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Original Research Paper

Local and Regional Features of Surface Radiation Fluxes Over the Tropical Atlantic Ocean Near Sao Pedro and Sao Paulo Archipelago: Evidence of Small Scale Upwelling

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ABSTRACT

To properly describe the interactions between the ocean and atmosphere, it is necessary to assess a variety of time and spatial scales phenomena. Here, high resolution oceanographic and meteorological data collected during an observational campaign carried out aboard a ship in the tropical Atlantic Ocean, on May 15-24, 2002, is used to describe the radiation balance at the ocean interface. Data collected by two PIRATA buoys, along the equator at 23ºW and 35ºW and satellite and climate data are compared with the data obtained during the observational campaign. Comparison indicates remarkable similarity for daily and hourly values of radiation fluxes components as consequence of the temporal and spatial consistence presented by the air and water temperatures measured *in situ* and estimated from large scale information. The discrepancy, mainly in the Sao Pedro and Sao Paulo Archipelago area, seems to be associated to the local upwelling of cold water, which is not detected in all other estimates investigated here. More *in situ* data are necessary to clarify whether this upwelling flow has a larger scale effect and what are the meteorological and oceanographic implications of the local upwelling area on the tropical waters at the Brazilian coast.

INTRODUCTION

A modern and important concern that has worried the scientists and the society as a whole is whether climate change of the planet is due to anthropogenic action or to natural climate variability. The quantification of the possible effects of these changes in the terrestrial climate has been made through numerical models of climatic systems. An important aspect of this simulation is the radiation balance between the ocean and the atmosphere, which occurs by accounting the short and long wave radiation components at the interface. These fluxes are responsible by (and consequence of) a significant fraction of the coupling between the ocean and the atmosphere and therefore representing a key process in the climatic system.

The ocean-atmosphere system is intrinsically coupled, although feedbacks across the air-sea interface are often masked by temporal and spatial differences in the dynamic response of both systems. The difficulty of obtaining measurements in the open ocean and the relationship between point measurements and large-scale fields are of particular importance when trying to apply the results of process studies to large scale monitoring of the earth by satellites (Liu 1993). The small-scale exchange processes are generally related to the global-scale problems via parameterizations of the fluxes using readily obtained mean quantities measured from various platforms such as buoys, ships and satellites (Liu et al. 1979). These parameterizations are also used extensively in operational meteorological models as well as in many research general circulation models of the coupled ocean-atmosphere system (Meehl 1993, Ribeiro et al. 2011). Large uncertainties exist in the derivations of parameteri-zations due to the difficulty of measuring surface fluxes directly (Bradley et al. 1991) and the difficulty of extrapolate this information to scales larger than a few hundred kilometres and several hours. The problems are particularly acute in the tropics where low wind velocities and high sea surface temperatures result in primarily buoyancy-driven fluxes that are not well parameterized by most prevailing methods (Wainer et al. 2003, Miller et al. 1992, Webster & Lukas 1992), Bonekamp 2001, Skielka et al. 2011) and coastal regions where fetch, topography and water depth vary considerably (Ribeiro et al. 2011a, 2011b, Geernaert 1990). According to Hsu & Blanchard (2003) many more field experiments are needed in order to further understand the air-sea interaction.

Despite its enormous importance, observational studies of the Brazilian maritime regions measuring radiation fluxes in the surface interface of the ocean are practically inexistent in the tropical region (Dourado & Oliveira 2011). In 1997 the PIRATA Program (Pilot Research Moored Array in the Tropical Atlantic) started to collect oceanographic and meteorological data in the Tropical Atlantic Ocean (Servain et al. 1998). PIRATA deployed and currently maintains an array of next generation ATLAS (Autonomous Temperature Line Acquisition System) buoys with the principal objective of describing and understanding the evolution of the sea surface temperature (SST), upper ocean thermal structure and air-sea fluxes of momentum, heat and freshwater in the tropical Atlantic (Servain et al. 1998). After 10 successful years of the program, a synthesis paper has been published in 2008 (Bourles et al. 2008) and the PIRATA initial denomination has been modified in "Prediction and Research Moored Array in the Tropical Atlantic". Despite the importance, the buoys in the PIRATA Program measures only incoming solar radiation and all the other fluxes of the surface energy balance at the interface had to be estimated from indirect methods. Therefore, the estimated fluxes need to be compared with other products to assess their quality.

The objective of this work is to investigate how well the high resolution (temporal and spatial) meteorological and oceanographic data obtained on board of the Brazilian Navy Ship compares to equivalent information compiled by satellite and climate data available in the investigated region.

The expedition was conducted in the Tropical Atlantic Ocean, during May 2002, near the Sao Pedro and Sao Paulo Archipelago (SPSPA), as part of the FluTuA Program (Soares et al. 2001, Bacellar et al. 2009, Oliveira et al. 2009). The ship trajectory is illustrated in Fig. 1.

The Sao Pedro and Sao Paulo Archipelago is a group of 15 small islets and rocks in the central equatorial Atlantic Ocean. It is located in the open sea at (00°55.01' N, 29°20.76' W), approximately 1100 km from the Brazilian continent (Fig. 1). It is Brazil's closest point to Africa, about 1820 km from Guinea Bissau.

