Northwest Atlantic Fisheries Organization

Serial No. N3080 NAFO SCR Doc. 98/79

SCIENTIFIC COUNCIL MEETING - SEPTEMBER 1998

Satellite Measurements of Sea Surface Temperature: an Application to Regional Ocean Climate

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Abstract

A readily available multichannel sea surface temperature (MCSST) dataset is used to examine the annual temperature cycle in a region of the Northwest Atlantic Ocean. The data are from October 1981 to December 1997, are updated regularly, have a spatial resolution of 18 km by 18 km, and a temporal resolution of 1 week. The spatial pattern of the long-term mean temperature on the Scotian Shelf derived from the satellite observations agrees with that derived from *in situ* measurements. The annual temperature cycles from MCSST and *in situ* data for the Avalon Channel and Emerald Basin, sites of two long-term climatological temperature time series, have rms differences of 0.5°C. The variances for the monthly and annual temperature anomalies from satellite and ships' data are within 0.1°C of each other at both sites with correlations ranging from 0.4 to 0.7. The data and the images created from them are available both as a database and as an image archive including WEB access from the Department of Fisheries and Oceans homepage.

Key words: remote sensing, sea surface temperature, ocean climate

Introduction

Satellite measurements of sea-surface temperature (SST) are available from the Physical Oceanography Archive Centre of the Jet Propulsion Laboratory (JPL). This study used the JPL product of weekly global (2048x1024 pixels) 18 kilometre gridded multichannel sea-surface temperature (MCSST) derived from the daytime NOAA Advance Very High Resolution Radiometer (AVHRR). The data cover the period from October 1981 through December 1997. Two time series of temperature values are available - one for daytime or ascending orbits and a second for night-time or descending orbits. Because the night-time data are sparse, only the daytime values were used in this study. Each data file contains a composite weekly map of gridded temperatures with a spatial resolution approximately 18 km by 18 km at the equator. An ocean buoy match-up SST dataset was used by NOAA to compute global coefficients to calibrate the JPL product. Additional details are provided by Mason et al. (1998a).

The monthly mean surface temperature distribution covering the ocean area from 35°N to 67°N and 35°W to 77°W has been derived by Mason et al. (1998a). This dataset has proven useful in addressing fisheries and ocean variability issues (Mason et al., 1998b; Petrie, 1998). In this paper, we shall present the seasonal mean temperature distributions estimated from satellite observations for the Scotian Shelf and compare them to the same seasonal pictures derived from ships' data. We shall compare the annual temperature cycle, and the monthly and annual temperature anomalies derived from satellite observations to *in situ* data collected at 2 sites in the Atlantic region, Avalon Channel (Station 27) on the Grand Banks and Emerald Basin on the Scotian Shelf. These two sites are used each year to evaluate the state of the ocean environment in the region (Drinkwater et al., 1998). Finally, we shall comment on the relationship between the satellite observations and subsurface *in situ* data.

An additional purpose in presenting this paper is to indicate that the monthly temperature climatologies based on the 1981-1996 data for the entire Northwest Atlantic and for three subareas, the Newfoundland Shelf, the Gulf of St. Lawrence and the Scotian Shelf, the individual monthly temperature and temperature anomaly maps from 1981-1997 are available through the internet at the Department of Fisheries and Oceans website. All of the weekly temperature values, more than 3.5 million entries, are also available in a geographically referenced database with on-line query and statistical capabilities. The images and the database are located on the world wide web at the following address:

http://www.maritimes.dfo.ca/science/ocean.

Monthly MCSST Climatology

False colour images of the average monthly temperatures for the large Northwest Atlantic (full) region and for the three sub-regions are provided by Mason et al. (1998a). The images for February, May, August and November corresponding to the midpoint of the four seasons for the Scotian Shelf are shown in Fig. 1. The white areas of Fig. 1 are the 18 km by 18 km pixels with insufficient data to calculate a long-term mean. Coverage up to the shelf break is extensive for all months except December and January. There is almost complete coverage for the entire Scotian Shelf from April to October. The maps for the full region (35-67°N, 35-77°W) show that data coverage is sparse for northern latitudes particularly, with almost no measurements from November to May (Mason et al., 1998a). Clouds, fog and ice cover are the major factors reducing data return.

