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Trends of variations in the mean annual surface temperature and salinity anomalies in the Southern Hemisphere

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Using linear and quadratic regression approaches, the present work aims at drawing the general long-term behaviour of the mean annual surface temperature and salinity anomalies (MASTA & MASSA) within the South Atlantic and the South Pacific Oceans. The dataset covers 103 years (1911-2013) within the former, while it covers 155 years (1859-2013) within the latter ocean. The MASTA variations in the two southern oceans reflect opposite linear and quadratic trends of variations. The linear trends of MASSA are also in contrast. On the other hand, the quadratic regression, reflecting a cyclic trend of variation in the MASSA, has the same parabolic form in the two basins but with different years of maximum occurrence. The decreasing trends in the MASSA of Pacific Ocean may be attributed to the ice melting process, the interannual variability of evaporation and the amount of precipitation over the Pacific than on the Atlantic.

[**Keywords**: Anomalies, Atlantic Ocean, Pacific Ocean, Surface temperature, Surface salinity, Southern Hemisphere]

Introduction

The sea surface temperature (SST) is one of the important parameters identified by the Intergovernmental Panel on Climate Change (IPCC) for climate change research[1]. However, monitoring long-term changes in global SST is stuck by many factors[2]: (1) size of world oceans, (2) changes in instrumentations and (3) difficulty of taking measurements at sea. In general, the patterns of warming and cooling of SST depend on the interval over which trends have been calculated[2]. Variations in sea surface salinity (SSS) are also vital for our understanding of the global climate change[3]. Salinity variations affect sea level change; due to the addition/removal of freshwater and also due to the haline contraction factor in sea level density calculations[3,4]. Changes in the SSS are linked to alterations in global hydrographical cycle and are expected to be a consequence of climate change[5]. The poor spatial and temporal samplings in addition to inhomogeneous measurement practices preclude accurate determination of long-term SST and SSS trends[3,6].

Despite the above-mentioned difficulties, attempts to investigate trends of the two parameters, SST and SSS, have been reported on both regional and global scales. This comprises, but not limited to the cited studies[7-23]. The investigated trend in the majority of the work so far done on the changes in these surface hydrographic parameters was from a liner trend point of view; in order to specify the rates of increase/decrease. However, many researchers have spotted light on and concluded the cyclic nature in the long-term variations of the investigated parameters rather than the widely known concept of continuous increasing/decreasing trends.

On a local scale, the authors of the present study initially investigated the long-term variations in the hydrography[18,19]; the climate[24] and fish catch[25] in the South-eastern Mediterranean Sea. The results obtained strong-minded cyclic behaviour in the changes of the studied parameters, and expanded the focal point of interest from local to regional scale[26] depending on the cyclic occurrence of the phenomenon of the Nile drought. Moreover, the authors expanded their investigation to cover the long-term changes in hydrographic parameters in the Northern Hemisphere[21]. The outcomes were in agreement with the detected 70-year cycle determined by other researchers worldwide[27-30].

The present work aims at modelling the general long-term trends in the mean annual SST and SSS anomalies of the Southern Hemisphere within the Atlantic and the Pacific Oceans. It is carried out by applying the same techniques of linear and quadratic regressions, applied by the authors in the previous research. The paper compares the present results with those at the same latitudinal area in the Northern Hemisphere, comprising the South-eastern Mediterranean Sea; in an attempt to contribute in the conclusions about the global behaviour of variation in the mean annual SST and SSS anomalies.