The next section presents the previous *in situ* measurements carried out in the SPSPA. The data used in this work are exposed in "dataset section". The observational data obtained onboard of the ship whenever possible have been compared with the available data from buoys and satellites.

CLIMATE OF SPSPA REGION

Very little is known about the meteorological and oceanographic conditions in the SPSPA oceanic region.

The SPSPA is an outcrop of the mid-Atlantic Ridge and its largest island has an area of approximately 7500 m^2 with the highest point at 18 meters above sea level.

Previous measurements indicate the influence of the Intertropical Convergence Zone (ITCZ), which is an area of low pressure that forms where the Northeast trade winds meet the Southeast trade winds near to the Equator, over the Sao Pedro and Sao Paulo Archipelago. As these winds converge,

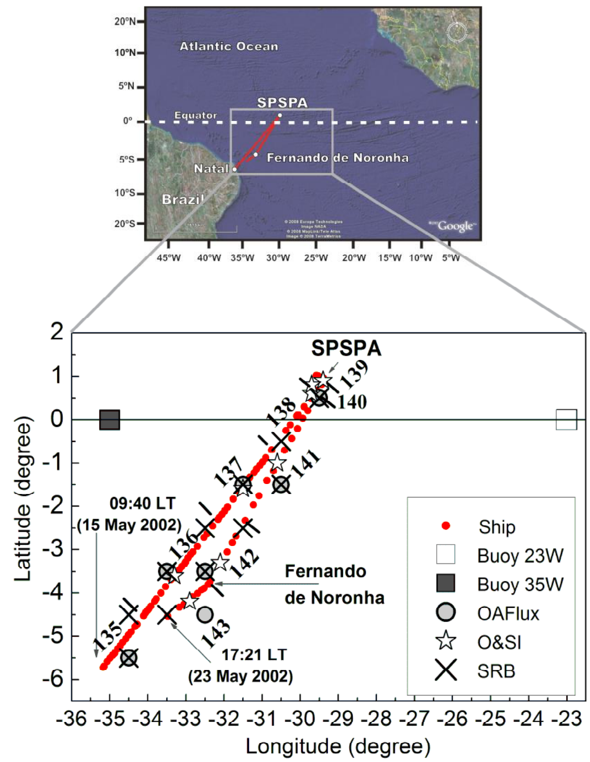

Fig. 1: Trajectory described by the ship (red circles) during the observational campaign carried out between 15 (year day 135) and 23 May (year day 143) 2002 and the geographic position of Fernando de Noronha and Sao Pedro and Sao Paulo Archipelago (SPSPA). The ship left on 15 May at 09:40 local time (LT) and arrived at SPSPA on 19 May at 10:25 LT. On 20 May at 19:40 LT the ship left SPSPA and arrived in Fernando de Noronha on 22 May at 11:50 LT and left on 23 May at 09:10 LT (LT = UTC - 3). White and gray squares indicate, respectively, the PIRATA buoy at equator and, respectively, 23ºW and at 35ºW. Gray circles indicate the OA Flux data, crosses the SRB data and gray circle designate the O&SI data.

moist air is forced upward causing water vapour to condense as the air cools and rises, resulting in a band of clouds and precipitation around the globe. This band moves seasonally and from February to May it is over the SPSPA. The maximum accumulated precipitation of 370 mm occurs in April (Soares et al. 2001, Bacellar et al. 2009, Oliveira et al. 2009).

During 1983-1984, *in situ* wind measurements were collected at the SPSPA, as part of FOCAL/SEQUAL experiment. The data indicated that the wind velocity shows a relaxation period observed from at least February through April in 1983 and from January through May in 1984. From April through November 1983 and from May to the end of October 1984, the winds were practically constant, with a mean velocity of about 6.9 m/s in 1983 and 6 m/s in 1984 (Colin & Garzoli 1987).

At the beginning of 2003, the Brazilian National Meteorological Institute sets, at the SPSPA, an automatic surface meteorological station in the middle of the island.

However, sensors and/or communication problems have prevented a complete data time series. The available data are displayed in Fig. 2.

The monthly-averaged hourly values of atmospheric pressure decrease from August to January (Fig. 2a) as a direct consequence of the seasonal migration of the Intertropical Convergence Zone or ITCZ (Soares et al. 2009, Skielka et al. 2010). The hourly values of the wind velocity do not present any diurnal cycle (Fig. 2b) and the wind direction is always from southeast (Fig. 2c). The wind velocity data, obtained in the SPSPA, experience considerable effect of the highly heterogeneous fetch. The wind intensity seems to be weaker in January when compared with the other investigated month. These results are in agreement with Colin & Garzoli (1987) and reflected again the seasonal migration of the ITCZ. During Southern Hemisphere summer the ITCZ moves towards north inducing northeasterly flow at the surface. During southern hemisphere winter it moves towards south inducing southeasterly flow at the surface levels.

