COMPARISON BETWEEN REMOTELY-SENSED SEA-SURFACE TEMPERATURE (AVHRR) AND *in situ* RECORDS IN SAN MATÍAS GULF (PATAGONIA, ARGENTINA) IN THE CONTEXT OF SAC-D/AQUARIUS MISSION.

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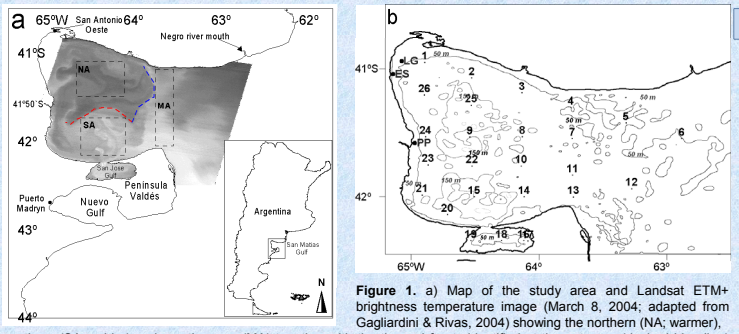

Figure 1. a) Map of the study area and Landsat ETM+ brightness temperature image (March 8, 2004; adapted from Gagliardini & Rivas, 2004) showing the northern (NA; warmer), southern (SA; colder) and mouth areas (MA) together with the thermal fronts identified at the entrance (dashed blue line) and along 41°50´ (dashed red line); b) location of in situ data (black dots) on a bathymetric map.

INTRODUCTION

The spatial and temporal patterns of water temperature are important topics to be studied in order to reach sustainable management of fisheries and aquaculture. Remote sensing methods in particular have been applied to improve the knowledge of the environmental conditions of the fisheries ecosystem of San Matías Gulf (Ocampo-Reinaldo *et al.*, 2013, Romero *et al.*, 2013). Even though these methods have been used in the gulf with increasing success to confirm previous oceanographic findings (Scasso & Piola, 1988, Gagliardini & Rivas, 2004; Williams *et al.*, 2010), satellite data have not still been compared with *in situ* records.

The aim of this study 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).

In the context of SAC-D/Aquarius mission we propose the use NIRST data for supporting research in fisheries and ecosystem management in San Matías Gulf (Patagonia Argentina). As NIRST data are not fully available for San Matias Gulf in the form of calibrated data, in this work we show part of our experience in the use of AVHRR data in order to consider it as a basis for future comparisions involving NIRST data.

MATERIALS AND METHODS

In situ data

Table 1. Research cruises carried out for recording *in situ* temperature in SMG.. Temperature was measured using two YSI (6600v2, ±0.15°C and YSI 556, ±0.15°C) at 5 meters deep. (n: number of records).

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

Table 2. Location of the coastal fixed stations. At Las Grutas (LG), there was an oceanographic buoy at approximately 3 kilometers from the coast, which measured SST every hour at two depths, 1 and 5 meters. In PP and ES SST was measured every six hours using data-loggers (Optic Stow Away-Temp (ºC) ONSET, ± 0.20°C). (n: number of records).

Place	Latitud	Longitud	Date	Available NOAA satellite data	n
Las Grutas (LG)	40º57´S	65º 4,1´W	Jul 4 - Dec 27, 2005	12-14-15-16	4144
Punta Pozos (LP)	41º35´S	64º 58´´W	Oct 3, 2007 - Sep 7, 2008	15-16-17-18	1362
El Sótano (ES)	41º 2'S	65º 8´W	Sep 7, 2007 - Aug 26, 2008	15-16-17-18	1420

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). The images (n= 363) were processed using Erdas Imagine 8.7 software and applying the MCSST split window algorithm (McClain *et al.*, 1985, Brown & Minnet, 1999).

Match-up procedure

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:

$$MD = \frac{\sum_{n=1}^{N}(x_{sat} - x_{situ})}{n} \qquad SD = \sqrt{\frac{\sum_{i=1}^{n}(MD - \overline{MD})^2}{n}} \qquad RMSE = \sqrt{\frac{\sum(x_{sat} - x_{situ})^2}{n}}$$

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).
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.

