ACCURATE REMOTELY SENSED SEA SURFACE OBSERVATIONS IN THE CANARY ISLANDS REGION

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ABSTRACT

The aim of the project was to explore the improvement achieved in the study of oceanic phenomena in the area of the Canary Islands and the Northwest African coast by the joint use of ATSR and AVHRR to estimate SST.

Comparisons were made of satellite derived sst with in situ measurements of temperature and other oceanic parameters, such as salinity and density. These comparisons were made at different scales: Monthly mean temperatures in 1º by 1º squares and scene to scene comparisons. It was made over a region limited by the island of Gran Canaria and the Northwest African coast, thus encopassing two different oceanic environments: open ocean and upwelling areas.

Monthly mean values from 1991 to 1995 were used to derive a mean year at 1x 1 degree scale from ATSR SST, AVHRR SST and in situ measurements. Generally the ATSR algorithm gives lower values compared to AVHRR. The magnitude of the difference in open ocean areas was very stable throughout the mean year at arround 1.4ºC, while in the upwelling areas mean difference showed strong seasonality. Similarly the linear regression coeficient between both time series was higher in the oceanic areas (r^2 above 0.9) than in the upwelling zone (r^2 about 0.65). By comparing both satellite derived averaged years with independent in situ measurements we extracted the mean relative error distribution between both sensors which was found to be related to latitude and time of the year within the studied area.

We also compared individual scenes of satellite derived SST's and in situ data for the same region. The differences found between both sensors were rather similar to the ones found at the larger (refered here as seasonal) scale. Although the dual viewing geometry of ATSR introduced certain patchiness in the imagery, this could be removed after finding that the amplitude of this noise was approximately 0.25ºC, and vanished for spatial scales larger than 17 Km. Given the great similarity between the detector response functions for the infrared channels of AVHRR and ATSR, the differences in temperature estimations are atributable to the different behavoir with respect to atmospheric phenomena specially due influence of saharan aerosols that are quite frequent in the studied region.

The use of both sensors as a constellation allows the study of relatively high frequency (few hours) procceses that give rise to changes in SST patterns. Being these patterns related to heat transfer procceses across the air-sea interface and to the dynamics of shallow water masses.

Introduction:

The ocean properties in the Canary Archipelago are largely influenced by the eastern part of the North Atlantic Subtropical Gyre System and the seasonal influence of Northwest African Upwelling driven by the northeasterly Trade winds. Both regimes largely influence the SST patterns which are found in the region.

The synoptic performance of remote sensors and its large spatial and temporal coverage provides a powerful tool for oceanographic researh given its sampling capacity is beyond any other oceanographic sampling technique. Because this measurement is in principle only related to the skin of the ocean it is essential to relate this skin behavoir with respect to the bulk sea surface temperature and even with the processes occurring in the subsurface water column.

Dual viewing capability of the ATSR instruments on board ERS satellites , provide a qualitative advance in radiometric determination of SST. This is of crucial importance in tropical atmospheres in general because of the large variability of atmospheric water vapor content, and specifically in the vicinity of Saharan Desert due to the presence of eolian dust produced in the continent. Both factors affecting directly the radiative transfer in the region.

In this paper we present a comparison between ATSR and AVHRR derived SSTs and in situ measurements of temperature (and density) at seasonal scale, which is derived from averaged “or climatological” years, and also through the comparisons of individual scenes with coincident conventional oceanographic data.

We will analyse the differences found in the thermal fields obtained from each data set, and we will try to explain several features in view of the known atmospheric and oceanic characteristics of the region. We will see that cross validation of the data is needed to give an unified view of the thermal phenomena of the ocean surface. This cross validation or adjustement will allow the joint use of the data from both sensors making it possible to study higher frequency phenomena, that appear quite often over satellite imagery, superimposed on the mean signal.