The SPSPA automatic surface meteorological station also measured air temperature and relative humidity but these data are significantly affected by the SPSPA rocks and therefore there are not representative of the oceanic conditions.

In situ observations of air-sea interface fluxes, near SPSPA, are not available and estimates obtained from different climatology show important discrepancies among the fluxes (Wainer et al. 2003). This indicates that the quality of fluxes derived from various sources need to be assessed to evaluate the impact of the different author parameterizations on these discrepancies. Another factor requiring attention is how the limitations in the spatial resolution of the observations affect the representativeness of surface air-sea interactions in these estimates. In this work the latter issue will be investigated comparing surface radiation balance high resolution data with satellite and climate data estimates.

MATERIALS AND METHODS

The meteorological and oceanographic data obtained on board of the Brazilian Navy Ship on May 2002 were whenever possible compared to (i) satellite (O&SI and SRB) dataset, (ii) data collected by two PIRATA buoys, along the equator at 23ºW and 35ºW and (iii) OAFlux dataset. In this work all fluxes are considered positive when oriented upward and vice versa.

Observational Campaign Data

The observational campaign was carried out between May 15 (year day 135) and May 24 (year day 144) of 2002 on board of a ship between (60S, 35.20W) and Sao Pedro and Sao Paulo Archipelago (10N, 29.30W).

The ship positions, displayed as red circles in Fig. 1, were obtained from an onboard GPS system. This information was also used to estimate the ship velocity and direction. The wind velocity and direction were estimate using the wind velocity components measured on board of the ship and considering the ship aligned with a straight line between two consecutive GPS positions.

To reduce discrepancies between the sun actual positions at different longitudes occupied by the ship during the trip, all measurements were reported in terms of the Brazilian standard time (45°W) by taking into account the longitude variation of the ship.

The ship was set up with sensors of wind velocity and direction, air temperature, radiation and sea surface temperature (Fig. 3). The sensors were connected to the data acquisition system Datalogger 21X, manufactured by Campbell Inc. The sampling rate was set equal to 0.2 Hz and 5-min average was calculated for all variables. The characteristic of each sensor is described in Bacellar et al. (2009).

The net radiation sensor was set up in the upfront of the vessel, about 1 meter far from the ship and 6 meters above the sea surface. The air temperature sensor was set up at the upper level of the ship, near the wind sensors, at 11 m above the sea surface. Two anemometers were set up in the boom located at the upper level of the ship, also 11 m above the sea surface (Fig. 3). The anemometers were oriented in the direction parallel and perpendicular to the ship.

The measurements were performed, most of the time, at open oceanic conditions where the air temperature was higher than the sea surface temperature. Only near the continent (very beginning of the experiment and near Fernando de Noronha, Fig. 4) the air temperature was, during a relatively long time period, lower than the sea surface temperature. Fernando de Noronha is an archipelago of 21 islands and islets in the Atlantic Ocean, 354 km offshore from the Brazilian coast. The main island has an area of 18.4 km^2 being 10 km long and 3.5 km wide at its maximum and has a population of around 3,012 people.

Prediction and Research Moored Array in the Tropical Atlantic (PIRATA)

From PIRATA dataset it was selected values of sea surface temperature, velocity and direction of wind (measured at 4 m above the mean sea level), air temperature (3 m above the mean sea level) and downwelling shortwave radiation (3.5 m above the mean sea level), collected by two ATLAS buoys with temporal resolution of 10 minutes (http://www.pmel.noaa.gov/pirata/), along the equator at 23ºW and 35ºW (Fig. 1).

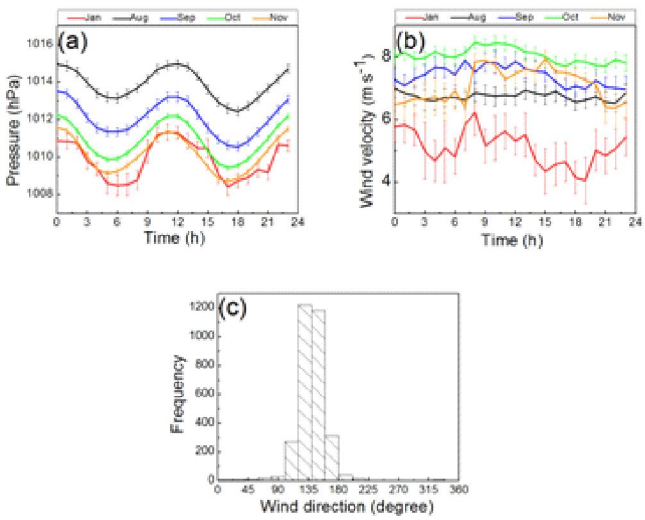

Fig. 2: Monthly-averaged hourly values of (a) atmospheric pressure (hPa), (b) wind velocity (ms^{-1}) and (c) wind direction (degree). The error bars indicate the standard deviation of the average values. Data obtained in the SPSPA by the Brazilian National Meteorological Institute.

