensitivity study by changing the topology in northeast Irian Island (Kepala Burung area) by introducing land areas in the north of that area. The purpose of this change is to reduce the amount of flow into north Molucca in order to

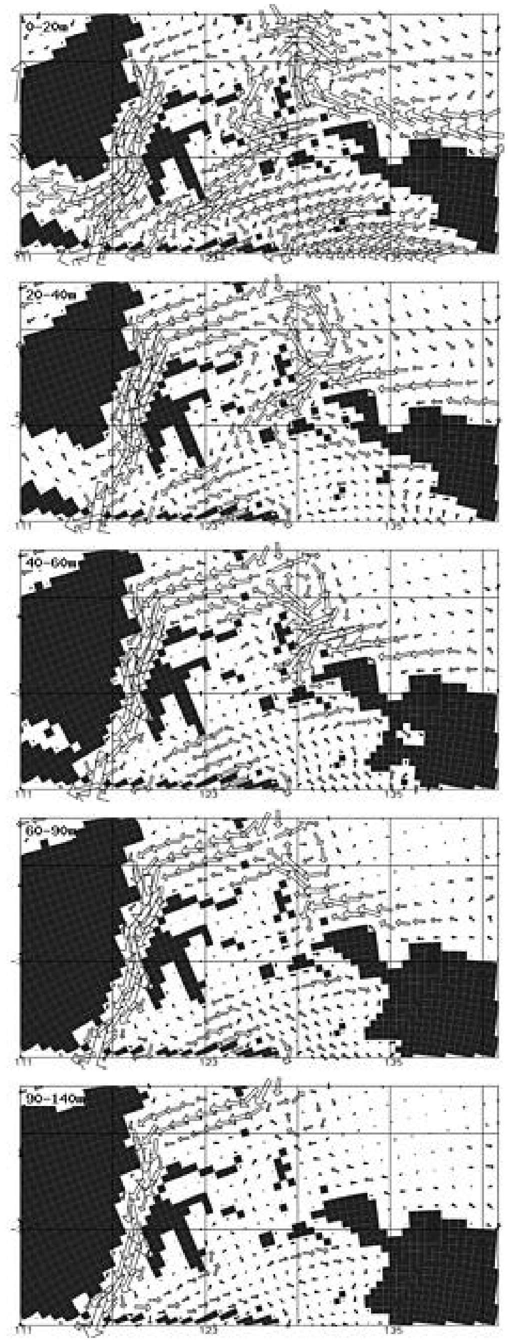

Figure 5. Vertical profiles of sea current in July from the first 5 layer of the model. The first layer is from surface to 20 m depth

understand the impact of this reduced flow in annual SST cycle.

The resulted SST's annual cycles are shown in Fig. 6, with a narrower range SST in north Molucca. This result agrees well with the empirical study above although with a constant 1^0C bias in north Molucca. This result shows a simple validation of the model performance in this region. Furthermore, the figure shows that a smaller intrusion amount will reduce the SST in north Molucca by around 0.5^0C considerably, but not in south Molucca. Thus the intrusion has a function to hold a high annual SST cycle in north Molucca. Although there is no certain value as by how much percentage the presence of intrusion will holds such a high SST cycle, it is possible that without the intrusion the SST in mid of the year will drop below 28^0C, where lower rainfall is expected and the shape of the annual cycle will look like that of region A.

The question remains as which annual SST cycle is more realistic between observation and that of HOPE ocean model. According to the empirical study and previous study by Bony *et. al* (1997), there are three SST range in the tropics: below 28^0C, between 28^0C-29.4^0C and above 29.4^0C. The annual SST resulted from HOPE ocean model seems to be more realistic if we consider the rainfall and SST annual cycle in north Molucca. There are many possible causes of the discrepancies between observation and model: different grid system, different land sea mask representation and resolution problem. Hence we could conclude that the anti monsoonal type of annual rainfall in region C is due to:

- high annual SST values that contributes to high rainfall average all year round
- higher rainfall amount in MJJ due to the SST drops into the range of higher SST-rainfall range between 28^0C and 29.4^0C
- the presence of intrusion in the mid of the year, which holds high SST values and distinguish the area to just few degree south of it.