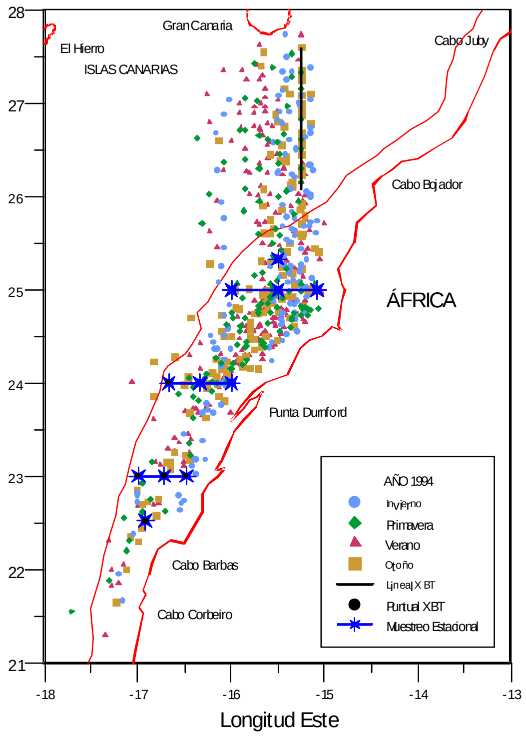

Figure 1: Study region between Gran Canaria and the African coast, showing surface sampling points for 1994 and its seasonality: Winter (circles), Spring (diamonds), Summer (triangles) and Autum (squares). The black line with NS orientation correspond to the XBT section repeated monthly from 1998 to 1995. Asterisks represent the locations of 11 aditional XBT stations over the continental shelf carried out in May 1994.

We finally will point out some of the advantages of the enhanced temporal coverage derived from the combined use of satellites, and how this can produce accurate estimations of the variability of the surface thermal fields.

In situ and satellite SST:

In the present study we use several sources of data, both in situ and satellite derived:

a) Time series of monthly averaged sea surface temperature from AVHRR and ATSR.

b) Ten years of repeated surface measurements from the Hospital vessel Esperanza del Mar in the area between Cannary Islands and Cap Barbas.

c) Eeight years of repeated XBT section from the same ship.

d) One month imagery from both sensors in coincidence with an oceanographic campaign in the same area in May 1994.

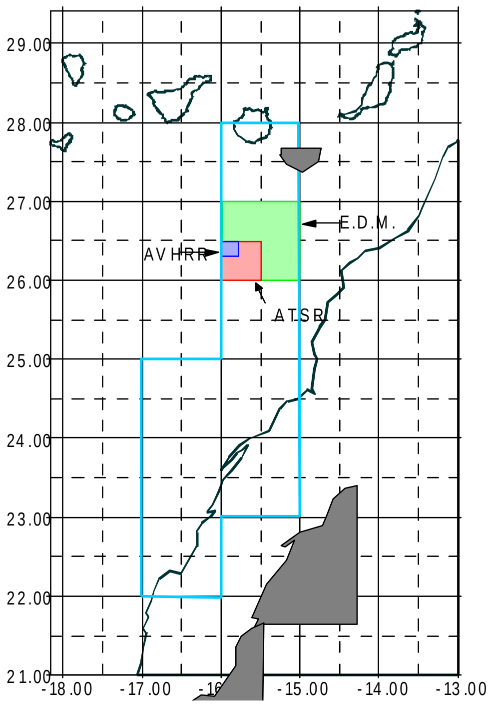

Figure 2: Map showing the original resolution of the monthly mean temperature data used: approx. 1/6º for AVHRR MCSST, ½º for ATSR ASST and 1º in the case of ship sampling. They all were averaged to a common resolution of 1ºx1º

Ship data: A ten year (july 1985 to december 1995) series of surface measurements was produced by the hospital ship "Esperanza del Mar" in cooperation with the Instituto Canario the Ciencias Marinas in Gran Canaria. [Llinás et al 1996] This Dataset includes surface temperature measured ellectrónically at a water intake situated about 2m below the water surface, coincident measurements of salinity, nutrients and meteorological data are also avaliable. On average two samples per day were obtained during the 25 days per month operation of the ship in the area; as logistical support to the international fishing fleet working off Sahara. In the figure 1 we present the locations, types of sampling and its seasonality for 1994. The locations are always outside the 12-mile coastal range where fishing is not permitted.