RESULTS

Table 3. Statistical results of the comparison between *in situ* data and MCSST algorithm.

Source of data	b	a	r^2	RMSE	Mean difference (ºC)	SD differenc e (ºC)	*in situ* SD	*SST* SD	n
LG (1m)	0.96	1.96	0.72	1.67	1.44	0.84	1.54	1.47	112
LG (5m)	0.98	1.77	0.71	1.67	1.49	0.83	1.51	1.47	112
PP	1.28	-2.39	0.82	2.24	1.63	1.54	2.72	3.47	234
ES	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

Table 4. Statistical results of the comparison between temperature data from LG and NOAA 12 and 14 MCSST algorithms.

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 5. Statistical results of the comparison between temperature data from ES and NOAA 17 and 18 MCSST algorithms.

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

Table 6. Statistical results of the comparison between temperature data from PP and NOAA 17 and 18 MCSST algorithms.

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

Table 7. Statistical results of the comparison between temperature data from two fixed stations (PP and ES) and NOAA 15 and 16MCSST algorithms.

Data	b	a	r^2	RMSE	Mean differenc e (ºC)	SD differenc e (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 8. Statistical results of the comparison between *in situ* oceanographic cruise data and estimates from NOAA 12, 15, 16, 17 and 18 MCSST algorithms.

Source of 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

From the 1327 *in situ* data collected, 621 match-ups were left (cloud cover and temporal coincidence). In situ temperatures ranged between 9.64 and 20.30ºC, while the AVHRR data ranged between 8.36 and 23.71ºC.
Match-up results, showed a good fit and statistical significance ($P < 0.05$) (Table 3). 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 .
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). NOAA 15 showed a negative bias (and greater scatter (Table 7). Although less represented, the nighttime match-ups showed less scattering and bias.
Finally, results of the comparison between *in situ* data of oceanographic cruises and SST from different overpass times did not show much different results when considering all the data set, except for a decrease of bias in daytime match ups (Fig. 4, table 10).

DISCUSSION AND 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 spatio-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 be improved 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.

REFERENCES

Bailey S.W., P.J. Werdell. 2006. A multi-sensor approach for the on-orbit validation of ocean color satellite data products. Remote Sensing of Environment 102:12–23.
Brown, O.B. & P. J. Minnett. 1999. MODIS Infrared Sea Surface Temperature Algorithm Theoretical Basis Document, Ver. 2.0. [on line]. Available from: [http://modis.gsfc.nasa.gov/data/atbd/atbd_mod25.pdf]. Revision: November 21, 2011.
Gagliardini D. A. & A. L. Rivas. 2004. Environmental characteristics of San Matías gulf obtained from Landsat – TM and ETM+ data. Gayana, 68(2), TI, 186-193.
McArdle, B. H., 1988: The structural relationship: Regression in biology. Canadian Journal of Zoology 66: 2329–2339.
McClain E. P., W. G. Pichel, C. C. Walton. 1985. Comparative performance of AVHRR based multichannel sea surface temperature. J. Geophys. Res., 90: 11587-11601.
Ocampo-Reinaldo M. 2010. Evaluación pesquera integral de la merluza común (*Merluccius hubbsi* Marini, 1933) del Golfo San Matías y efectos de la explotación de esta especie sobre otros componentes de la trama trófica. Tesis de Doctorado en Ciencias Biológicas. Universidad Nacional de Córdoba, Argentina, 156 pp.
Romero M. A., R. González, M. Ocampo Reinaldo. 2010. When conventional fisheries management measures fails to reduce the catch and discard of juvenile fish: a case study of Argentine hake trawl fishery in San Matías Gulf. N. Am. J. Fish. Manage. 30:702-712.
Sokal R. R., F. J. Rholf. 1995. Biometry. W.H. Freeman and Company (eds.), New York, 408 pp.
Williams, G. N., M. Sapoznik, M. Ocampo-Reinaldo, M. Solís, M. Narvarte, R. González, J. L. Esteves, D. A. Gagliardini. 2010. Comparison of AVHRR and SeaWiFS imagery with fishing activity and in-situ data in San Matias Gulf, Argentina. Int. J. Remote Sens., 31: 17, 4531-4542.

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