Ocean and Sea Ice Satellite Application Facility (O&SI-SAF) dataset

This work uses surface incident shortwave radiation (SW_{DW}) and downward longwave radiation (LW_{DW}) data from "Ocean and Sea Ice Satellite Application Facility" (O&SI-SAF) available in the same time and place of the ship data. The input satellite data are the GOES-E + MSG and the data have spatial resolution of 0.1 degree and frequency of three hours, at 02:30, 05:30,...,23:30 UTC. O&SI-SAF dataset details can be found in (http://www.osi-saf.org). Fig. 1 shows, with stars, the places where there are simultaneous data from O&SI-SAF and from the ship. The data utilized here were obtained in the internet (http://www.ifremer.fr/las/servlets/dataset).

NASA/GEWEX Surface Radiation Budget (SRB)

The NASA/GEWEX Surface Radiation Budget (SRB) data used here consist of three-hourly values of incoming and outgoing shortwave (SW_{DW} and SW_{UP}) and longwave radiation (LW_{DW} and LW_{UP}) at the surface estimated from satellite data and provided by the SRB project of the Atmospheric Science Data Center of NASA (http://gewex-srb.larc.nasa.gov/). These estimates have a spatial resolution of 1° of latitude by 1° of longitude and are derived from the vertical structure of the atmosphere and surface properties datasets combined with satellite observations and radiation transfer equations for shortwave and longwave radiation (Pinker & Laszlo 1992, Gupta et al. 1999, Stackhouse et al. 2000). Fig. 1 illustrates, with crosses, the places where there are simultaneous data from SRB and from the ship.

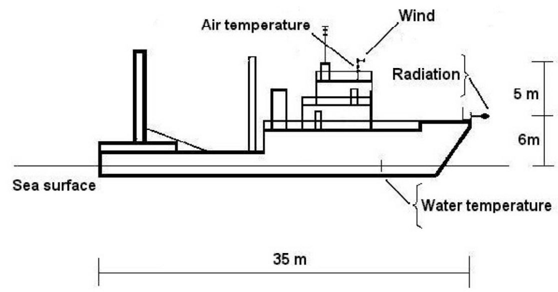

Fig. 3. Scheme of the Brazilian Navy Ship illustrating the instrument positions.

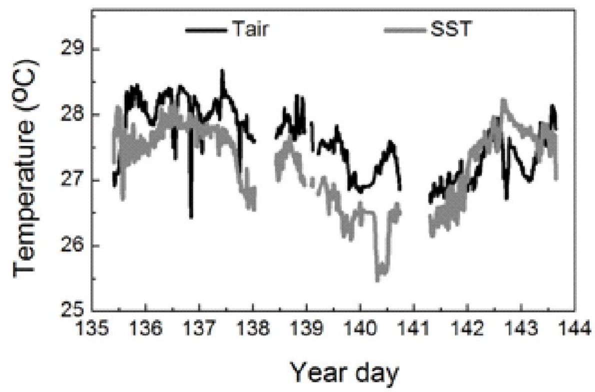

Fig. 4: Air (black line) and sea surface temperature (gray line) obtained by the ship experiment.

Objectively Analysed Air-Sea (OAFlux)

Wind velocity at 10 m, air temperature at 2 m and sea surface temperature data were obtained from "Objectively Analysed Air-Sea" (OAFlux). The data provided 1-degree global analysis and temporal resolution of 1 day (http://oaflux.whoi.edu/data.html). Details can be found in Yu & Weller (2008). In Fig. 1 the OAFlux data are displayed as gray circles.

RESULTS

The daily-average values of SST, air temperature and wind velocity obtained by the ship show, in general, a good agreement with the data collected by the PIRATA buoys and with the OAFlux data (Figs. 5 a-c).

The daily-average SST values vary, during the investigated period, from 26.1°C to 28.3°C (Fig. 5a). The lowest SST value is obtained by the ship, at year day 140, when the ship is near the SPSPA (Fig. 1). These smaller values occur probably due the local upwelling induced by the SPSPA presence, however, the spatial resolution of the OAFlux data is not enough to solve small scale phenomenon. Araujo & Cintra (2009) suggest that the interaction of currents with the SPSPA topography can generate local