In addition an XBT section was repeated monthly on the way from the Canary Islands to the African shelf or vice versa. This includes ten probe launchings along the 15.25ºW meridian between 27.6ºN to 26ºN, black line in Figure1. This section was carried out for eight years (1988 1995). (Due to the biological stops required in the fishing agreement between the EC and Morocco there is some reduced sampling in October).

An extension of this sampling activity was made in May 1994, which will be refered as COMPLEX - 94 cruise. In this case we use 21 XBT stations, this is 11 stations over the shelf in adition to the regular section , blue asterisks in Figure 1.

Satellite Imagery : ATSR on board ERS-1 and AVHRR on NOAA-11 scenes were provided by ESA for the period of COMPLEX experiment. In both cases the CEOS level 2B files were used, using respectively SADIST [Bailey, 1993] and SeaSHARK [ESA, 1992] specifications, these included infrared brightness temperatures and sun and satellite angles. For sea surface temperatures operational algorithms were used [McClain et al, 1985, Reynolds, 1991; Mutlow et al, 1994].

Time series of monthly averaged sea surface temperatures from both sensors were obtained through the space agencies: NOAA-NASA Oceans Pathfinder MCSST data from AVHRR with a resolution of 0.1718º x 0.1718 º and (NCRC) Global ASST from ATSR with a ground resolution of one half degree in latitude and longitude.

Data processing:

For a study of time series a window between Gran Canaria and the African shelf was established according to the ship's sampling scheme, covering 6 degrees in latitude, (Figure 2). Two diferent oceanographic environments exits: open ocean conditions near the islands and upwelling related phenomena in the vicinity of the African coast. In order to minimize the effects of the differences in sampling coverage and small scale spatial variability, the monthly averaged time series of sea surface temperatures were averaged to in boxes of 1ºx1º .

For the comparison of individual scenes with coincident in situ data, each sampling point was used as the center of an extraction window of variable size, from which all relevant geophysical parameters: infrared brightness temperatures, sun and satellite angles and visible radiances were extracted. Data from these windows were then tested against cloud contamination and sun glitter using threshold and homogeneity criteria. Those windows that passed the tests were compared with the ship measurements.

In a similar way large datasets were extracted for quantitative image to image comparison of overpasses of the same day.

Results:

a) Time series of SST
Neither of the time series obtained showed any trend of warming or cooling. The energy spectrum of all the SSTs time series showed the dominance of the annual signal in the oceanic environment as well as in upwelling areas, the percentage of the total variance explained by this component is only 40 to50 % in both environments. After removing the seasonal signal from the time series other periodic signals were found including one with 7 to 9 month period distinctive of the upwelling influenced zone.

For each one of the datasets an averaged year for the monthly and 1ºx1º resolution was computed after removing extreme 10 % data. In figure 3 the spatio temporal distribution of each one of the thermal fields is shown. It is possible to identify several causes for the differences found:
.-Discrete versus continous sampling.
.-Skin versus bulk measurements
.-Differences in coverage
.-Differences in atmospheric correction.

In general the temperature derived from ATSR is lower than the one measured from the ship and this again is lower to the one obtained through ATSR . Between both sensors, the differences are homogenously distributed in the open ocean with an average value of 1.4ºC throughout the year, while in the upwelling area they exhibit a seasonal pattern, being larger during summer.

The regression coefficients between in situ and sensor data showed great influence of oceanic environment, that is linearity increasing rapidly towards the open ocean areas, this holds true for the whole time series (Table I) and for the annual means derived from them (Table II).

