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Research Article

Comparison between remotely-sensed sea-surface temperature (AVHRR) and *in situ* records in San Matías Gulf (Patagonia, Argentina)

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ABSTRACT. *In situ* records of sea surface temperature collected between 2005 and 2009 were used to compare, for the first time, the temperature estimated by the Multichannel algorithms (MCSST) of the Advanced Very High Resolution Radiometer (AVHRR) sensors in San Matías Gulf, in the north of the Argentinean Patagonian Continental Shelf (between 40º47'-42º13'S). Match-ups between *in situ* records and satellite sea surface temperature (SST) were analyzed. *In situ* records came from fixed stations and oceanographic cruises, while satellite data came from different NOAA satellites. The fitting of temperature data to a Standard Major Axis (SMA) type II regression model indicated that a high proportion of the total variance ($0.53 \leq r^2 \leq 0.99$) was explained by this model showing a high correlation between *in situ* data and satellite estimations. The mean differences between satellite and *in situ* data for the full data set were 1.64 ± 1.49ºC. Looking separately into *in situ* data from different sources and day and night estimates from different NOAA satellites, the differences were between 0.30 ± 0.60°C and 2.60 ± 1.50°C. In this paper we discuss possible reasons for the above-mentioned performance of the MCSST algorithms in the study area.

Keywords: sea surface temperature, *in situ* records, MCSST-AVHRR, San Matías Gulf, southwestern Atlantic.

Comparación entre datos de temperatura del mar estimados mediante el sensor AVHRR y registros *in situ* en el golfo San Matías (Patagonia, Argentina)

RESUMEN. Se utilizaron mediciones de campo de temperatura del mar realizadas entre 2005 y 2009 para comparar, por primera vez, las estimaciones de los algoritmos Multicanal de temperatura (MCSST) del sensor Advanced Very High Resolution Radiometer (AVHRR) en el golfo San Matías, norte de la plataforma continental Argentina patagónica (40º47'-42º13'S). Se analizaron diferentes pares de datos considerando registros *in situ* de estaciones fijas y oceanográficas y estimaciones diurnas y nocturnas de temperatura superficial (TSM) de diferentes satélites NOAA. Se ajustaron los datos a un modelo de regresión Standard Major Axis (SMA) tipo II el cual explicó una alta proporción de la varianza total ($0,53 \leq r^2 \leq 0,99$). La diferencias medias entre los datos satelitales e *in situ* para todo el conjunto de datos fue de 1,64 ± 1,49ºC, al discriminar entre diferentes fuentes de datos *in situ*, y estimaciones diurnas y nocturnas de diferentes satélites NOAA, las diferencias medias variaron entre 0,30 ± 0,60ºC y 2,60 ± 1,50ºC. En este trabajo se discuten las posibles razones que explican el desempeño de los algoritmos MCSST en el área de estudio.

Palabras clave: temperatura superficial del mar, registros *in situ*, MCSST-AVHRR, golfo San Matías, Atlántico sudoccidental.

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INTRODUCTION

Remote sensing of infrared data has been demonstrated to be a useful tool for monitoring the marine ecosystem. It has provided near real-time, long-term, synoptic and global estimates of key parameters such as sea surface temperature (SST) that can be integrated in numerical weather predictions, basinscale hydrodynamic and primary production models (Longhurst *et al.,* 1995; Behrenfeld & Falkowski, 1997).

The Advanced Very High Resolution Radiometer (AVHRR) sensor, onboard NOAA satellites, has been the most used sensor for the estimation of SST for scientific and operational applications in oceanography and fisheries. In the Southwest Atlantic Ocean (SWA), Bava (2004) obtained a significant correlation between *in situ* temperature and SST estimated by the AVHRR sensor. However, under or over-estimation of AVHRR temperature values could be caused by residual errors in the atmospheric correction of the AVHRR data, small changes in the values of emissivity from the sea surface (Masuda *et al*., 1988), or different spatial separations and time intervals in comparison methods used (Minnett, 1991).

The aim of this work is to compare the values obtained by the current standard AVHRR Multi Channel Sea Surface Temperature (MCSST) algorithm for SST with values from *in situ* measurements in San Matías Gulf (SMG).

SMG is a semi-enclosed basin located north of the Patagonian Continental Shelf between 40º47'S and 42º13'S (Fig. 1a). This gulf covers an area of approximately 20,000 km^2, being the second largest gulf of Argentina. Around 55% of its total area is deeper than 100 m, with a maximum of 180 m in the center. The continental shelf on the eastern side of the gulf forms an open basin with a mean depth of 70 m at its mouth (Fig. 1b). The precipitation in this zone is scarce (250 mm year^{-1}), corresponding to a semi-arid region where westerly winds predominate (Hoffmann, 1997). There is no river discharge to the gulf, but it is worth mentioning the presence of the Negro River, located off the north coast of SMG, with a flow rate of about 1000 m^3 s^{-1} that influences the region around the entrance of the gulf. This river is used primarily for agriculture, livestock and other urban activities.