5. DISCUSSIONS

The CHOPE model shows the position of the Indonesian throughflow and the intrusion of surface water into the Molucca Sea. There is a slight amount of water passes from west pacific to Indian Ocean through the Molucca Sea. The model

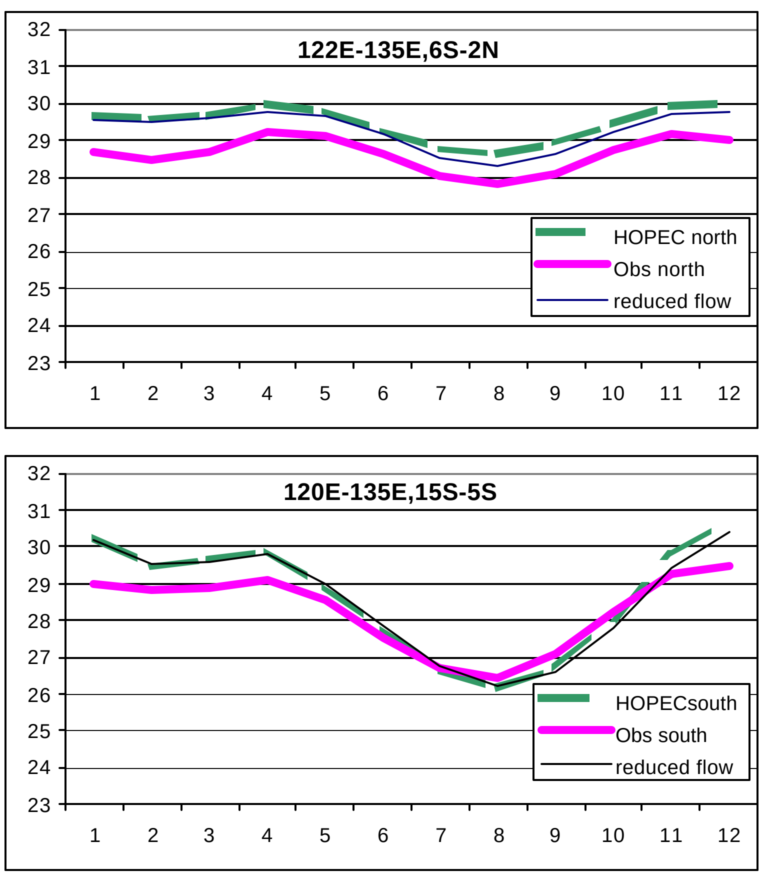

Figure 6. Annual SST cycle from model and GISST observed data in two area prescribed by empirical study

describes the change of temperature distributions quite well and the empirical study show strong relation between SST and rainfall. The empirical relationship between SST and rainfall shown here are made of two independent observations. The model could produce such a result with a constant bias in north Molucca. There are more works to be done in the future such as presenting changes of the temperature distribution in an atmospheric model and seeing the change in precipitation due to the adopted SST distribution. A better way is to run a coupled ocean-atmosphere model, however up to date there is no such model working in the region. Since the current model working on a climatological data set, the result of the OGCM presented here is more qualitative than quantitative, a real and long term simulation using real prescribed reanalyses data will give more quantitative results.

One big problem in this simulation is the resolution. Although we have used a very high spatial resolution, there are many small islands that can not be resolved even with this resolution. The topology of the deep ocean is not always representative due to some step slopes of ocean floors. Nonetheless, the result of the simulation is realistic enough in describing the anatomy of the flow.

Then there is a problem of the peak of the annual cycle, which occurs in MJJ while the minimum of SST occurs in JAS. So far there is no clue why there is such differences although the observed SST shows similar SST minimum as the one by OCGM.

Another problem is the unexpected result such as the SST distribution that follows the throughflow too much such as in the Java Sea and the Makasar strait. The last problem is the intrusion of water from Pacific in Molucca resemble the region C only in north Molucca. If we look at the rain gauge distribution over Molucca, we would understand that the mistake is in regionalization method for region C, where the region extends to far south, where there is only a limited amount of gauges in the south Molucca.

6. CONCLUSIONS

Despite some limitations, the study indicates a clear signal of sea-air interaction over the Molucca Sea. The result of regionalization method by the "double correlation" method, the empirical study of the SST-rainfall and the ocean model result support this idea. There are possible extensions of this work with a coupled ocean and atmospheric model or adopting the SST changes from this study to an atmospheric model. Furthermore, it is possible to run the ocean model with realistic (not climatological) data set using 40 years NCEP data in order to sea the interannual variability of the intrusion and studying other important climatic factor in this area such as ENSO. The sea-air interaction in the Molucca is produced by a continue intrusion of surface water from west Pacific into North Molucca and the SST over that area are kept high by this intrusion. Although SST is not the only factor contribute to the rainfall amount in this area, we proved that with exclusion of other factor, there is an indication of an air sea interaction over this area.

ACKNOWLEDGEMENT

This research was conducted in Max Planck Institut für Meteorologie with parts of the supports come from BMBF and DAAD. The author are grateful to Ernst Meier Reimer, Uwe Micolajewicz, Lydia Dumenil Gates and other colleagues for giving a lot of helps and attentions in finishing this study. All computing works are done with the facility from the Deutsches Klima Rechen Zentrum (DKRZ). The author was supported by DAAD grant of scholarship A/99/1039.