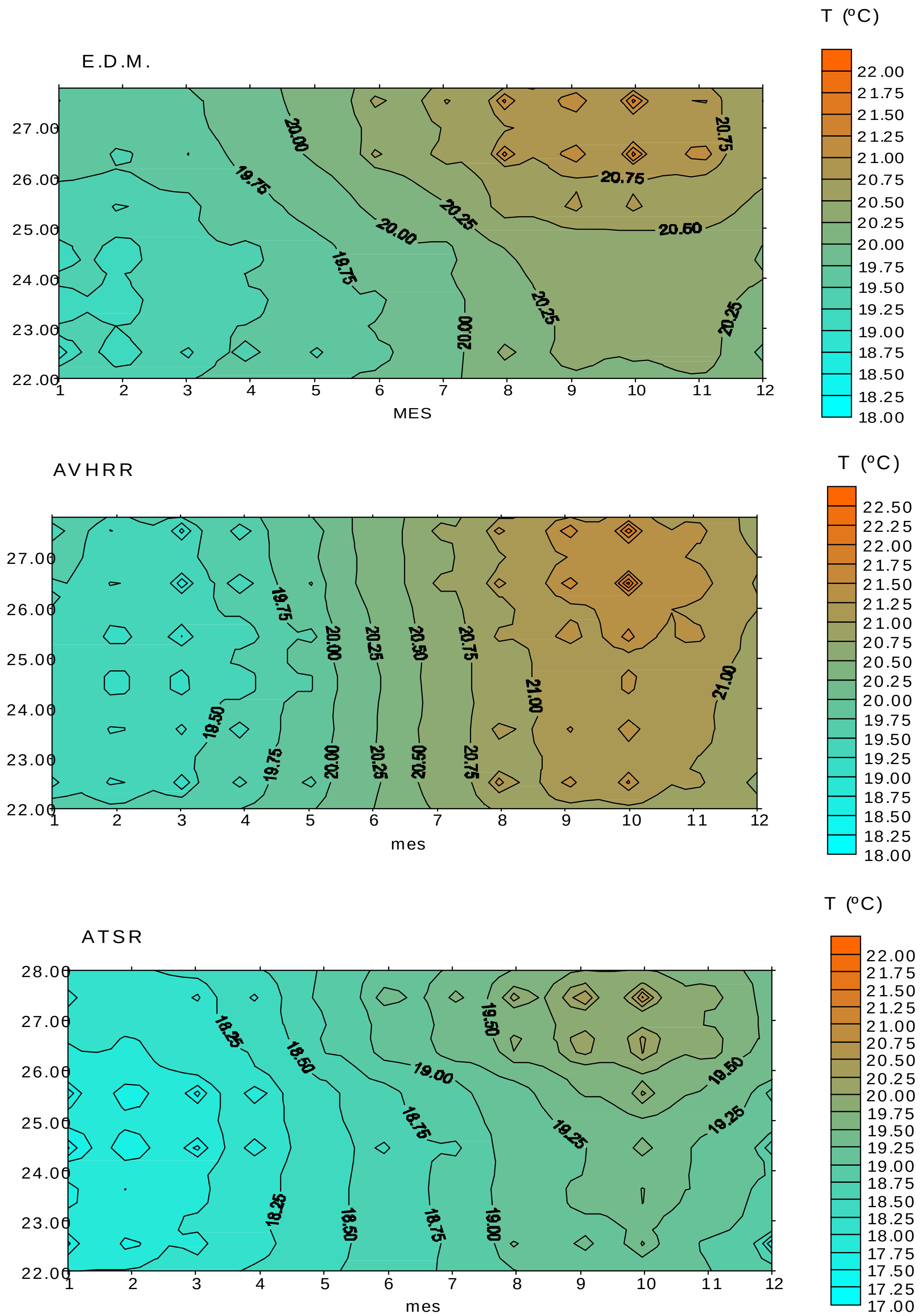

Figure 3: Latitudinal (vertical axis) distribution of SST for the averaged year (months in the horizontal axis) as obtained for each of the data sets: Esperanza del Mar (top), AVHRR (middle) and ATSR (bottom) for the 1º by 1º scale.