The SMG has been studied through oceanographic surveys between 1971 and 1994. These studies showed the presence of two distinct areas from November to March: the northern and western areas with relatively high temperature and salinity, a marked thermocline, limited concentrations of nitrate and a low renewal rate; and the southern and south-eastern areas, strongly influenced by the intrusion of water from the south (Carreto *et al*., 1974a, 1974b; Scasso & Piola, 1988; Rivas & Beier, 1990; Williams, 2004; Williams *et al*., 2010), with lower temperature and salinity, no stratification and relatively higher nitrate concentrations. Piola & Scasso (1988) used hydrographic data to describe a thermal front located around 41°50'S, which separates these two areas during the austral summer (red dashed line in Fig. 1a). This thermal front has been also observed using Thematic Mapper (TM), Enhanced Thematic Mapper plus (ETM+) and AVHRR infrared data (Piola & Scasso, 1988; Bava *et al.,* 2002; Gagliardini & Rivas, 2004; Williams, 2011). Thus, the gulf is separated from the continental shelf and shows two regions with water masses of different SST, being the northern area more isolated than the southern one. SST satellite data showed an average difference of 1-3°C between the northern and the southern areas, except during winter when the thermal front vanishes and the SST distribution is spatially homogeneous (Piola & Scasso, 1988; Gagliardini & Rivas, 2004).

One of the most outstanding features of the SMG is that it constitutes a relevant site for fisheries, being the Argentine hake (*Merluccius hubbsi*) the most important resource in terms of landings and economical revenues (González *et al*., 2007; Romero *et al*., 2010; Ocampo-Reinaldo, 2010). Maps of high temporal and spatial resolution of AVHRR-SST, together with the distribution of trawl fleets, suggested that the seasonality of the thermal front would be one of the main factors conditioning the fisheries in SMG. The fishery production was higher in the presence of the thermal front, showing the biological relevance of this oceanographic structure (Williams *et al*., 2010). Thus, the spatial and temporal patterns of water temperature are very important for studying physical and biological conditions, and for a sustainable management of fisheries and aquaculture (Santos, 2000). Remote sensing methods in particular are an efficient way of improving the knowledge of the environmental conditions of fisheries ecosystems (Ocampo-Reinaldo *et al*., 2010; Romero *et al*., 2013). Even though these methods have been used in SMG with increasing success to confirm previous oceanographic findings (Gagliardini & Rivas, 2004; Williams *et al*., 2010), satellite data have still not been compared with *in situ* records.

MATERIALS AND METHODS

In situ measurements

In situ temperature data from San Matías Gulf were collected during six research cruises conducted by the Centro Nacional Patagónico (CENPAT) and the Instituto de Biología Marina y Pesquera Almirante Storni (IBMPAS) between 2007 and 2009 (Table 1). Temperature was measured using an YSI 6600v2 (±0.15°C) probe and a handheld multiparameter probe YSI 556 (±0.15°C) at 5 m deep.

Between 2005 and 2007 *in situ* temperature was recorded at three fixed coastal stations (Table 2). At the first one, Las Grutas (LG), there was an oceano-