Materials and Methods

Data and methods of analysis

Figure 1 shows two water bodies within the South Atlantic and South Pacific Oceans, extending latitudinally between 30°00’ and 33°00’ S and longitudinally between 20°00’ and 40°00’ W, and from 140°00’ to 180°00’ W in the two oceans, respectively. While four grids of the size 5°x3° were constructed to cover the South Atlantic, and four grids of the size 10°x3° were constructed in the South Pacific. These are chosen to be large enough to get records through most of the available period. Surface hydrographic data on temperature and salinity records were collected from all possible sources; in order to examine the long-term variations in the surface hydrographic anomalies, in the specified areas within the two oceans. While available surface hydrographic parameters in the South Pacific cover the period 1859-2013, and those in the South Atlantic cover the period 1911-2013. The sources of data are the World Data Centre WDC A (Washington) & WDC B (Moscow), in addition to the Ocean Data View (ODV) data bank and the ARGO archive (2005-2013). However, due to the well-known bad data distribution, both spatially and temporally, the present research can be considered as a qualitative research. According to previous research[20,21,31,32], the surface layer record is taken as the mean of the upper 20 m layer records; in order to compensate the diurnal variation.

The mean annual surface temperature over the available period of records and the annual mean surface temperature for every available year in the whole data set were calculated. This is essential to secure a full elimination of effects of any cycles on the final calculations and results.

The deviation from the annual mean is calculated to express the Mean Annual Surface Temperature Anomaly (MASTA), using the following equation:

$$\Delta T = T - T_a \qquad \text{... (1)}$$

Where, ΔT - is the MASTA (°C), T - is the mean annual surface temperature (°C, mean for specific year) and T_a - is the annual mean surface temperature (°C, mean for all available years).

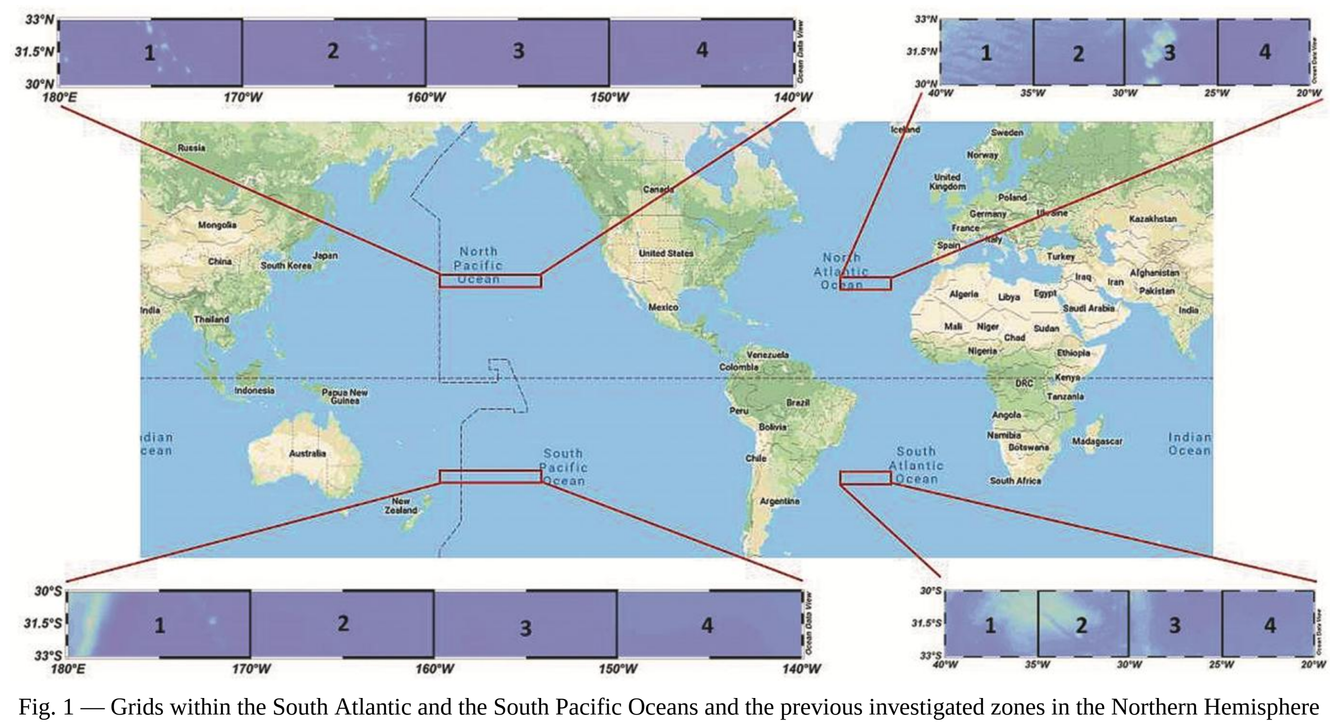

Fig. 1 — Grids within the South Atlantic and the South Pacific Oceans and the previous investigated zones in the Northern Hemisphere

