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Retrieving Remotely Sensed Data Using Plank Algorithm in the Black Sea and Surrounding Seas (2008-2018)

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Abstract

The Black Sea is the world's largest inner sea, its only connections with other seas being the Kerch Strait, which leads to the Azov Sea, and the Istanbul Strait, which connects it with the Mediterranean Sea. The main aim of this study processes to image analysis and applied algorithm, to retrieve remote SST data from satellite, to assess the estimated SSTs, to understand the characteristics of SST by presenting in the Black Sea and surrounding seas, to discuss the SSTs changes according to climate change impacts. In this study, Landsat 7 and Landsat 8 Operational Land Imager (OLI)/Thermal Infrared Sensor (TIRS) Level-1 images of TIR bands are used to predict Sea Surface Temperature (SST) changes using the Plank algorithm in the Black Sea and surrounding seas between 2008 and 2018. The SST values were taken from 55 different stations chosen from the study area. The SST result presented the central months of the four hydrological seasons. The increasing temperature data were supported by the literature studies that alien invasive species entered the Black Sea. The climatic fluctuations obtained as a result of this study will increase the invasion level of non-native species and their invasion will continue into the Black Sea and surrounding seas.

Keywords

Black Sea, SST, Invasive Species, Mediterranization

1. Introduction

The temperature is a key parameter on the physical, chemical and biological features of the marine environment. Therefore, temperature data play a significant role in a wide range of environmental resources management activities (Lillesand & Kiefer, 1987; EPA, 2016; NOAA, 2016). Sea surface temperature

(SST) is a vital parameter in the context of biodiversity in marine environments (Wloczyk et al., 2006). SST is needed to study predictions of marine protected areas, climate change, sea-level rise, pollution estimations. Satellite technologies provide to evaluate information (the brightness values) from a distance that understands changes in the seas for more than 40 years (Bartolucci et al., 1988; Lillesand & Kiefer, 1987; Tarigan & Wouthuyzen, 2017). This makes SST a very valuable indicator for the marine studies. Increasing amounts of greenhouse gases into the atmosphere due to climate warming are the main reason for the rising SST levels (Tseng et al., 2011; Hoegh-Guldberg & Bruno, 2010; EPA, 2016; NAC, 2014). The significant reason for considering the SST changes is that to take precautions against potential impacts on marine life and living organism (Ostrander et al., 2010; Deser et al., 2010; IPCC, 2011).

The SST retrieval using brightness temperatures of satellites sensors was based on multi-channel algorithms in the early 1970's (Anding & Kauth, 1970; Prabhakara et al., 1974). Landsat satellites are operated by the Earth Observation Program of the National Aeronautics and Space Administration (NASA) for coastal regions. The first Landsat satellite was launched in 1972. Also, Landsat 1 was developed and improved the sensors and the technology in 1972 to Landsat 8 in 2013. Currently, the Landsat 7 Enhanced Thematic Mapper Plus (ETM+) and the Landsat 8 Operational Land Imager and Thermal Infrared Sensor (OLI/TIRS) are in operation (Ranagalage et al., 2017). In remote sensing, to predict the surface temperature, it is necessary that satellite images have convenient spatio-temporal resolution. The surface temperature is retrieval by the radiative transfer equation method using thermal bands of remotely sensed images. The computation of Sea Surface Temperature (SST) is obtained using thermal infrared data sets since the 1970s. And this development improved measurements tool and increased the accuracy of the computation (Alavipanah, 2006).

In recent years, different algorithms have been derived from satellite images for the prediction of sea surface temperatures. These algorithms are based on assumptions and approximations variety of radiation equation (Li et al., 2013).

This study ensured an information content analysis for the Landsat thermal bands using the Plank method with ArcGIS software. Also, previous studies with similar objectives did not address the entire Black Sea and surrounding seas using the Plank method. The main purposes of this paper are to retrieve remote SST data, to assess the estimation and analyse the trends of the SST, to understand the characteristics of SST by presenting in the Black Sea and surrounding seas, to discuss the SSTs changes according to climate change impacts.

2. Data Analysis

2.1. Study Area

The Black Sea is the world's largest inner sea, its only connections with other seas being the Kerch Strait, which leads to the Azov Sea, and the Istanbul Strait, which connects it with the Mediterranean Sea (Blatov et al., 1984; Ivanov & Belokopytov, 2013).