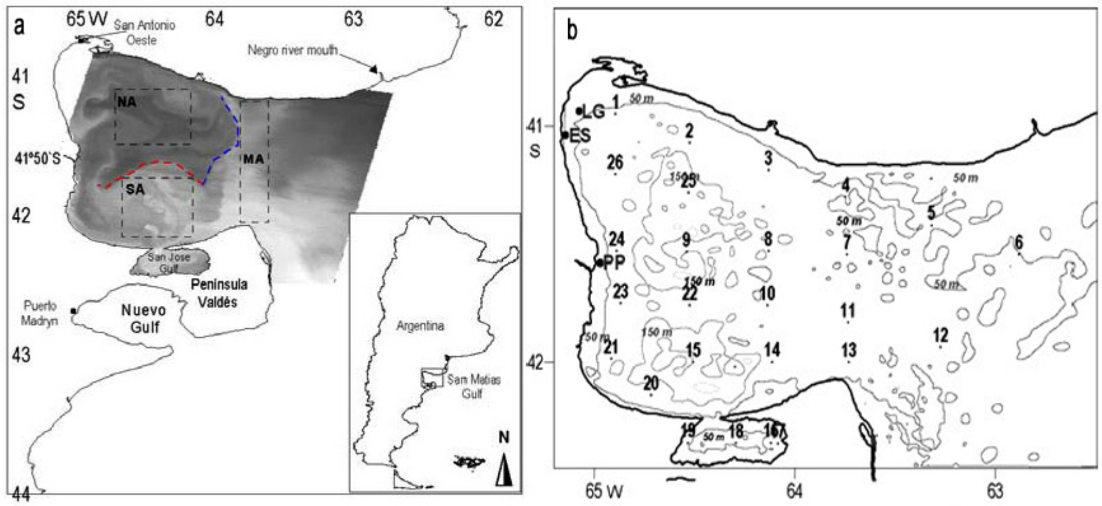

Figure 1. a) Map of the study area and Landsat ETM+ brightness temperature image (March 8, 2004; adapted from Gagliardini & Rivas, 2004) showing the northern (NA; warmer), southern (SA; colder) and mouth areas (MA) together with the thermal fronts identified at the entrance (dashed blue line) and along 41º50´S (dashed red line), b) location of in situ data (black dots) on a bathymetric map.

Table 1. Research cruises carried out for recording *in situ* temperature in SMG. Date, season and number of data (n) are indicated.

Cruise name	Date	Season	Available NOAA satellite data	n
GSM-I-07	23-27 June 2007	Autumn	12-16-17-18	25
GSM-II-07	17-19 October 2007	Spring	12-16-17-18	18
GSM-III-08	20-23 February 2008	Summer	15-16-17-18	26
GSM-IV-08	19-21 June 2008	Autumn	15-16-17-18	25
GMS-V-08	27-30 November 2008	Spring	15-16-17-18	23
GMS-VI-09	2-3 October 2009	Spring	16-17-18	17

Table 2. Location of coastal fixed stations (n: number of records).

Place name	Latitude (S)	Longitude (W)	Date	Available NOAA satellite data	n
Las Grutas (LG)	40º57´	65º4,1’	July 4 - December 27, 2005	12-14-15-16	4144
Punta Pozos (LP)	41º35´	64º58’	October 3, 2007 - September 7, 2008	15-16-17-18	1362
El Sótano (ES)	41º 2’	65º 8’	September 7, 2007 - August 26, 2008	15-16-17-18	1420

graphic buoy at approximately 3 km from the coast, which measured SST every hour at two depths, 1 and 5 m. At the other two, Punta Pozos (PP) and El Sótano (ES), located 1 and 2.5 km from the coast respectively, SST was measured every six hours using temperature data-loggers (Optic Stow Away-Temp (ºC) ONSET, ±0.20°C) (Fig. 1b) at 5 meters deep.

Remote sensing data

In situ measurements from fixed coastal and oceanographic stations were compared with daily Level 1b local area coverage (LAC) data from NOAA-AVHRR systems acquired through the Argentine National Commission of Space Activities (CONAE). During the periods of study, the operational satellites were NOAA 12, 14, 15, 16, 17 and 18 (Tables 1, 2), which provided a total of 363 scenes. The images were processed using Erdas Imagine 8.7 software and applying the MCSST split window algorithm (McClain *et al.,* 1985; Brown & Minnet, 1999).

SST algorithms are regression formulas that use empirical comparisons between buoy SST data and a series of measurements from different bands of the AVHRR sensor (Bernstein, 1982; McMillin & Crosby, 1984; Walton, 1988; McClain *et al.*, 1995). There are two kinds of SST algorithms in common use, MCSST and NLSST (Non Linear Sea Surface Temperature). The reason for choosing the MCSST is that, unlike the NLSST, it does not require extra information to that provided by the satellite. The split technique was also chosen because it is less sensitive to air-sea temperature differences (May & Holyer, 1993).

Equation 1 shows the form of the MCSST split-window algorithm:

$$MCSST= B_1(T_4)+B_2(T_4-T_5)+B_3(T_4-T_5)(\sec\theta -1)-B_4 \quad (1)$$

where: T_4 is the band 4 brightness temperature (BT); T_5 is the band 5 brightness temperature (BT); θ is the satellite zenith angle; B_1, B_2, B_3 and B_4 are AVHRR coefficients and day/night specific (McClain, 1985).

All AVHRR images, with a pixel size of 1.1 km, were corrected for geometric distortion (RMSE ≤0.55 pixel), mapped to a WGS84 reference system (datum WGS84, ellipsoid WGS84) and co-registered with a reference landmask. Clouds were removed using a combination of threshold values from channels 2 and 4 (Kelly, 1985; Monaldo, 1996) and flagged to zero.

Match-up procedure

In situ data were collected independently of the satellite overpass times; thus, a criterion for comparing different estimations had to be determined. Records from oceanographic and fixed stations were compared with data from satellite images taken within an interval of three hours around the *in situ* records. Satellite SST values used for the match-ups were the averages of all the unmasked pixels within 3×3 pixel boxes centered on the *in situ* targets, to allow for potential positional errors in the satellite imagery (Bailey & Werdell, 2006); satellite data were excluded when more than 55.5% of marine pixels within those boxes were masked.