Table I. Linear correlation coefficient r^2 and rms variance for each one degree latitude belt, for the three time series of sea surface temperature.

Latit. Belt	AVHRR VS EDM (N=119)		ATSR VS EDM (N=45)		AVHRR VS ATSR (N=48)	
	r^2	Rms	r^2	rms	r^2	rms
22º23	0.34	1.44	0.29	1.11	0.62	0.56
23º24	0.29	1.48	0.24	1.19	0.73	0.43
24º25	0.28	1.56	0.36	1.10	0.69	0.56
25º26	0.47	1.32	0.41	1.25	0.75	0.57
26º27	0.63	0.91	0.52	1.38	0.91	0.28
27º28	0.61	0.98	0.51	1.29	0.93	0.19

Table II. Linear correlation coefficient r^2 and rms variance for each one degree latitude belt, for the three time series of sea surface temperature.

Latit. Streep	AVHRR VS EDM		ATSR VS EDM		AVHRR VS ATSR	
	r^2	Rms	r^2	rms	r^2	rms
22º23	0.88	0.25	0.768	0.28	0.799	0.44
23º24	0.812	0.41	0.807	0.28	0.807	0.25
24º25	0.849	0.35	0.800	0.29	0.881	0.28
25º26	0.900	0.28	0.842	0.33	0.905	0.27
26º27	0.938	0.19	0.937	0.21	0.949	0.15
27º28	0.938	0.19	0.941	0.19	0.947	0.16

The annual latitudinal means were found to be rather different, specially in the upwelling related zone; this is basically due to the increasing importance of high frequency processes. In the oceanic areas near the islands the agreement amongst all temperatures is in general very good.

With the exception of the EDM data the amplitudes of the annual signals are within an error of 0.5ºC, this is mainly due to the particularities of ship's sampling: with undersampling in October, which is one of the warmest months, and near the coast were the lowest temperatures are found.

Table III. Mean temperature <T>, inter-annual variability σ^2, thermal amplitude ΔT and phase φ of the annual signal per latitude belt. The phase is refered to the month of minimum temperature.

E.D.M.

	22ºN 23ºN	23ºN 24ºN	24ºN 25ºN	25ºN 26ºN	26ºN 27ºN	27ºN 28ºN
<T>	19.55	19.46	19.33	20.17	20.87	20.81
σ^2	0.846	0.805	0.809	1.10	1.19	1.15
ΔT	2.49	2.47	2.40	3.21	3.13	3.17
φ	2/12	2/12	2/12	2/12	2/12	2/12

A.T.S.R.

	22ºN 23ºN	23ºN 24ºN	24ºN 25ºN	25ºN 26ºN	26ºN 27ºN	27ºN 28ºN
<T>	18.31	18.56	18.03	18.19	19.83	19.61
σ^2	1.06	1.15	1.15	1.38	1.75	1.72
ΔT	2.97	3.51	3.51	4.34	4.83	4.72
φ	2/12	2/12	1/12	2/12	2/12	3/12

A.V.H.R.R.

	22ºN 23ºN	23ºN 24ºN	24ºN 25ºN	25ºN 26ºN	26ºN 27ºN	27ºN 28ºN
<T>	20.25	20.27	20.03	20.24	20.61	20.52
σ^2	1.41	1.41	1.47	1.62	1.67	1.70
ΔT	3.68	3.64	3.91	4.45	4.69	4.70
φ	2/12	3/12	3/12	3/12	3/12	3/12

X.B.T. 5 m.

	26ºN 27ºN	27ºN 28ºN
<T>	20.52	20.75
σ^2	1.68	1.72
ΔT	4.44	4.39
φ	3/12	3/12

Using the calculated averaged years we have derived a distribution of relative differences by comparing each remotely sensed SST with an independent dataset such as ship measurements. The results are displayed in Figure 4.