As the Black Sea is an inner sea, its sea surface temperature is less parallel to the air temperature. The regional and seasonal differences in the sea surface temperature of the Black Sea are higher than in other seas (Büyükhatipoğlu et al., 2002).

The Black Sea has weak vertical mixing due to peculiarities of its density stratification. Because of the low density of its upper mixed layer, its air temperature and sea surface temperature (SST) react rapidly to atmospheric and climate forces. Therefore, the Black Sea SST is exposed to important periodical, synoptic and interannual changes (Blatov et al., 1984; Altman et al., 1987). Sea surface temperature regulates the sea-air heat exchange and impacts circulation (Staneva et al., 1998; Gregoire et al., 1998).

The Black Sea changed significantly through impacts of climate change, eutrophication, overfishing, and increase in biomass of gelatinous and adaptable species. These effects were studied potently throughout the last two decades (Murray, 1991; Oguz & Ediger, 2006).

This paper presents results on sea surface temperatures over the Black Sea and surrounding seas on time scales ranging from 2008 to 2018.

2.2. Remote Sensed SST Data

In this study, Landsat7 and Landsat 8 Operational Land Imager (OLI)/Thermal Infrared Sensor (TIRS) Level-1 images of TIR bands are used to predict Sea Surface Temperature (SST) changes in the Black Sea together with the Sea of Azov. The TIR bands (B10 and B11) are defined with thermal infrared spectrum at the wavelength with a 30 m spatial resolution after the resampling process (Acharya & Yang, 2015).

Landsat data (Level 1) products consist of quantized and calibrated scaled Digital Numbers (DN) that can be rescaled to the top of atmosphere (TOA) reflectance or radiance using radiometric rescaling factors and thermal constants used to convert thermal band data to TOA brightness temperature (BT). These coefficients and the image characteristics are provided in the metadata file (MTL.txt) of the bands. Level 1 images are in GeoTIFF format were calibrated (Pinto et al., 2020; USGS, 2015).

The estimation of SST analysis was started with image pre-processing atmospheric and radiometric correction via top-of-atmosphere (TOA) spectral radiance values (1) using the rescaling factors with ArcGIS 10.6 software.

$$L\lambda = ML \cdot Qcal + AL \quad (1)$$

where:

$L\lambda$ = TOA spectral radiance (Watts/(m^2 * srad * μm));

ML = Band-specific multiplicative rescaling factor;

AL = Band-specific additive rescaling;

Qcal = Q.

The radiance value of images are converted into Brightness Temperature value by using Plank algorithm (2):

$$Ts = BT \big/ \left(1 + (\lambda \cdot BT/\rho) \cdot \ln \varepsilon\right) \tag{2}$$

where:

T_s =SST in Kelvin (K);

BT = Brightness Temperature at sensor (K);

λ = wavelength;

$\rho = (h * c/\sigma) = 1.438 \times 10^{-2}$ mK;

ε = spectral emissivity (Isaya Ndossi, & Avdan, 2016).

The SST temperature value in Kelvin (K) is converted to temperature in Celcius using the Equation (3):

$$T^{\circ}C = T(K) - 273 \tag{3}$$

The Landsat 7 and 8 OLI/TIRS images are obtained from the USGS/Earth Explorer portal for the four seasons (February-May-August-November) during the periods of 2008 to 2018.

The research of annual temperature changes of the Black Sea is particularly significant for consideration of climate change (Strong, 1989; Levitus et al., 2000).

The 11 yearly (2008-2018) mean SST fields for the central months of four hydrological seasons (spring: May, summer: August, autumn: November, winter: February) are presented in "**Figure 1**". The SST values were taken from 55 different stations chosen from the Black sea.