Comparison between AVHRR standard SST algorithms and *in situ* records

The relationship between *in situ* SST and AVHRR derived SST was analyzed through linear regression analyses. Besides r^2, slope and intercept, the statistical parameters used were the mean difference (MD), the standard deviation of the mean difference (SD) and the root mean square error (RMSE) between the algorithm-derived and the *in situ* SST. The parameters are defined as:

$$MD = \frac{\sum_{n=1}^{N}\left(x_{sat} - x_{situ}\right)}{n} \quad (2)$$

$$SD = \sqrt{\frac{\sum_{i=1}^{n}\left(MD - \overline{MD}\right)^2}{n}} \quad (3)$$

$$RMSE = \sqrt{\frac{\sum\left(x_{sat} - x_{situ}\right)^2}{n}} \quad (4)$$

where: X is SST; X_{sat} is the satellite-derived value; X_{situ} is the *in situ* measured value and *n* is the number of pairs of data analyzed.

Bias, slope and the determination coefficient (r^2_{SMA}) were calculated following a type II linear regression model, Standard Major Axis (SMA) (McArdle, 1988; Sokal & Rohlf, 1995). SMA techniques provide a better estimate of the relationship between two variables than that provided by ordinary linear regression, because the residual variance is minimized in both *x* and *y* dimensions, rather than in the *y* dimension only (Sokal & Rohlf, 1995). The statistical analyses were carried out using (S) MATR software (version 1, Falster DS, Warton DI & Wright IJ: http://www.bio.mq.edu.au/ecology/SMATR/).

The coefficient of determination indicates the overall degree of linear association between *in situ* and satellite estimates (proportion of the variance explained by a statistical model), but it is not a measure of the algorithm performance. Thus, the slope (closer to 1), the intercept (closer to 0) and the above-mentioned statistics are used to evaluate the comparison between MCSST algorithms and the *in situ* records.

The MCSST algorithms were first evaluated over the whole AVHRR dataset. Afterwards, fixed and oceanographic stations were considered separately, as well as the different satellites and overpass times. The satellites available at each station are summarized in Tables 1 and 2.

Data from NOAA 15 and 16 satellites were compared with *in situ* records from different fixed stations due to the low number of cloud free images obtained in the period considered (Table 3). Also, due to the limitations in match-up oceanographic data with a single satellite system, these data were compared with SST from different NOAA satellites (Table 4).

RESULTS

A total of 1327 *in situ* data was collected. Due to cloud cover in satellite images and after applying the temporal coincidence criteria, a total of 621 match-ups were left. The *in situ* data covered a temperature range

Table 3. Detail of the number of NOAA 15 and NOAA 16 images available for the fixed stations (±3h). LG: Las Grutas, PP: Punta Pozos, ES: El Sótano.

Satellite-time	LG	PP	ES
NOAA 15-day	0	2	2
NOAA 15-night	1	3	4
NOAA 16-day	1	3	3
NOAA 16-night	1	3	4

Table 4. Detail of the number of data from satellite images available for oceanographic *in situ* records (±3 h).

Time \ Satellite	12	14	15	16	17	18
day	0	0	1	4	1	9
night	2	0	0	5	3	4

between 9.64ºC and 20.30ºC, while the AVHRR data were between 8.36ºC and 23.71ºC.

Match-up results, regardless of the satellite system, overpass times and source of the *in situ* data, showed good fit (r^2 = 0.83), statistical significance ($P < 0.05$) and a bias (MD), scatter (SD), and RMSE of 1.64ºC, 1.49ºC and 2.21ºC respectively (Fig. 2a, Table 5). In this case, the mean difference and slope of the SMA model indicated an overestimation of the MCSST algorithm in respect to *in situ* records.

Taking into account the sources of the *in situ* data, records from oceanographic cruises showed a good fit (r^2 = 0.88), less bias and a slope close to one (b = 1.08), while data from Punta Pozos (PP), El Sótano (ES) and Las Grutas (LG) showed slightly more scattering, higher bias and a slope greater than one (Fig. 2, Table 5). Data from LG showed no significant differences in these parameters between the two depths considered (Table 5), so the results of Tables 6 to 10 refer to records at 1 m depth.

Results of the comparison between different sources of *in situ* data and SST from different satellites and overpass times are shown in Tables 6 to 10. In summary, the results showed generally positive biases greater than 0.55°C, except for NOAA 16 where nighttime match-ups showed the least bias of all data sets analyzed (0.30ºC). Bias of nighttime match-up between NOAA 17 and PP station were 0.70ºC followed by bias of NOAA 16 match-up (0.73°C). On the other hand daytime match-ups between NOAA 18 and PP station showed the greatest bias (2.60ºC), followed by daytime match-ups between NOAA 17 and PP/ES stations (1.87°C and 1.83°C, respectively). It is generally observed that the nighttime match-ups showed less scattering and bias however the number of data was lower.