The same calculation has been performed for the data set of the surface salinity. The Mean Annual Surface Salinity Anomaly (MASSA) is, therefore, mathematically expressed as:

$$\Delta S = S - S_a \quad \text{... (2)}$$

Where, ΔS - is the MASSA, S - is the mean annual surface salinity (mean for specific year) and S_a - is the annual mean surface salinity (mean for all available years).

The general trends of the variations in the MASTA and MASSA within the two oceans, representing the Southern Hemisphere in the present study, are examined using both linear and quadratic regression approaches. The representative equations for each regression model are generated and the trends of variations are drawn. This technique was previously applied by the authors at the same latitudinal and longitudinal zones in the Northern Hemisphere[21] to examine its long-term variations in the surface hydrographic anomalies.

Results

The South Atlantic Ocean

Trends of variations in the South Atlantic MASTA

Figure 2a shows the distribution and the trends of variation in the South Atlantic Ocean MASTA. Linearly, there is a general increase in the calculated MASTA. This increase has a rate of 0.02 °C/yr. Quadratically, over the period of investigation, the South Atlantic Ocean MASTA has a concave-down parabolic form, the maximum of which occurred in the year 2008. The representative equations of both the linear and quadratic regression models, respectively, are:

$$y = 0.0182\,x - 36.248;\ r = 0.50 \quad \text{... (3)}$$

$$y = -0.0003\,x^2 + 1.0107\,x - 1014.2;\ r = 0.54 \quad \text{... (4)}$$

Trends of variations in the South Atlantic MASSA

Over the period (1911-2013), the South Atlantic Ocean MASSA revealed a linear salinification trend with a rate of +0.003/yr (Fig. 2b). From a quadratic point of view, the South Atlantic MASSA is presented by a concave-down parabola, the maximum of which occurred in 2011. The variations in the South Atlantic Ocean MASSA can be mathematically represented by the following Equations:

$$y = 0.0029\,x - 5.8655;\ r = 0.50 \quad \text{... (5)}$$

$$y = -0.00004\,x^2 + 0.1727\,x - 172.95;\ r = 0.5 \quad \text{... (6)}$$

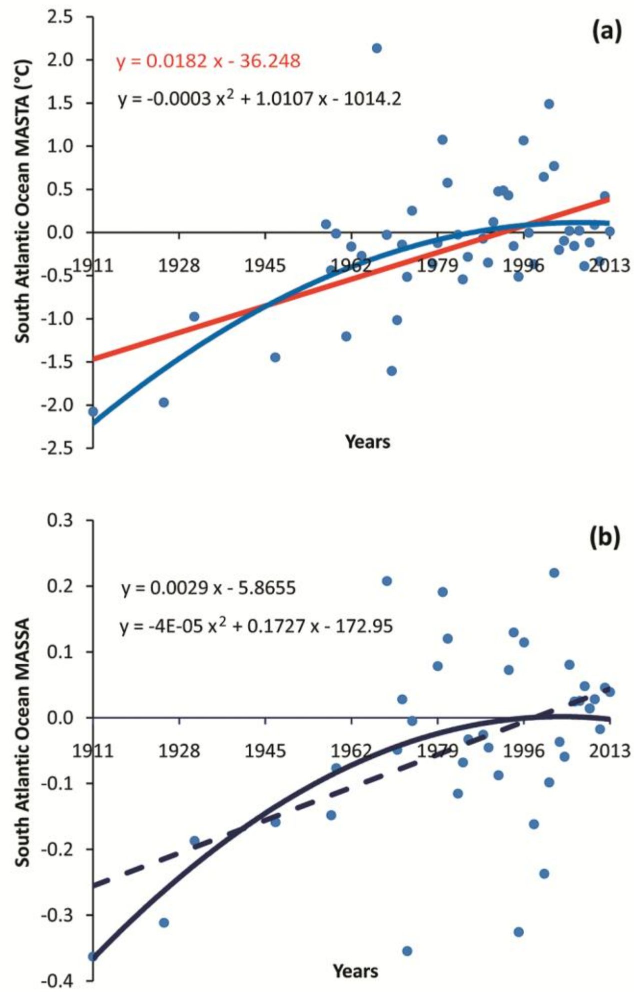

Fig. 2 — Variations in the South Atlantic Ocean during 1911-2013: a) MASTA and b) MASSA

The South Pacific Ocean

Trends of variations in the South Pacific MASTA

The MASTA in the South Pacific Ocean over the period of investigation (1859-2013) showed a decreasing linear trend, as shown in Figure 3a, with a rate of -0.01 °C/yr. Quadratically, the South Pacific Ocean MASTA has an up-looking parabola, the minimum of which occurred in 1971. The two regression models can be respectively presented by the following Equations:

$$y = -0.0078\,x + 15.604;\ r = 0.21 \quad \text{... (7)}$$

$$y = 0.0002\,x^2 - 0.6734\,x + 663.71;\ r = 0.33 \quad \text{... (8)}$$

Trends of variations in the South Pacific MASSA

Figure 3b shows the linear and quadratic regression models and distribution of the South Pacific Ocean MASSA. The linear trend over the period (1859-2013) reflects a very weak decrease in the MASSA,

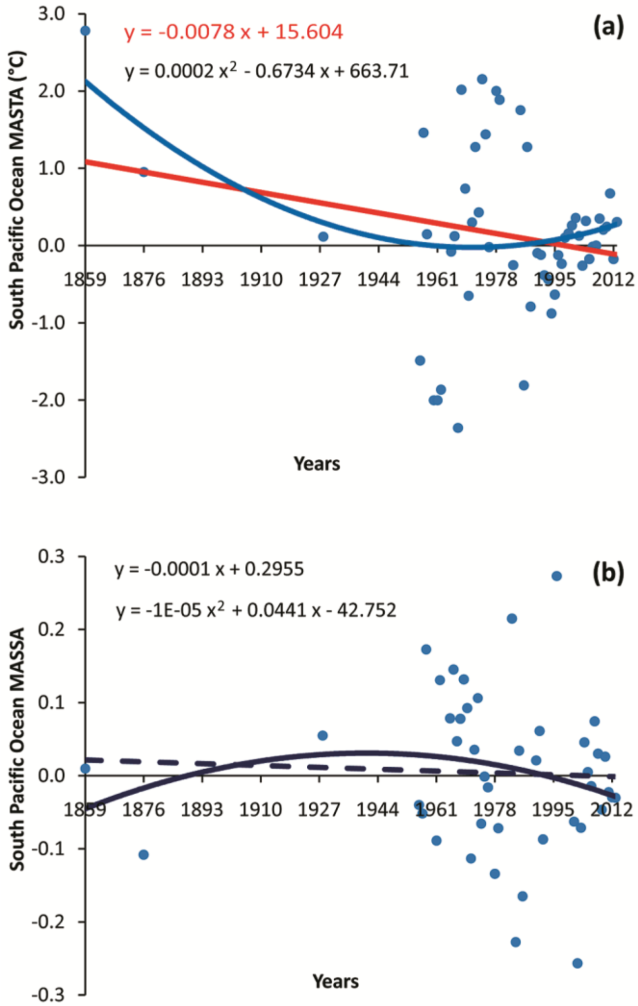

Fig. 3 — Variations in the South Pacific Ocean during 1859-2013: a) MASTA and b) MASSA