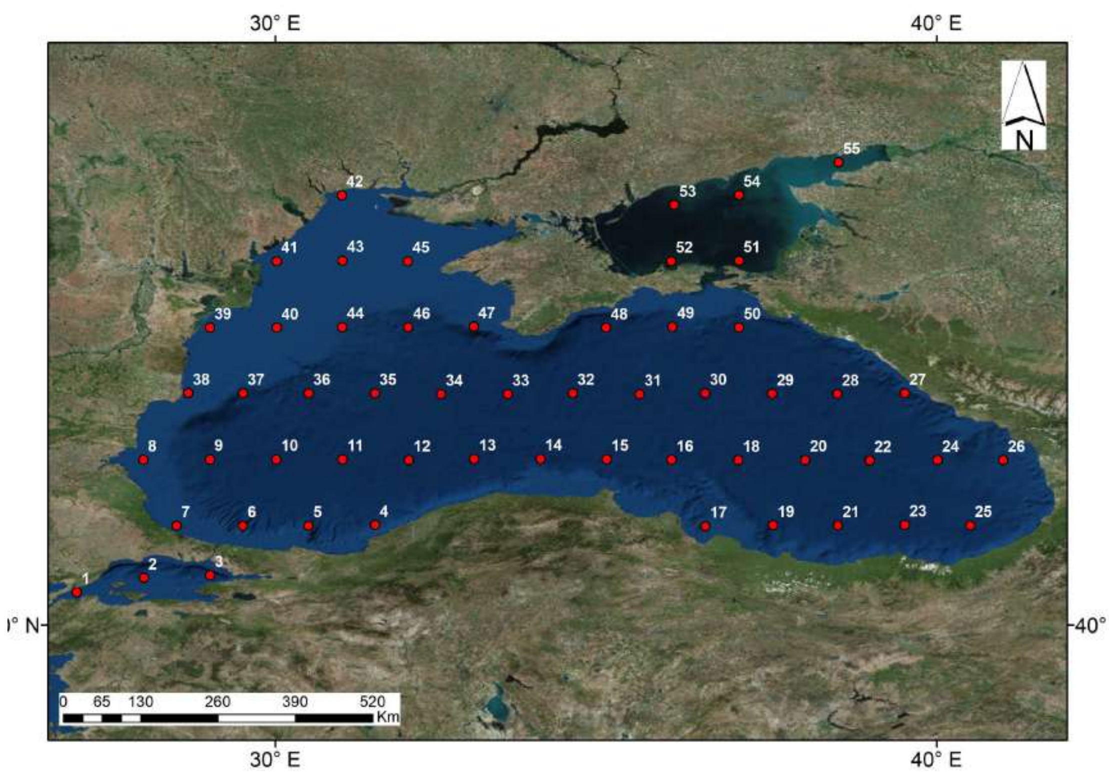

Figure 1. Study area.

3. Results

Between 2008 and 2018, seasonal data were retrieved from satellite images in selected stations using GIS and remote sensing programmes. The data were then processed using the STAT 10 programme. The lowest value was measured as 5.78˚C in February 2012. The highest value was measured as 29.20˚C in August 2010 ("**Table 1**").

Table 1. SST mean values between 2008 and 2018.

Year	Month	SST (˚C) mean	SST Std. error	SST −95.00%	SST +95.00%	N
2008	February	6.02854	0.222839	5.58178	6.47531	55
2008	May	14.31982	0.089099	14.14118	14.49845	55
2008	August	25.49891	0.087912	25.32266	25.67516	55
2008	November	14.75927	0.268716	14.22053	15.29801	55
2009	February	7.69836	0.239680	7.21783	8.17889	55
2009	May	14.93273	0.156065	14.61984	15.24562	55
2009	August	24.08564	0.099094	23.88696	24.28431	55
2009	November	14.32673	0.280376	13.76461	14.88885	55
2010	February	7.62636	0.222684	7.17991	8.07282	55
2010	May	17.24455	0.148017	16.94779	17.54130	55
2010	August	29.20964	0.093107	29.02297	29.39630	55
2010	November	15.14055	0.199380	14.74081	15.54028	55
2011	February	7.42800	0.241002	6.94482	7.91118	55
2011	May	13.60073	0.100328	13.39958	13.80187	55
2011	August	24.58527	0.168949	24.24655	24.92400	55
2011	November	11.44273	0.285544	10.87025	12.01521	55
2012	February	5.78182	0.243453	5.29373	6.26991	55
2012	May	17.70964	0.202229	17.30419	18.11508	55
2012	August	25.90345	0.138214	25.62635	26.18056	55
2012	November	15.75545	0.251133	15.25196	16.25895	55
2013	February	7.18727	0.261471	6.66306	7.71149	55
2013	May	17.65691	0.135205	17.38584	17.92798	55
2013	August	26.32836	0.066084	26.19587	26.46085	55
2013	November	14.32345	0.232898	13.85652	14.79039	55
2014	February	8.26164	0.252675	7.75505	8.76822	55
2014	May	15.75873	0.151218	15.45555	16.06190	55
2014	August	27.78582	0.081147	27.62313	27.94851	55
2014	November	13.62673	0.319974	12.98522	14.26824	55
2015	February	7.23363	0.263178	6.70599	7.76127	55
2015	May	16.29455	0.091862	16.11037	16.47872	55