It is necessary because of data scarcity to ensure that a reasonable number of monthly measurements are included before a climatological mean temperature is calculated. A number of criteria were examined. For a given pixel, at least 7 years of data were required before monthly average temperatures and their anomalies were calculated. This value was chosen as the cut-off based on experience with the images and since it reduced the spatial noise in the temperature anomaly fields.

The MCSST maps show a number of features that are similar to the average surface temperature maps derived from ships' data by Petrie et al. (1996). In February, the 2°C isotherm (shown as a yellow line in Fig. 1) moves along the Scotian Shelf break from east to west before moving towards shore at about mid-shelf. The 4°C isotherm (light blue) encompasses Georges Bank and penetrates deep into the Gulf of Maine to the mouth of the Bay of Fundy. These features are also seen in the atlas based on *in situ* data (Petrie et al. 1996). The water on the eastern Scotian Shelf that originated from the Gulf of St. Lawrence is about -0.5°C, about 0.5°C cooler than the temperatures reported by Petrie et al. (1996). This may be because the averaging period, 1981-1996, for the MCSST maps was different than for the atlas based on *in situ* data, 1910-1996, and corresponded to a cold period for the Gulf (Drinkwater et al. 1998). In May, the 4°C isotherm (yellow) is found along the Newfoundland and eastern Scotian Shelf edges, and subsequently moves onshore; the 6°C isotherm, marking the boundary between the blue and violet colours, penetrates into the Gulf of Maine. These are features seen in both atlases. In August, the penetration of the 18°C isotherm (purple) onto the central Scotian Shelf and the cool upwelling and tidal mixing zone in southwestern Nova Scotia are also features in both climatologies. In November, the 10°C isotherm (yellow) in the MCSST atlas, that moves from the shelf break on the eastern Scotian Shelf to the coastal area, corresponds to the 9.5°C contour from the *in situ* compilation. Overall, there is a remarkable correspondence between the climatologies derived from satellite observations and ships' measurements. This is so in spite of the fact that the sampling methodologies are quite different for the two atlases. Similar agreement is found for other areas of the Northwest Atlantic (Mason et al. 1998a).

Monthly Temperature Maps

The Scotian Shelf region exhibits considerable temperature variability on a number of temporal and spatial scales (Drinkwater et al., 1998). Drinkwater et al. (1994) indicated that temperatures in August, 1991, for the Scotian Shelf, the Gulf of Maine, the Gulf Stream and the Sargasso Sea were within about 0.5°C of normal values. This is also indicated from the satellite sea surface temperature map (Fig. 2, compare to Fig. 1). However, the satellite map provides more spatial detail than the broad scale averages of Drinkwater et al. (1994). South of 40°N, areas of above normal temperature are present (Fig. 2); in addition, there is an indication of cooler temperatures in 1991 just seaward of the shelf break. Drinkwater et al. (1994) indicated that slope water temperatures were 0.4 to 0.7°C below normal in August, 1991.

Sea surface temperatures are clearly well above normal in August 1994 (Fig. 2) compared to the long-term climatology (Fig. 1). Seaward of the shelf break, temperature is 2-4°C above normal. Drinkwater et al. (1996) show

July surface temperatures over the continental slope of 2-5°C above normal; moreover they conclude that the shelf/slope water front and the northern edge of the Gulf Stream were north of their average positions, the latter near its maximum northern extent in 15 years. The satellite data indicate that above normal temperatures persisted into August and were more widespread than Drinkwater et al. (1996) showed. The satellite data also show that the warmer than average temperatures characterized most of the Scotian Shelf, except for the nearshore zone. Drinkwater et al. (1996) indicated that Scotian Shelf and Gulf of Maine temperatures were generally about 2°C above normal.

Thus on broad spatial scales, satellite sea surface temperatures are providing a picture that is in agreement with ships' data. The former though gives broader spatial and potentially more frequent temporal coverage.