with a rate of 0.0001/yr. The quadratic model reflects a cyclic trend of variations with a concave-up parabola, the maximum of which occurred in 1959. The two regression models can be mathematically represented by the following equations, respectively:

$$y = -0.0001\ x + 0.2955;\ r = 0.03 \quad \text{... (9)}$$

$$y = -0.00001\ x^2 + 0.0441\ x - 42.752;\ r = 0.21 \quad \text{... (10)}$$

Discussion

The present work aims to draw the possible changes in the mean annual anomalies of the surface hydrographic parameters, namely: temperature and salinity in the Southern Hemisphere, taking two areas within the South Atlantic and South Pacific Oceans as areas of interest. The investigation is carried out by using the linear and quadratic regression approaches. This technique was previously used by the authors to examine the long-term variations in the South-eastern Mediterranean Sea[18,19] and within the Atlantic and Pacific basins at the same latitudinal area in the Northern Hemisphere[21].

Table 1 — Rates of variations in the MASSA in North and South Atlantic and Pacific Oceans

	North Atlantic (Maiyza *et al.*[15])	North Pacific (Maiyza *et al.*[15])	South Atlantic (Present work)	South Pacific (Present work)
MASSA rates	+0.045	-0.016	+0.003	-0.0001

The linear trends of variations of MASTA in the two oceans reflect opposite trends; while in the South Atlantic Ocean it has an increasing trend, as concluded in the North Atlantic Ocean[21], with a rate of 0.02 °C/yr. It has a decreasing trend in the South Pacific Ocean with a rate of -0.01 °C/yr. This decreasing trend contradicts the observations for the North Pacific Ocean[21]. The decreasing trend in the MASTA may be attributed to the effect of ice-melting process in the Antarctica. The MASTA quadratic trend in the South Pacific Ocean followed the results obtained for the Northern Hemisphere in both the Atlantic and Pacific Oceans, with a minimum occurrence in 1971. The MASTA in the South Atlantic Ocean, on the other hand has reflected an opposite parabolic form, with a maximum occurrence in 2008. Generally speaking, a cyclic behaviour in the variations of MASTA in the two basins can be concluded.

The linear trends of MASSA are in contrast between the two oceans. There was a general trend of increase over the study period (1911-2013) with a rate of +0.003/yr in the South Atlantic Ocean. The South Pacific had a very weak decreasing rate of -0.0001/yr over the period (1859-2013). This contradiction might refer to the interannual variability of ice melting, evaporation and rainfall process over the Pacific than on the Atlantic Ocean. In comparison with the results for the Northern Hemisphere[21], the rates of variations in the Southern Hemisphere are much less than those in the Northern Hemisphere as shown in Table 1.

From a quadratic point of view, the long-term variations in the MASSA in the two Oceans reflect a parabolic form, the maximum of which occurred in 2011 and 1959 for the South Atlantic and the South Pacific, respectively. These looking-down parabola are opposite to that concluded[21] for the same Oceans in the Northern Hemisphere. The produced forms may reflect a cyclic behaviour of variations in the MASSA.

Conclusion

In conclusion, cyclic trends of both sea surface temperature and surface salinity anomalies can be identified in the two oceans in the Southern Hemisphere. The decreasing trends in the MASSA over the whole basin of the Pacific Ocean (present work and Maiyza *et al*.[21]) may be attributed to the ice melting process, the interannual variability of evaporation and precipitation in the Pacific compared to Atlantic Ocean.

Conflict of Interest

The authors of the submitted manuscript 'Trends of variations in the mean annual surface temperature and salinity anomalies in the Southern Hemisphere' to 'Indian Journal of Geo-marine Sciences' declare that they have no affiliation with any organization with a direct or indirect financial interest or personal relationships in the subject reported in the manuscript.

Author Contributions

Conception and design of the manuscript by all the authors; Analysis and interpretation of the data: TMG & HIM; Drafting the article TMG; Revising the manuscript content: IAM; and approval of the submitted manuscript version by all the authors.

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