Continued

2015	August	26.70691	0.116405	26.47353	26.94029	55
2015	November	14.24036	0.268852	13.70135	14.77938	55
2016	February	8.29800	0.260070	7.77659	8.81941	55
2016	May	16.39145	0.109197	16.17253	16.61038	55
2016	August	26.21673	0.188877	25.83805	26.59540	55
2016	November	13.87291	0.300629	13.27018	14.47563	55
2017	February	6.21946	0.224140	5.77008	6.66883	55
2017	May	14.49400	0.141654	14.21000	14.77800	55
2017	August	26.39182	0.174348	26.04227	26.74136	55
2017	November	14.32982	0.246778	13.83506	14.82458	55
2018	February	8.03673	0.277266	7.48084	8.59261	55
2018	May	17.07909	0.119085	16.84034	17.31784	55
2018	August	25.29927	0.141208	25.01617	25.58238	55
2018	November	15.23655	0.322133	14.59071	15.88238	55

According to spatial mapping analysis, the results were as follows. For February, the lowest value was 0.54˚C in 2008 and the highest value was 11.32˚C in 2018 ("**Figure 2**"). For May, the lowest value was 10.77˚C in 2011 and the highest value was 24.33˚C in 2012 ("**Figure 3**"). For August, the lowest value was 20.8˚C in 2009 and the highest value was 30.62˚C in 2010 ("**Figure 4**"). For November, the lowest value was 2.14˚C in 2011 and the highest value was 18.89˚C in 2012 ("**Figure 5**").

A total of 55 sampling points were used to measure the SST remote sensed with the Landsat processed data. The study used the thermal bands to retrieve SST based on the Plank method. The elaborated algorithm allowed to estimate SST from the Landsat 7 and 8 data for the Black Sea between 2008 and 2018. "**Figure 6**" shows that SST data were modelled as linear. In other words, the SST values increase gradually in the four seasons.

4. Discussion

The Black Sea is an almost closed sea that has limited interaction with the Mediterranean Sea and the Turkish Straits. Circulation is mainly cyclonic in the Black Sea and usually driven through surface fluxes and freshwater input from the Danube, Dnieper and Dniester rivers. Synoptic wind stress plays an unimportant role for the circulation in the Black Sea.

On the contrary the Mediterranean Sea, there is excess rainfall over evaporation in an average year, the situation equalled by outflow from the Black Sea to the Aegean Sea through the Turkish Straits.

For the spatio-temporal distribution of surface sea temperature in the Black Sea, the most outstanding feature is its growth in the route from northwest to southeast in all seasons. This is because of the common atmospheric conditions