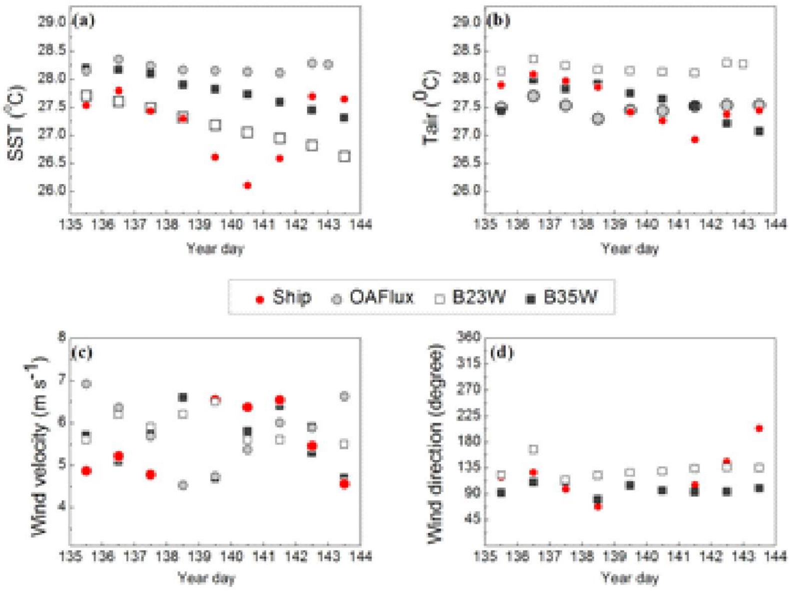

Fig. 5: Daily-average values of (a) sea surface temperature (ºC), (b) air temperature, (ºC) wind velocity (ms^{-1}) and (d) wind direction (degree). Red circle indicates the ship data, gray circle the OAFlux data and the white and black squares specify, respectively, the data from the PIRATA buoy at equator and 23ºW and at 35ºW, respectively.

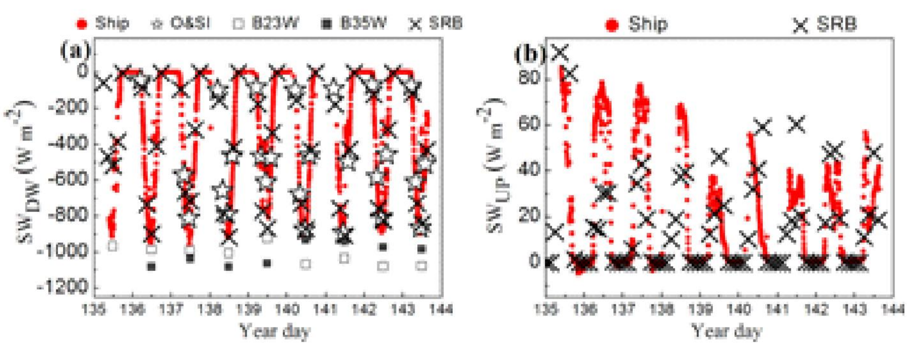

Fig. 6: Time variation of the (a) incoming shortwave radiation data (SW_{DW}) and (b) reflected shortwave radiation (SW_{UP}) collected during the whole observational campaign aboard of the ship (red circle). The white stars represent the O&SI data, the black crosses the SRB data and white and gray squares represent, respectively, the SW_{DW} daily maximum values obtained by the 23ºW and by the 35ºW PIRATA buoys.

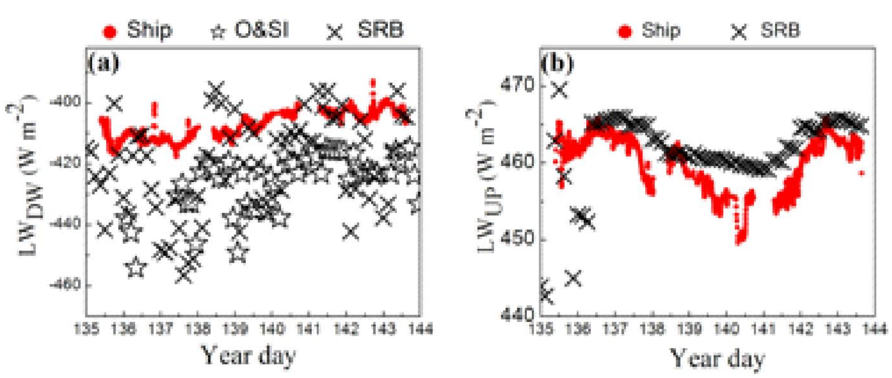

Fig. 7: Time variation of the longwave radiation emitted by the (a) atmosphere (LW_{DW}) and (b) sea surface (LW_{UP}) during the whole observational campaign aboard of the ship (red circle), the O&SI data (white star) and the SRB data (black cross).

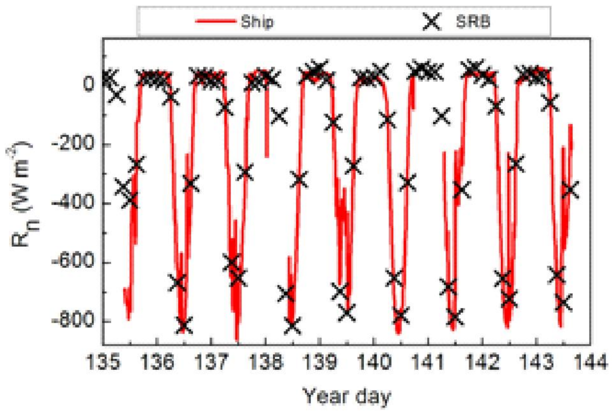

Fig. 8: Time variation of the net radiation (R_n) during the whole observational campaign aboard of the ship (red line). The SRB data values are displayed as black crosses.

upwelling. According to Diaz et al. (2008), the SPSPA area is characterized by the presence of local upwelling that induces the ascent of bottom waters rich in nutrients, generating areas of larger productivity than the typically oligotrophic equatorial Atlantic waters. Becker (2001) also observed upwelling in the oceanic area close to the Sao Pedro and Sao Paulo Archipelago, based on the elevations of the isotherms, low oxygen and high superficial concentration of the nutrients. According to Tiburcio et al. (2011) the upwelling presence could explain the higher number of phytoplankton in the SPSPA area.