As previously mentioned SST from NOAA 15 and 16 were compared with *in situ* records from different sites so as to increase the number of match-ups. NOAA 15 showed a negative bias (-0.29ºC) and greater scatter (2.58ºC). Due to only 6 pairs of data being obtained for this sensor, it was not possible to analyze the differences between daytime and nighttime match-ups (Fig. 3 and Table 9).

Finally, results of the comparison between *in situ* data of oceanographic cruises and SST from different overpass times did not show very different results when considering all the data set, except for a decrease of bias in daytime match ups (Fig. 4, Table 10).

DISCUSSION

These results show significant correlations between satellite and *in situ* data, and a positive deviation of the MCSST algorithm from the *in situ* records. A previous study using the same *in situ* data set, but applying the NLSST algorithm for MODIS sensor data also showed a high correlation, however, the dispersion and mean differences were slightly lower (Williams *et al.*, 2013). Although the significance of the correlations obtained in this work, it should be noted that the correlations of match-ups obtained over the open ocean tend to be higher and show lower average mean differences (Lee *et al.*, 2005, SQUAM, 2013).

Here the analysis considered separately day and nighttime images. The latter showed less bias, so nighttime SST products showed a better correlation with *in situ* SST data (Montgomery & Strong, 1995). Thus, the use of nighttime observations only attempts to minimize the effects of diurnal variation (Minnett, 2010). Besides, looking at the performance of the different satellite systems, NOAA 12 showed the lowest correlation coefficient for both day and night images, probably because of the sensor degradation over time (Trischenko *et al.*, 2002). On the other hand although the match-ups between oceanographic cruise and satellite data was the most heterogeneous data set, it showed no large biases compared to match-ups from fixed stations.

MCSST algorithms were generated from the correlation between satellite data and temperature from buoys located mainly in the tropical Pacific Ocean. So the average errors indicated for the AVHRR-SST estimates (Llewellyn-Jones *et al.*, 1984; Strong & McClain, 1984; Lee *et al.*, 2005; Parra *et*