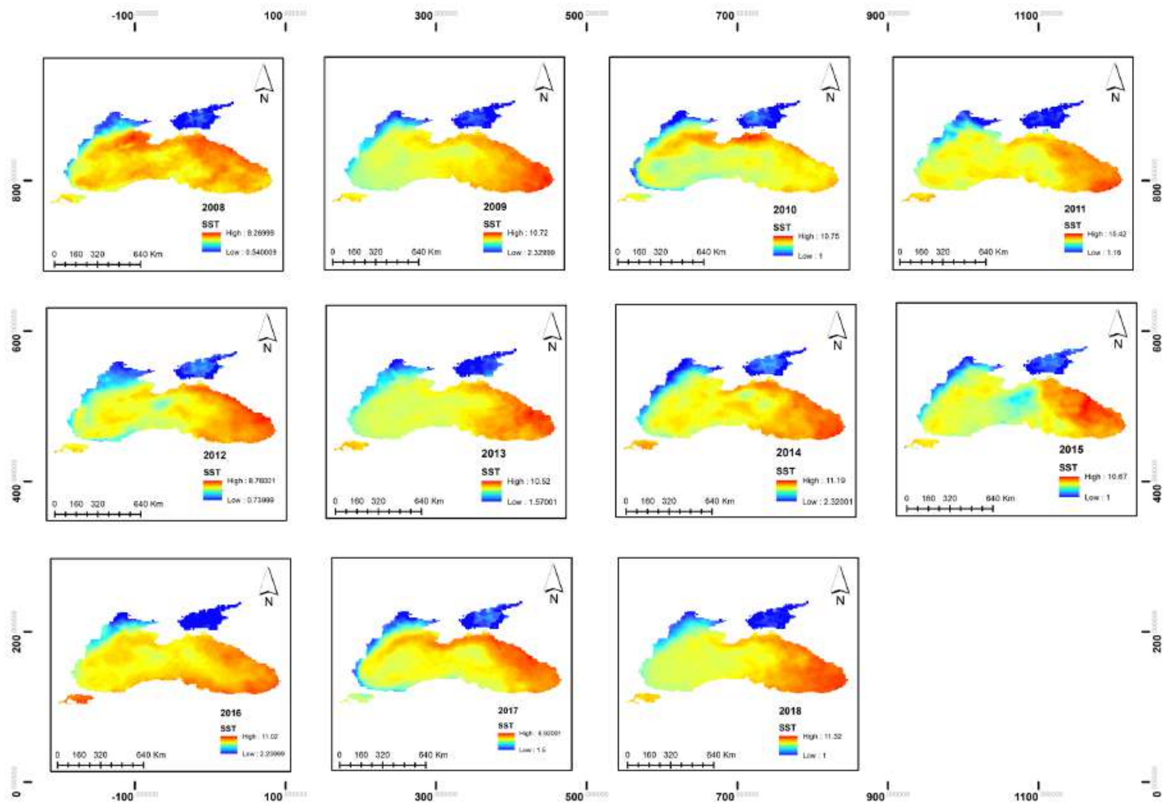

Figure 2. Spatial SST Map for February between 2008 and 2018.

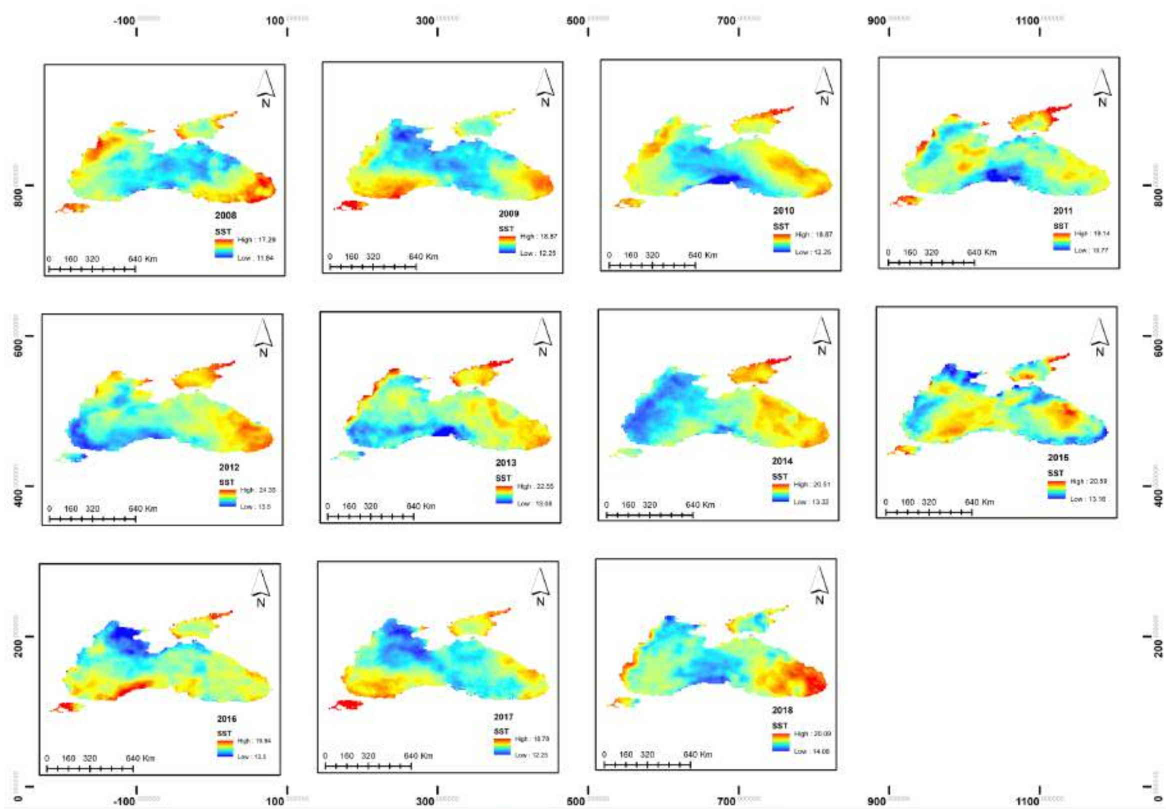

Figure 3. Spatial SST Map for May between 2008 and 2018.