After year day 142 the SST values from OAFlux dataset and from ship increase due to the presence of Fernando de Noronha. Fernando de Noronha is an archipelago of 21 islands and islets in the Atlantic Ocean, 354 km offshore from the Brazilian coast. The main island has an area of 18.4 km^2 and has a population of around 3,012 people.

The SST values obtained by the PIRATA buoys decrease during all the investigated period (Fig. 5a) because the buoys are placed far from SPSPA and Fernando de Noronha to feel their presence.

The higher daily-average air temperature values were obtained by the PIRATA buoy at 23ºW but, in general, there is a good agreement among the different dataset. During the investigated period, the air temperature varies 1.5°C. The small temperature was obtained by the ship near the SPSPA (Fig. 5b).

In general, there is agreement among the daily-average wind velocity values. The smallest value (4.5 m/s) and the highest value (6.9 m/s) were obtained using OAFlux dataset (Fig. 5c). The wind direction daily-average values are predominant from east, varying from 45° to 180° (Fig. 5d) in all the investigated dataset.

The observational radiation fluxes obtained aboard the ship are discussed in details in Bacellar et al. (2009). Here, only the main results are presented.

The incoming shortwave radiation data (SW_{DW}) collected during the whole observational campaign aboard the ship, the O&SI data, the SRB data and the SW_{DW} daily maximum values obtained by the 23°W and 35°W PIRATA buoys, are displayed in Fig. 6a. In general, there is a remarkable agreement between the ship and the satellite datasets. The agreement among the maximum SW_{DW} values obtained by the ship and by the PIRATA buoys indicates that the incoming shortwave radiation data collected by ship can be considered representative of the investigated region. The agreement is also good between the reflected shortwave (SW_{UP}) obtained by the ship and by the SRB dataset (Fig. 6b).

The longwave radiation emitted by the atmosphere (LW_{DW}) indicates a reasonable agreement between the ship data and the satellite data (O&SI and SRB), as indicated in Fig. 7a. Most of the difference between them is less than 10%.

There is a good agreement between the longwave radiation emitted by the sea (LW_{UP}) measured by ship and the SRB values (Fig. 7b). However, in the beginning of the investigated period there are some suspicious low values from OAFlux. At year day 140, the longwave radiation emitted by the sea (LW_{UP}) measured by the ship (Fig. 7b) reflects the low SST values observed near the SPSPA (Fig. 5a).

The time evolution of the net radiation (R_n) obtained by the ship and from the SRB dataset shows a good agreement between them (Fig. 8). It indicates that the radiation data obtained by the ship are representative of the radiometric properties of the air-sea interface in the region of the Tropical Atlantic Ocean.

SUMMARY AND CONCLUSIONS

The air-sea surface fluxes are characterized by a large spatial and temporal variability and play an important role in the atmospheric and oceanic circulation. Therefore, a good knowledge of air-sea fluxes is required for the understanding and prediction of climate changes.

The air-sea surface fluxes are characterized by a large spatial and temporal variability and play an important role in the atmospheric and oceanic circulation. Therefore, a good knowledge of air-sea fluxes is required for the understanding and prediction of climate changes.

Direct measurements of the air-sea fluxes, in general, are not available in a number large enough to reduce the uncertainties inherent to the calculation of the large-scale flux fields over the ocean. Rather they are used for developing, calibrating and verifying the parameterization formula used to estimate the fluxes from basic variables. The accuracy of the direct flux determinations thus represents a limit for the accuracy of the indirect estimates (WGASF 2000).

The air-sea energy fluxes, near the SPSPA, obtained from different climatology show important discrepancies among them indicating the need of more intensive quality assessment of the fluxes derived from different sources. An accurate determination of exchanges between the ocean and the atmosphere is a prerequisite to identify and evaluate the mechanisms of interaction that control part of the variability in both media over a wide range of spatial and temporal scales.

The objective of this work was to investigate how well the high resolution (temporal and spatial) meteorological and oceanographic data obtained on board of a ship compare to equivalent information compiled by satellite and climate data available in the SPSPA area. It was considered a period of almost 10 days in May of 2002 when it was performed 5-min average measurements of (a) solar radiation fluxes (incoming and outcoming) and longwave radiation fluxes (atmospheric and surface emission), at 6 m above the sea level; (b) air temperature, relative humidity and horizontal wind components, at 11 m and (c) sea surface temperature.

The comparison between the ship data and other datasets showed, in general, a good spatial representation of the data collected during the observational campaign. However, local phenomena were only captured by *in situ* measurements.

There are evidences from biological studies supporting the inference that the SPSPA is located in an upwelling area as indicated by the ship data. This small scale phenomenon is not captured by all the other estimates investigated here.