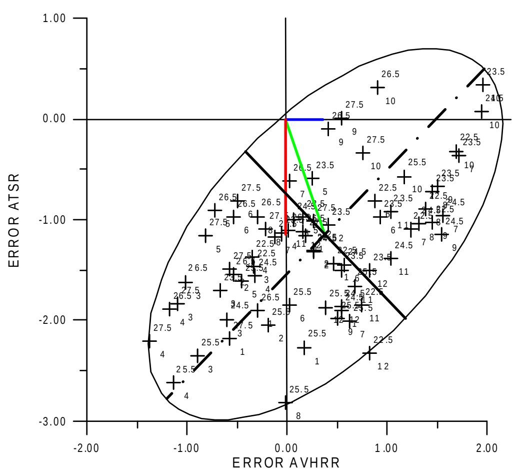

Figure 4: Distribution of relative differences (in ºC) between ATSR and AVHRR, when compared to an independent set of data as surface measurements from the ship.

The distribution of these errors suggests that they are related mainly to the season, and also to the latitude or more properly to the oceanic domain. This is for a given latitude the variations occur mainly along the major axis of the ellipse shown in figure 4, where the warm periods tend to be located to the right and to the upper part, while winter months are in the opposite corner. If we take for example one month variaions take place mainly along the minor axis with the higher latitudes (oceanic) are situated to the upper left part of the ellipse.

The mean absolute difference between the two radiometers is about 1.21ºC for the region considered, and hence this is the order of the systematic error which we can expect when using them together.

b) Synoptic comparisons:
When comparing coincident individual scenes, very similar results are found; however for ATSR spatial filtration is neccesary for visual interpretation, given the noise patterns exhibited by this images (Figure 5). For the particular case shown, the length scale of the noise is about 17 km while its amplitude is close to 0.25ºC.

As an example we show in figure 6 an image obtained by substracting ATSR filtered values from AVHRR ones and

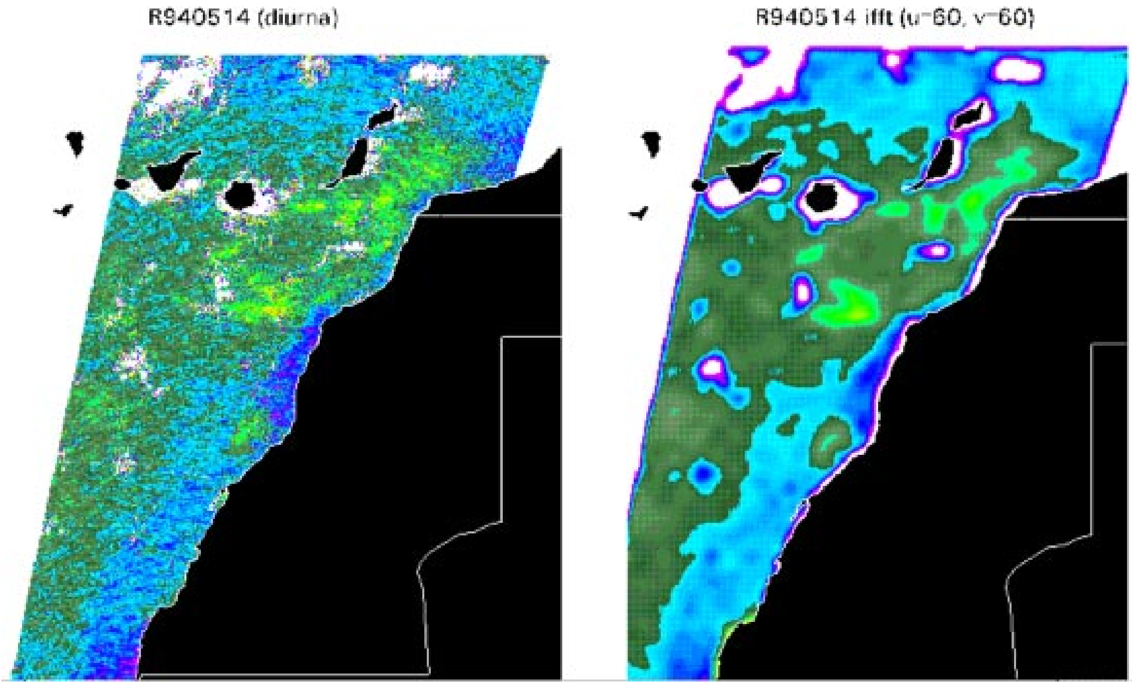

Figure 5: ATSR SST image of the Canaries and the North West African Coast acquired on the 14th of May 1994 at 11.30 UTC. To the right the same image after low pass filtering in the frequency domain and finaly reverted to the spatial one.