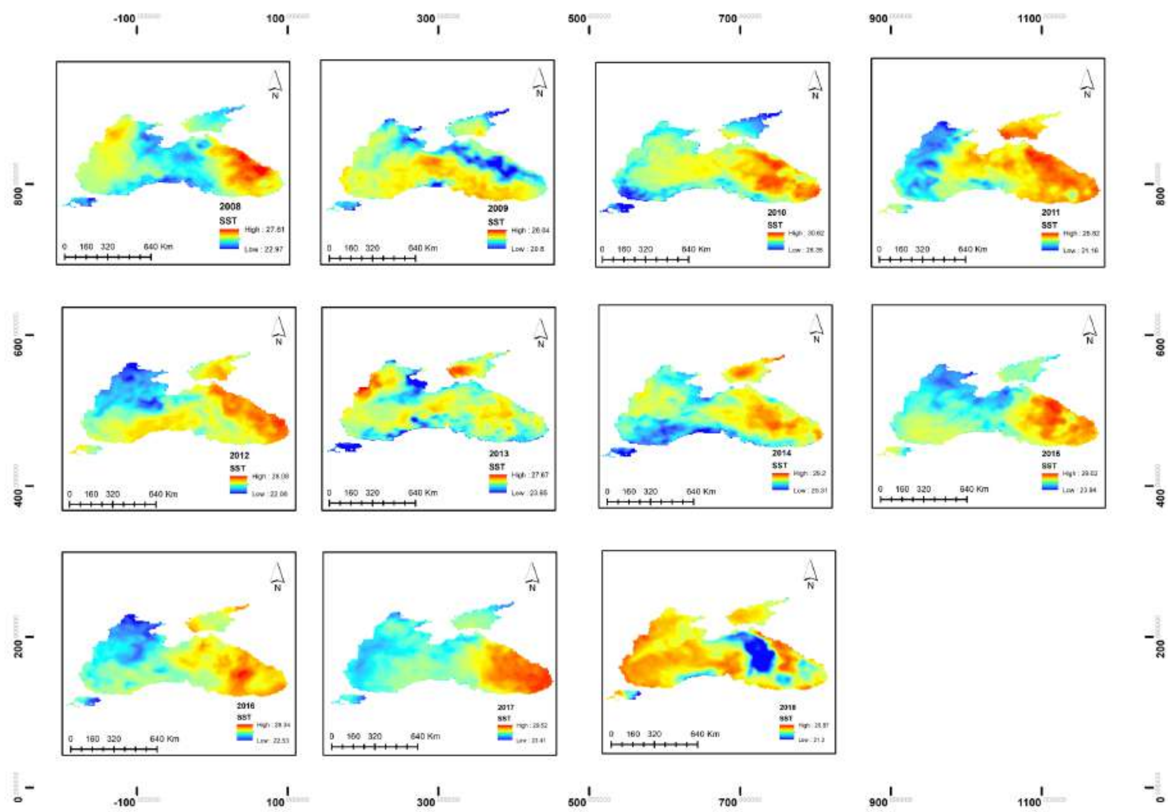

Figure 4. Spatial SST Map for August between 2008 and 2018.