References

Aldrian, E., 1999, Division of Climate Type in Indonesia based on Rainfall Pattern, Oceanica - J. of Marine Sci. and Tech, BPPT, 5, 165-171

Aldrian, E., 2001: Pembagian Iklim Indonesia berdasarkan pola curah hujan dengan metoda "double correlation", J. Sains & Tek. Mod. Cuaca, 2, 11-18

Bony, S., K. M. Lau and Y. C. Sud, 1997a, Sea surface temperature and large-scale circulation influences on tropical greenhouse effect and cloud radiative forcing, J. Climate, 10, 2055-77

Bony, S., Y. Sud, K.M. Lau, J. Susskind, S. Saha, 1997b, Comparison and satellite assesment of NASA/DAO and NCEP-NCAR Reanalyses over tropical ocean: Atmospheric hydrology and radiation, J. Climate, 10, 1441-62

Godfrey, J. S., A. C. Hirst and J. Wilkin, 1993: Why does the Indonesian throughflow appear to originate from the North Pacific? J. Phys. Oceanogr., 23, 1087-1098

Gordon, A.L., R. D. Susanto, A. Ffield, 1999: Thorughflow within Makasar Strait, Geophys. Res. Lett., 26, 3325-3328

Haylock, M., J. McBride, 2001: Spatial coherence and predictability of Indonesian wet season rainfall. J. Climate, 14, 3882-3887

Hirst, A. C., J. S. Godfrey, 1993: The role of Indonesian throughflow in a global ocean GCM. J. Phys. Oceanogr., 23, 1057-1086

Kalnay, E, M. Kanamitsu, R. Kistler, W. Collins, D. Deaven, L. Gandin, M. Iredell, S. Saha, G. White, J. Woollen, Y. Zhu, M. Chelliah, W. Ebisuzaki, W. Higgins, J. Janowiak, K. C. Mo, C. Ropelewski, J. Wang, A. Leetmaa, R.Reynolds, R. Jenne, D. Joseph, 1996: The NCEP/NCAR 40-year reanalysis project. Bull. Amer. Meteorol. Soc., 77, 437 – 471

Lau, K. M., H. T. Wu, S. Bony, 1997, The role of large-scale atmospheric circulation in the relationship between tropical convection and sea surface temperature, J. Climate, 10, 381-92

Nicholls, N., 1979, A simple air-sea interaction model, Quart. J. Roy. Met. Soc., 105, 93-105

Ramage, C. S., 1971: Monsoon meteorology. Academic Press, New York, 296 pp.

Rayner, N. A., E. B. Horton, D. E. Parker, C. K. Folland, and R. B. Hackett, 1996: Version 2.2 of the global sea-ice and sea surface temperature data set, 1903-1994. Climate Research Tech. Note CRTN74, 35 pp

Rodgers, K. B., M. Latif, S. Legutke, 2000: Sensitivity of equatorial pacific and Indian Ocean watermasses to the position of the Indonesian throughflow. Geophys. Res. Lett., 27, 2941-2944

Wyrtki, K., 1956, The rainfall over the Indonesian waters. Kementrian Perhubungan Lembaga Meteorologi dan Geofisik, Verhandlingen. 4

Wolff, J.O., E. Maier-Reimer and S. Legutke, 1997, The Hamburg Ocean Primitive Equation Model., DKRZ Report no 13, Hamburg, 98 pp, (available in Max Planck Institut fur Meteorologie)

BIOGRAPHY

EDVIN ALDRIAN. Born in Jakarta, 2 August 1969, received Bachelor degree in Engineering Physics in McMaster University Canada, 1993, received Master of Science in Earth Science in Radar Meteorology from Nagoya University Japan, 1998. Now doing a Doctoral degree in Max Planck Institut für Meteorologie, Germany. Work as a scientist in UPT Hujan Buatan, BPPT since November 1993. Participating several short courses: STMDP preparation program, 1988-1989; short course on Meteorology in UI, March 1995; training on data analysis of wind profiler radar in Radio Atmospheric Science Center, Kyoto University, Japan, November 1995; basic training Geographic Information System, Geography Dept. UI, June 1996; International Hydrology Programme Training Course with topic Ice and Snow Hydrology, IHAS, Nagoya University and UNESCO, March 1998; Visiting scientist in Max Planck Institut für Meteorologie, Hamburg, learn the Indonesian climate variability and ECHAM GCM, Jan – March and July – September 1999; Advanced Course: Climate change in the mediterranean region part I: physical Aspects, The Abdus Salam International Center for Theoretical Physics, Trieste, Italy, March 2001; short course on Meteorology: Predictability, Diagnostics and Seasonal Forecasting, European Center for Medium Range Weather Forecast (ECMWF), Reading, UK, April 2001; PRISM/COACh Summer School on Climate Modelling, Max Planck Institut für Meteorologie-KNMI The Netherlands, Les Diablerets, Switzerland; School on the physics of the Equatorial Atmosphere, The Abdus Salam International Center for Theoretical Physics, Trieste, Italy, September 2001.