then grouping them into 1ºC bins. These were two day overpasses relatively cloud free obtained for the 14th of May 1994, that was about 11.30 UTC in the case of ATSR and around 15.30 hours for the AVHRR.

The mode of the differences was (0-1ºC) is in the line of the one encountred for this month at yearly scale, this is around 1ºC regardless of the time of the year. In this image hot and cold spots that can be related to higher frequency changes in surface thermal pattern.

Assuming no change in atmospheric conditions during the six hours period between the two overpasses, blue spots could be interpreted as surface coolings which are related to the extension of the upwelled water offshore by Ekman transport, at the same time larger coolings are found near the coast which is consistent with an intensification of upwelling. In contrast hot spots are likely related to very shallow warmings of the sea surface.

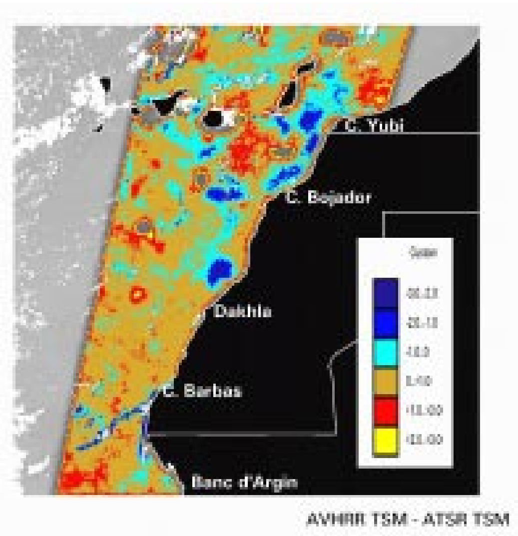

Figure 6: Image of differences AVHRR SST minus ATSR SST, corresponding to the 14th of May 1994. Results are grouped in 1ºC bins. The time lag between both overpasses was about 6 hours.

Conclusion

Mean differences of the order of 1º to 1.5ºC have been found in the sea surface temperature fields derived from ATSR and AVHRR between Gran Canaria and the North West African upwelling region. Part of these differences may be due to the fact that AVHRR is refered to bulk temperatures since it is obtained through a wide set of SST obtained from drifters and ships, while ATSR atmospheric correction lies only in radiative transfer theory [Harris and Saunders, 1996] . Nevertheless wind and wave conditions that usually prevail in the studied area produce large turbulent mixing making the surface layer quite homogeneous, except perhaps in shadow areas southwest of the islands.

Oceanic domain exerts large influence on the degree of linearity, and rms variance, between both time series of satellite measurements as well as on the corresponding averaged years. This shows clearly the relative importance of fast processes over each of the environments considered, those with periods comparable to the time lag between overpasses. Thus can be related to differences in time coverage. This last is to be reduced by averaging to obtain the mean years but is still considerable. This last portion of the difference is consistent with the variable presence of atmospheric aerosols, which is larger near the coast and during the Summer.

The great similarities in amplitudes of the annual signals, specially in the open ocean, joined to the high degree of linear correlation, allows to trust statistical models to adjust the mean behavoir of both sensors. In fact these mean diferences agreed very well with the ones found when comparing two individual scenes of the same day.

So after adjusting (or cross validating) both satellite derived temperatures, it is possible to use together data from both sensors to assign an energy level “or persistence level” to the mesoscale (spatially) patterns observed in the imagery, through for example its autocorrelation function.

Acknowlegdments

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