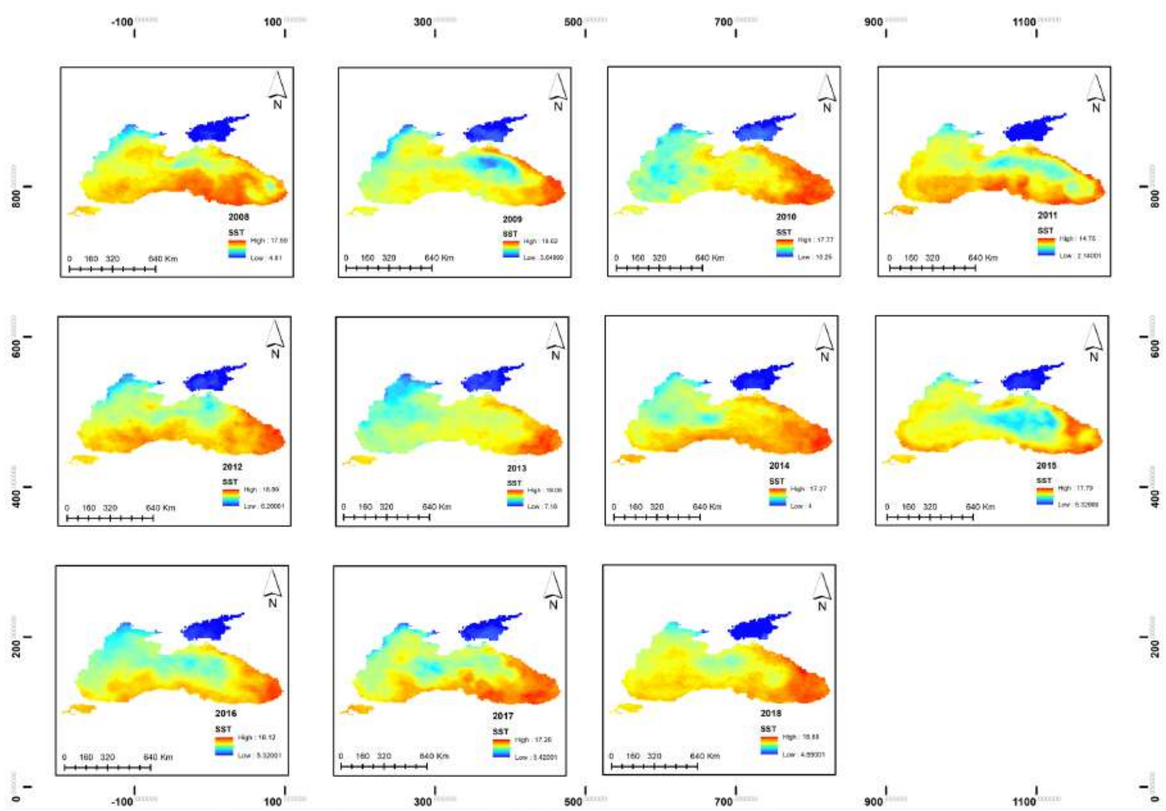

Figure 5. Spatial SST Map for November between 2008 and 2018.

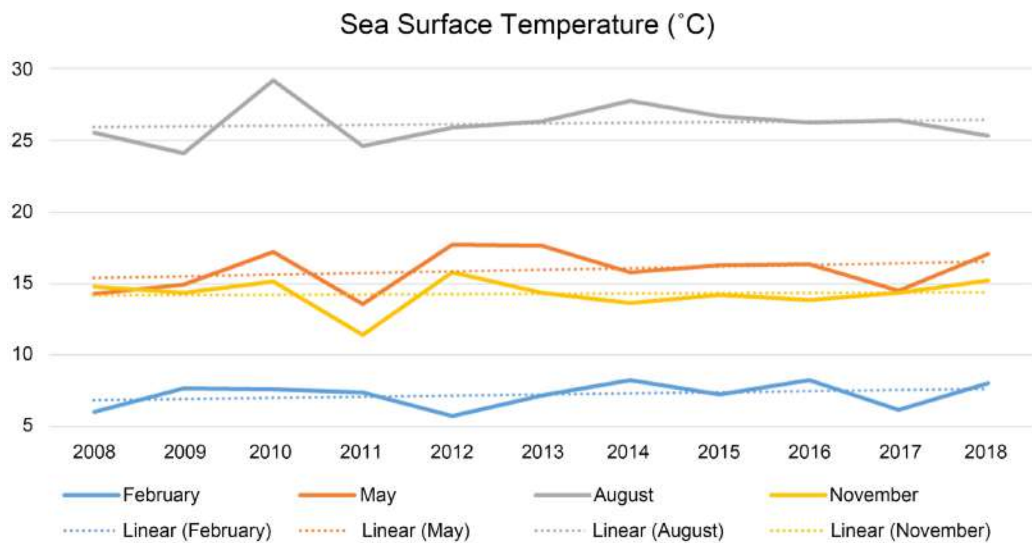

Figure 6. The graph of SST changes between 2008 and 2018.

in the area: the climate in the north-west of the Black Sea is mild, while it is more subtropical in the eastern part of the Black Sea.