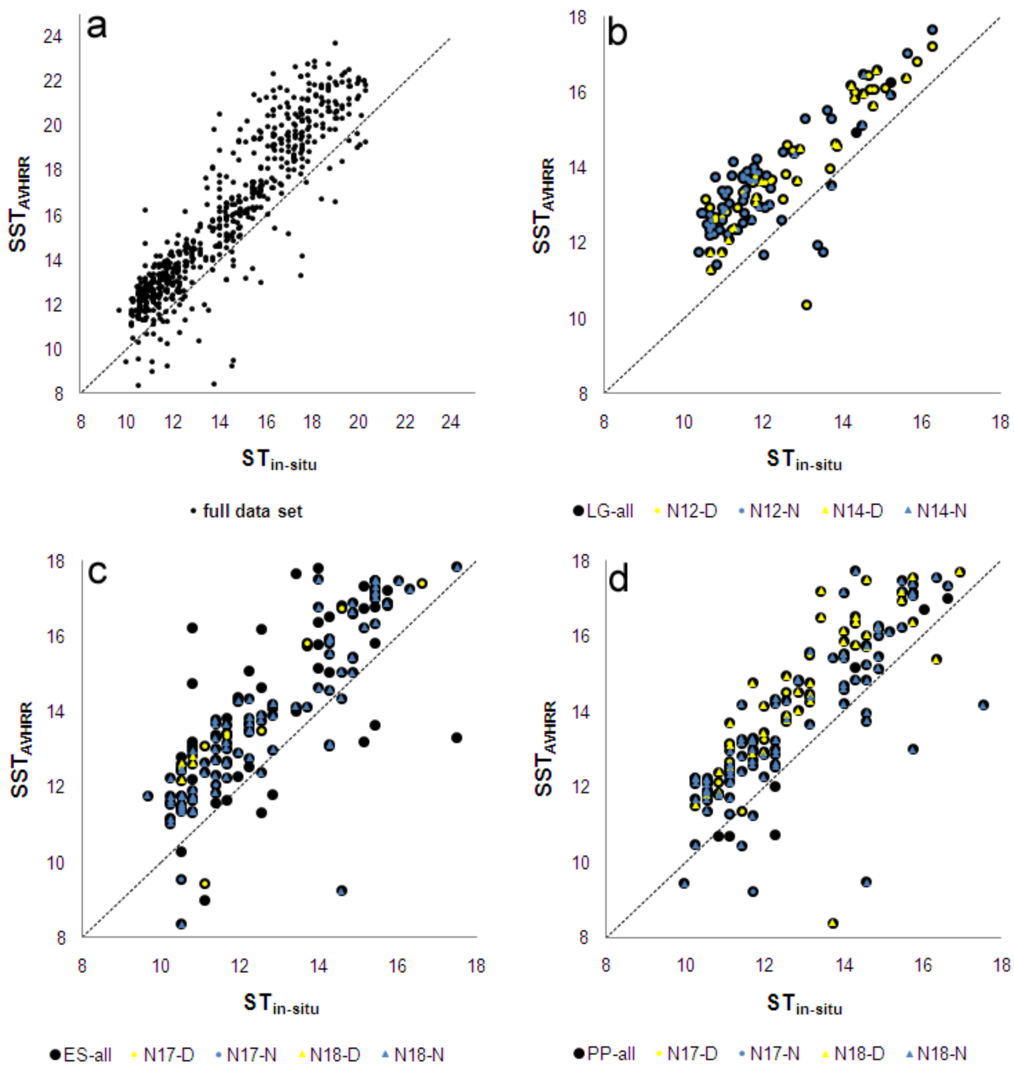

Figure 2. Satellite-derived estimates *versus* measured sea surface temperature (ºC) for (a) Full data set (b) Las Grutas$_{1m}$ (c) El Sótano, and (d) Punta Pozos. The data were fitted to a SMA type II regression model; n_tes UTF-8 21 the dotted line corresponds to the ratio 1:1.

Table 5. Statistical results of the comparison between *in situ* data and MCSST algorithm. RMSE: root mean square error, SD: standard deviation, SST: sea surface temperature.

Data	b	a	r^2	RMSE	Mean difference (ºC)	SD difference (ºC)	*in situ* SD	SST SD	n
Las Grutas (1m)	0.96	1.96	0.72	1.67	1.44	0.84	1.54	1.47	112
Las Grutas (5m)	0.98	1.77	0.71	1.67	1.49	0.83	1.51	1.47	112
Punta Pozos	1.28	-2.39	0.82	2.24	1.63	1.54	2.72	3.47	234
El Sótano	1.25	-1.81	0.82	2.59	1.83	1.64	3.01	3.76	247
Oceanographic cruises	1.08	-0.43	0.88	1.54	1.36	1.34	3.52	3.80	28
Full data set	1.22	-1.47	0.83	2.21	1.64	1.49	2.86	3.49	621

al., 2011) are only nominal for north-eastern Atlantic Ocean and tropical latitudes and may not be representative of the average atmospheric conditions of our study area. In this sense, windblown dust emission events from the Patagonian desert towards the South Atlantic Ocean are known to occur and have

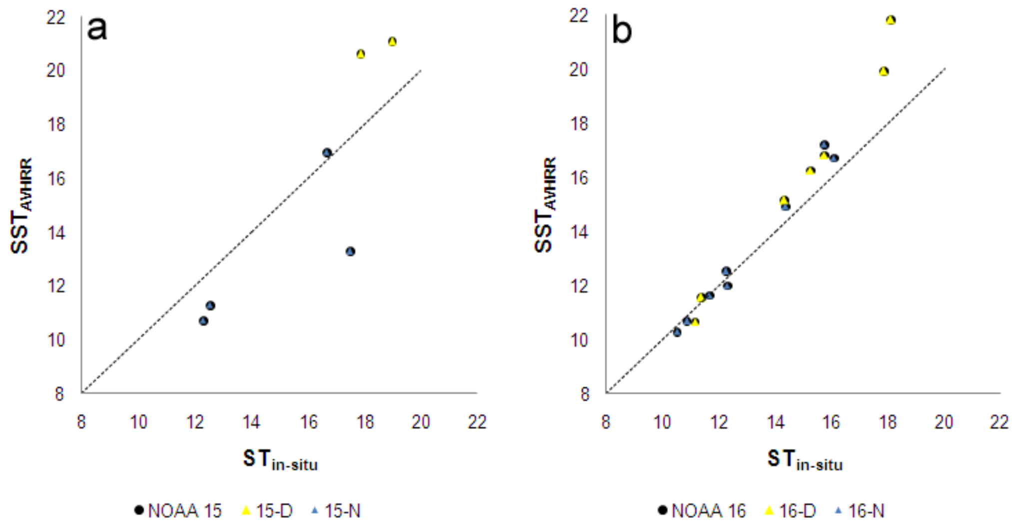

Figure 3. Satellite-derived estimates *versus* measured sea surface temperature (ºC) for (a) NOAA 15 and (b)NOAA 16. The data were fitted to a SMA type II regression model; the dotted line corresponds to the ratio 1:1.

Table 6. Statistical results of the comparison between temperature data from *Las Grutas* and NOAA 12 and 14 MCSST algorithms. RMSE: root mean square error, SD: standard deviation, SST: sea surface temperature.