More *in situ* data are necessary to clarify whether this upwelling flow has an effect on larger area and what are the meteorological and oceanographic implications of the local upwelling area on the tropical waters at the Brazilian coast.

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REFERENCES

Araujo, M. and Cintra, M. 2009. Modelagem matematica da circulacao oceanica na regiao equatorial do Arquipelago de Sao Pedro e Sao Paulo. In: O arquipelago de São Pedro e Sao Paulo: 10 anos de estacao cientifica. ISBN: 978-85.62033-00-1. SECIRM, Brasilia, 106-113. https://www.mar.mil.br/secirm/publicacao/arquipe.pdf.

Bacellar, S., Oliveira, A.P., Soares, J. and Servain, J. 2009. Assessing the diurnal evolution surface radiation balance over the Tropical Atlantic Ocean using in situ measurements carried out during the FluTuA Project. Meteorological Application, 16: 255-266. http://dx.doi.org/10.1002/met.111.

Becker, H. 2001. Hidrologia dos bancos e ilhas oceânicas do nordeste brasileiro. Uma contribuição ao Programa Revize. PhD Thesis, Universidade Federal de Sao Carlos, Brazil. http://www.bdtd.ufscar.br/htdocs/tedeSimplificado/tde_arquivos/2/TDE-2004-06-18T14:35:48Z-73/Publico/TeseHB.pdf.

Bonekamp, H. 2001. On the Physical Air-Sea Fluxes for Climate Modeling. Ph.D. Thesis, University of Utrecht, Utrecht.

Bourles, B., Lumpkin, R., McPhaden, M.J., Hernandez, F., Nobre, P., Campos, E., Yu, L., Planton, S., Busalacchi, A.J., Moura, A.D., Servain J. and Trotte, J. 2008. The PIRATA program: history and accomplishments of the 10 first years tropical Atlantic observing system's backbone, Bulletin of the American Meteorological Society, 89(8): 1111-1125. http://dx.doi.org/10.1175/2008BAMS2462.1.

Bradley, E.F., Coppin, P.A. and Godfrey, J.S. 1991. Measurements of sensible and latent heat flux in the western equatorial Pacific Ocean. J. Geophys. Res., 96: 3375-3389.

Colin, C. and Garzoli, S.L. 1987. In situ wind measurements and ocean response in the equatorial Atlantic during the Programme Francais Ocean et Climat Dans l'Atlantique Equatorial and seasonal response of the Atlantic Ocean experiment. J. Geophys. Res., 92(4): 3741-3750. http://dx.doi.org/10.1029/JC092iC04p03741.

Diaz, X.F.G., Gusmao, F.G., Oliveira, L.M. and Neumann-Leitao, S. 2008. New record of Thalia cicar van Soest 1973 (Urochordata: Thaliacea) in the Equatorial Atlantic. Biota Neotrop. [online], 8: 3. http://dx.doi.org/10.1590/S1676-06032008000300009.

Dourado, M. and Oliveira, A.P. 2001. Observational description of the atmospheric and oceanic boundary layers over the Atlantic Ocean, Braz. J. Oceanogr., 49 (1-2): 49-59. http://dx.doi.org/10.1590/S1679-87592001000100005.

Geernaert, G.L. 1990. Bulk parameterizations for the wind stress and heat fluxes. In Surface Waves and Fluxes, Volume 1, Current Theory, Edited by G.L. Geernaert, and W.J. Plant, Kluwer Academic Publishers, pp. 91-172.

Gupta, S.K., Ritchey, N.A., Wilber, A.C, Whitlock, C.H., Gibson, G.G. and Stackhouse, P.W. Jr 1999. A climatology of surface radiation balance derived from satellite data. J. Climate, 12: 2691-2710. http://dx.doi.org/10.1175/1520-0442(1999)012.

Hsu, S.A. and Blanchard, B.W. 2003. Recent Advances in Air-Sea Interaction Studies Applied to Overwater Air Quality Modeling: A Review, 1: 297-316.

Liu, W.T. 1993. Evaporation from the ocean. In: Atlas of Satellite Observations Related to Global Change, Edited by R.J. Gurney, J.L. Foster, and C.L. Parkinson, Cambridge University Press, pp. 265-278.

Liu, W.T., Katsaros, K. and Businger, J.A. 1979. Bulk parameterization of air-sea exchanges of heat and water vapor including the molecular constraints at the surface, J. Atmos. Sci., 36: 1722-1735. http://dx.doi.org/10.1175/1520-0469(1979)036<1722:BPOASE>2.0.CO;2.

Meehl, G.A. 1993. A coupled air-sea biennial mechanism in the tropical Indian and Pacific regions: Role of the ocean. J. Climate, 6: 31-41. http://dx.doi.org/10.1175/1520-0442(1993)006<0031:ACASBM>2.0.CO;2

Miller, M.J., Beljaars, A.C.M. and Palmer, T.N. 1992. The sensitivity of the ECMWF model parameterization of evaporation from the tropical oceans, J. Climate, 5: 418-434. http://dx.doi.org/10.1175/1520-0442(1992)005<0418:TSOTEM>2.0.CO;2

Oliveira, A.P., Soares, J. and Servain, J. 2009. Preliminary results from the

FluTuA Project: Micrometeorological in situ measurements at St. Peter and St Paul Archipelago (01°N-29°W). Tropical Atlantic Variability Meeting & PIRATA-14 SCC/PRB Meeting, Toulouse, France, 2nd-6th February, 21-22.