In winter season, low water temperatures are not restricted to the north-west, but also occur in the central part of the Black Sea, due to the extreme cooling of the surface layer in the centers of cyclonic gyres ("**Figure 7**"). The spatial contrasts of sea temperature are most recognizable in winter ("**Figure 2**"). In spring ("**Figure 3**") and summer ("**Figure 4**"), they are significantly smoothed.

The sea surface temperature is lowest on the northern, Ukrainian and Russian coasts in February. The temperature is highest in the cyclonic gyres of the Eastern, Batumi and Caucasus areas in August.

In February ("**Figure 3**"), warm waters distribute from the eastern to the western part and cold waters distribute from the north eastern region along the western and southern coasts (Blatov et al., 1984; Simonov & Altman, 1991; Özsoy & Ünlüata, 1997). This concurs with the satellites SST distribution for February and March presented in "**Figure 2**" and "**Figure 5**".

The climate changes are explained with fluctuations in the Atlantic multidecadal Oscillation index reported in the Black Sea region by Oğuz et al. (2006), Ilyin (2010), and Polonsky et al. (2013). The changing climate probably accelerated the invasion process in the Black sea. In addition, the Turkish Straits are the main transit corridors for invasive species in the Black Sea (Georgieva, 1993; Kovalev, 2006; Selifinova et al., 2008; Jakubova, 1948). The increase in temperature creates new habitats for alien and invasive species. The invasion of the Black Sea by new Mediterranean species and Mediterranization will continue by rise in temperature as a consequence of climate change (Oğuz, 2005; Öztürk, 2021). For fish, the number of alien species were 28 (4 alien and 24 new Mediterranean species) in the western and 16 (2 alien and 14 new Mediterranean fish species) in the eastern Black sea (Shalovenkov, 2019). This increase in the number of alien species could be in consequence of climate changes.

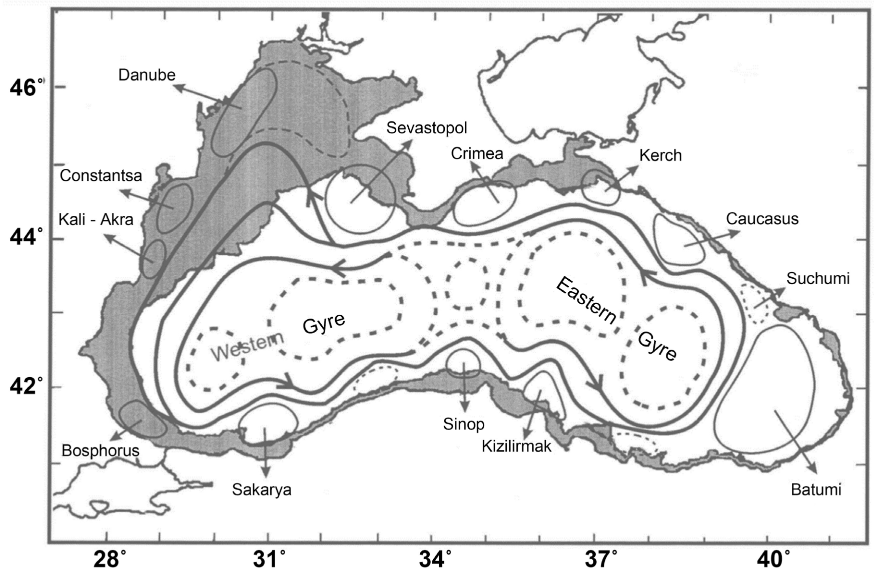

Figure 7. General circulation of Sea surface current in the Black sea (Oguz et al., 2005; Ivanov & Belokopytov, 2013).

5. Conclusion

The climatic fluctuations obtained as a result of this study will increase the invasion level of non-native species and their invasion will continue into the Black Sea. With the increase in SST, it seems likely that the invasion of alien species can increase from the Indo-pacific region. International studies should be continued and monitoring studies should be intensified.

This kind of remote sensed data studies enables an increased awareness, better understanding of the issues and risks as well as options for future actions in the Black Sea. However, the results of these studies must also be supported by *in-situ* measurements.

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Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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