Data	b	a	r^2	RMSE	Mean difference (ºC)	SD difference (ºC)	*in situ* SD	SST SD	n
LG-NOAA 12	1.03	-2.01	0.63	1.79	1.56	0.90	1.42	1.38	84
LG-NOAA 12-day	0.96	1.84	0.69	1.74	1.38	0.96	1.70	1.63	26
LG-NOAA 12-night	1.02	1.39	0.53	1.83	1.64	0.86	1.15	1.18	57
LG-NOAA 14	1.07	0.15	0.91	1.20	1.10	0.49	1.54	1.65	26
LG-NOAA 14-day	1.08	0.13	0.95	1.23	1.17	0.41	1.70	1.63	18
LG-NOAA 14- night	1.08	-0.11	0.81	1.11	0.94	0.64	1.35	1.46	8

Table 7. Statistical results of the comparison between temperature data from *El Sótano* and NOAA 17 and 18 MCSST algorithms. RMSE: root mean square error, SD: standard deviation, SST: sea surface temperature.

Data	b	a	r^2	RMSE	Mean difference (ºC)	SD difference (ºC)	*in situ* SD	SST SD	n
ES-NOAA 17	1.20	-1.50	0.91	2.03	1.65	1.20	3.05	3.68	28
ES-NOAA 17-day	1.16	-0.68	0.90	2.17	1.83	1.19	3.08	3.57	22
ES-NOAA 17-night	1.30	-3.30	0.97	1.38	0.97	1.07	2.99	3.88	6
ES-NOAA 18	1.24	-1.54	0.82	2.53	1.95	1.62	3.00	3.51	208
ES-NOAA 18-day	1.21	-0.66	0.77	3.06	2.60	1.50	2.81	3.40	97
ES-NOAA 18- night	0.85	-1.04	0.85	1.95	1.38	1.39	3.00	3.33	111

been previously reported (Gaiero *et al.*, 2003; Gasso & Stein, 2007). Also, the ash plumes generated by the eruption of two volcanoes in the last five years (Chaitén on May 2008 and Puyehue on June 2011) affected the atmospheric conditions of the study region (Lara, 2009; Okazaki & Heki, 2012). Aerosols from these events result in a deterioration of the ability of the AVHRR radiometer to measure the SST of the ocean (Reynolds, 1993; Singh *et al.*, 2008). The impact of these events on the SST estimates in Patagonia has not been evaluated yet. However, it must be taken into account since it may be affecting the estimation of the SST over the study area, despite the positive biases observed in this study.

Although at high latitudes the positive biases in the estimation of SST have been attributed to an

Table 8. Statistical results of the comparison between temperature data from *Punta Pozos* and NOAA 17 and 18 MCSST algorithms. RMSE: root mean square error, SD: standard deviation, SST: sea surface temperature.

Data	b	a	r^2	RMSE	Mean difference (ºC)	SD difference (ºC)	*in situ* SD	SST SD	n
PP-NOAA 17	1.24	-2.02	0.92	2.03	1.57	1.19	2.97	3.68	23
PP-NOAA 17-day	1.12	0.04	0.95	2.17	1.87	0.82	3.16	3.54	17
PP-NOAA 17-night	1.59	-7.80	0.94	1.38	0.70	1.68	2.55	4.04	6
PP-NOAA 18	1.25	-1.85	0.82	2.53	1.72	1.48	2.68	3.35	208
PP-NOAA 18-day	1.26	-1.64	0.81	3.06	2.26	1.46	2.57	3.24	97
PP-NOAA 18- night	1.28	-2.39	0.82	1.95	1.27	1.35	2.65	3.09	111

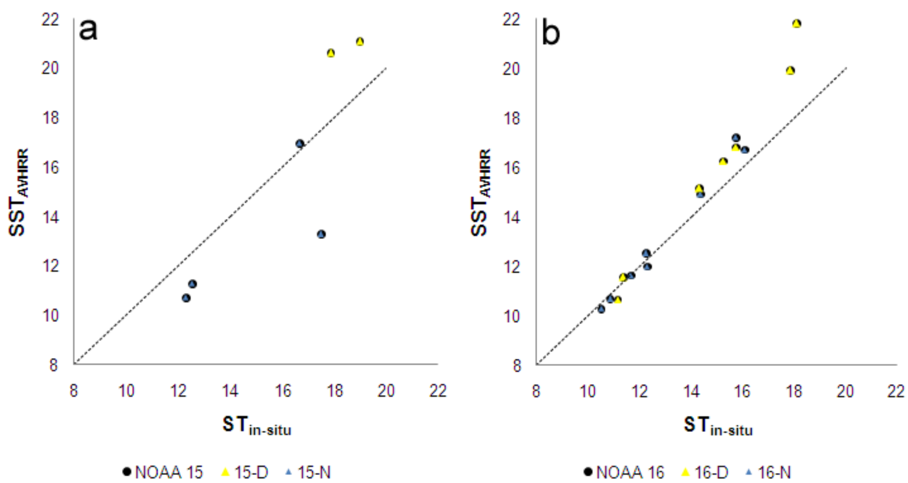

Figure 3. Satellite-derived estimates *versus* measured sea surface temperature (ºC) for a) NOAA 15 and b) NOAA 16. The data were fitted to a SMA type II regression model; the dotted line corresponds to the ratio 1:1.