Pinker, R.T. and Laszlo, I. 1992. Modeling surface solar irradiance for satellite applications on a global scale. J Appl. Meteor., 31: 194-211. http://dx.doi.org/10.1175/1520-0450(1992)031.

Ribeiro, F.N.D., Soares, J. and Oliveira, A.P. 2011a. A coupled numerical model to investigate the air-sea interaction at the coastal upwelling area of Cabo Frio, Brazil. Environmental Fluid Mechanics, 11(6): 551-572. http://dx.doi.org/10.1007/s10652-011-9220-5.

Ribeiro, F.N.D., Soares, J. and Oliveira, A.P. 2011b. The co-influence of the sea breeze and the coastal upwelling at Cabo Frio: A numerical investigation using coupled models. Braz. J. Oceanogr., 59(2): 131-144. http://dx.doi.org/10.1590/S1679-87592011000200002.

Servain, J., Busalacchi, A.J., McPhaden, M.J., Moura, A.D., Reverdin, G., Vianna, M. and Zebiak, S.E. 1998. A Pilot Research Moored Array in the Tropical Atlantic (PIRATA). Bull. Am. Met. Soc., 79: 2019-2031. http://dx.doi.org/10.1175/1520-0477(1998)079<2019:APRMAI>2.0.CO;2.

Skielka, U.T., Soares, J. and Oliveira, A.P. 2010. Study of the equatorial Atlantic oceanic mixing layer using a one-dimensional turbulence model. Brazilian Journal of Oceanography, 58: 57-69. http://dx.doi.org/10.1590/S1679-87592010000700008.

Skielka, U.T., Soares, J. and Oliveira, A.P. 2011. Diagnostic of the diurnal cycle of turbulence of the Equatorial Atlantic Ocean upper boundary layer. Natural Science, 3: 444-455. http://dx.doi.org/10.4236/ns.2011.36061.

Soares, J., Oliveira, A.P., Wainer, I. and Servain, J. 2001. Turbulent fluxes over the tropical Atlantic Ocean. Proceedings of the WCRP/SCOR Workshop Intercomparison and Validation of Ocean-Atmosphere Flux Field, 21-24 May 2001, Washington, DC, EUA, 334-337.

Soares, J., Oliveira, A.P., Skielka, U. and Servain, J. 2009. O Ar. In O arquipelago de Sao Pedro e Sao Paulo: 10 anos de estacao cientifica. ISBN: 978-85.62033-00-1. SECIRM, Brasília, 37-44. https://www.mar.mil.br/secirm/publicacao/arquipe.pdf.

Stackhouse, P.W. Jr, Gupta, S.K., Cox, S.J., Chiacchio, M. and Mikovitz, J. 2000. The WCRP/GEWEX Surface Radiation Budget Project Release 2: An Assessment of Surface Fluxes at 1 Degree Resolution. Technical Report. NASA Langley Technical Report Server.

Tiburcio, A.S.X.S., Koening, M.L., Macedo, S.J. and Melo, P.A.M.C. 2011. Microphytoplankton community of Sao Pedro e Sao Paulo Archipelago (Atlantic North Equatorial): diurnal and spatial variation. Biota Neotrop., 11(2): 1-13. http://www.biotaneotropica.org.br/v11n2/en/abstract?article+bn03811022011.

Wainer, I., Taschetto, A., Soares, J., Oliveira, A.P., Otto-Bliesner, B. and Brady, E. 2003. Intercomparison of heat fluxes in the South Atlantic. Part 1: The seasonal cycle. Journal of Climate, 16(4): 706-714. http://dx.doi.org/10.1175/1520-0442(2003)016<0706:IOHFIT>2.0.CO;2

Webster, P.J. and Lukas, R. 1992. TOGA COARE. The coupled ocean atmosphere response experiment. Bull. Am. Meteor. Soc., 72: 1377-1416. http://dx.doi.org/10.1175/1520-0477(1992)073<1377:TCTCOR>2.0.CO;2

WGASF 2000. Intercomparison and validation of ocean-atmosphere energy flux fields. Final Report of Joint WCRP/SCOR Working Group on Air-Sea fluxes-SCOR working group 110 (http://eprints.soton.ac.uk/69522/).

Yu, L., Jin, X. and Weller, R.A. 2008. Multidecade Global Flux Datasets from the Objectively Analyzed Air-sea Fluxes (OAFlux) Project: Latent and Sensible Heat Fluxes, Ocean Evaporation, and Related Surface Meteorological Variables. OA-2008-1, Woods Hole Oceanographic Institution, 64 pp., URL:http://www.dss.ucar.edu/datasets/ds260.1/docs/OAFlux_TechReport_3rd.