Table 9. Statistical results: comparisons between temperature data from two fixed stations (PP and ES), and NOAA 17 and 18 MCSST algorithms. RMSE: root mean square error, SD: standard deviation, SST: sea surface temperature.

Data	b	a	r^2	RMSE	Mean difference (ºC)	SD difference (ºC)	*in situ* SD	SST SD	n
NOAA 15	1.60	-9.93	0.74	2.38	-0.29	2.58	2.86	4.59	6
NOAA 16	1.39	-4.70	0.98	1.29	0.73	1.10	2.56	3.57	15
NOAA 16-day	1.46	-5.52	0.98	1.76	1.02	1.39	2.89	4.21	7
NOAA 16-night	1.25	-2.94	0.99	0.64	0.30	0.60	2.15	2.69	8

Table 10. Statistical results: comparison between *in situ* oceanographic cruise data and estimates from NOAA 12, 15, 16, 17 and 18 MCSST algorithms. RMSE: root mean square error, SD: standard deviation, SST: sea surface temperature.

Data	b	a	r^2	RMSE	Mean difference (ºC)	SD difference (ºC)	*in situ* SD	SST SD	n
Oceanographic cruises day	0.96	1.27	0.87	1.27	0.55	1.19	3.34	3.20	14
Oceanographic cruises night	1.29	-3.00	0.90	1.71	1.04	1.48	3.16	4.07	14

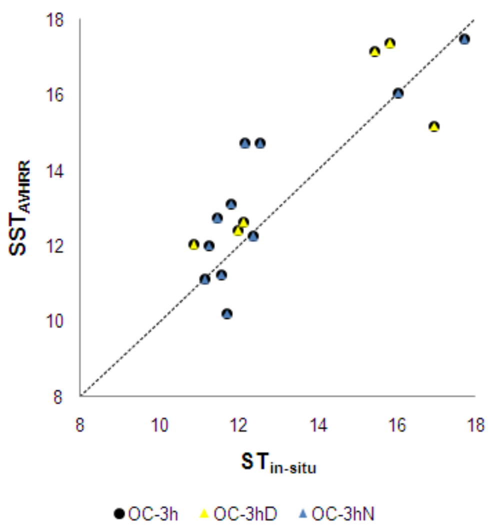

Figure 4. Satellite-derived estimates versus measured sea surface temperature (ºC) for *in situ* records from oceanographic cruises. The data were fitted to a SMA type II regression model; the dotted line corresponds to the ratio 1:1.

overestimation of the atmospheric absorption of infrared radiation (Vincent *et al.*, 2008), the biases observed here may indicate the lack of *in situ* data used in adjusting the satellite SST algorithms, and/or deficiencies in the globally tuned SST algorithms, which are incapable of representing local conditions (Zhang *et al.*, 2004).

Among the different types of existing algorithms, several studies have shown that nonlinear algorithms are more accurate than linear ones (Walton *et al.*, 1988; Hosoda *et al.*, 2007). However, nonlinear include a temperature value estimated a priori. In this regard, in the future it would be interesting to compare the *in situ* records presented here and the SST estimations derived from AVHRR-NLSST algorithms.

In order to understand the performance of MCSST and NLSST algorithms, it would be interesting to study the effect of the air-sea interaction on the atmospheric absorption of infrared radiation, as well as other sources of deviation between the satellite SST and the *in situ* temperature, such as the "cool skin layer effect" (Minnet, 1991). However, to evaluate these effects it is necessary to establish well-defined protocols for the collection of *in situ* data, including the measurement of parameters such as wind speed, relative humidity and cloud cover, among others.

This work is a first direct comparison between *in situ* measurements and MCSST-AVHRR estimates in SMG. It is also a starting point to the establishment of well-defined protocols for the collection and quality control of *in situ* data (Xu & Ignatov, 2010) so that it will be useful for the development of regional SST algorithms.

CONCLUSIONS

This study illustrates the comparison of remote sensing data for the analysis of a coastal water ecosystem. Attention has been focused on the usefulness of SST, usually retrieved from remotely sensed data, for describing the status of the ecosystem under study. There was a good correlation between the remotely sensed SST and the *in situ* temperature records over the whole area. However, SST derived from the MCSST algorithm showed considerably positive biases.

The results of this study show that AVHRR sensors can be used to analyze spatial and temporal patterns in SMG despite the overestimation of the algorithm. It would be desirable to check whether the differences in the mean and the standard deviation between both data-sets would improve after applying the NLSST algorithms and to evaluate the effect of the air-sea interaction and the near-surface vertical temperature structure. Finally it would be important to develop a regional algorithm after implementing a standard protocol for the collection of *in situ* data.

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