Site Comparisons

Although NOAA has performed global validations of the MCSST product, a regional validation acts as a check for local biases. In the Northwest Atlantic, temperatures measured at Sta. 27 on the Grand Banks of Newfoundland and in Emerald Basin on the central Scotian Shelf have been used as indicators of the ocean climate over the continental shelf off Canada (see Drinkwater et al., 1998 for example). Observations from October 1981 to present time were extracted from the Bedford Institute's hydrographic and satellite sea surface temperature databases, grouped by month and averaged to give monthly mean temperatures for Avalon Channel (site of Sta. 27) and Emerald Basin. The boundaries of these two areas were the same as those used by Drinkwater and Trites (1986, 1987). Hydrographic data from 0-5 m were taken as representative of the surface. Data from a particular month were averaged within a year before computing the overall monthly mean. There were 1930 *in situ* observations for the Avalon Channel, 1,699 or Emerald Basin; there were 9,373 temperature estimates from the satellite for Avalon Channel, 18,239 for Emerald Basin.

The annual cycles for both regions are shown in Fig. 3. Overall the agreement is very good with an rms differences of about 0.5°C in both cases. There are however systematic differences that may be caused by the method of sampling. For example, in both areas the summer temperatures are higher for the satellite data than for the *in situ* measurements. The satellite sensors detect the temperature in the very near surface which would favour higher summertime values (Topliss, 1995); in addition, *in situ* samples were from the depth range of 0-5 m which would favour lower values in the summer when shallow thermoclines can form. Since the satellite data can only be collected under cloud-free conditions, this also may result in small biases. In winter, the offset is not so systematic.

Mason et al. (1998a) compared all of the monthly *in situ* and satellite values for the two sites and found that the linear regression slopes were 1.05 and 1.03 for Avalon Channel and Emerald Basin (a slope of 1 is ideal), with intercepts not statistically different from 0, and average offsets of -0.4 and -0.55 (satellite higher).

Monthly Anomalies

Monthly anomalies of surface temperature were examined for both sites and were referenced to the 1981-1997 monthly mean temperatures (Fig. 4). There were 156 coincident months for Avalon Channel and 135 for Emerald Basin. There is good qualitative agreement for the two sites with periods of above and below normal temperatures generally occurring at the same time in both time series. A summary of the temperature statistics is given in Table 1.

Table 1
Temperature Statistics from Avalon Channel and Emerald Basin

Site	Std. Dev. of Monthly Anomalies (°C)		RMS Difference (°C)
	SST	*in situ*	
Avalon Channel	1.11	1.02	1
Emerald Basin	1.13	1.16	1.25

The standard deviation of the monthly temperature anomalies at Avalon Channel and Emerald Basin for the satellite SST and the *in situ* observations is about 1-1.2°C, i.e., at each site the same magnitude of ocean variability was measured by both means. On the other hand, the rms differences between the two time series at each site was 1-1.25°C. Thus, the discrepancy between satellite and *in situ* data is about the same magnitude as the climate variability. This leads to correlations between the two series of 0.39 in Avalon Channel and 0.58 in Emerald Basin.

Though these correlations are in the correct sense, they are not as high as we would have hoped. However, the false colour images of the monthly anomalies shown by Mason et al. (1998a,b) show broad scale patterns of SST anomalies with the same sign, showing that data error may be less of a problem than this comparison indicates. This was also indicated in the discussion of the 1994 SST image (Fig. 2). Moreover, the satellite data had 5 (Avalon Channel) to 11 (Emerald Basin) times more observations than the *in situ* dataset.

Mason et al. (1998b) found excellent agreement between MCSST and *in situ* observations for a number of other regions on the Grand Banks, Scotian Shelf and Gulf of Maine.

Average Annual Temperatures

The average annual temperature anomalies have been calculated for Avalon Channel and Emerald Basin using both the MCSST data and *in situ* measurements (Fig. 5). The comparison is made for coincident measurements, i.e., only those months which have both an MCSST temperature and ship temperature are used. There is good agreement between the two datasets particularly for Avalon Channel. The standard deviations of the annual temperature anomalies for Avalon Channel (Emerald Basin) are 0.62°C (0.54°C) from the MCSST observations and 0.53°C (0.56°C) for the *in situ* data. These standard deviations are about one half of the monthly standard deviations (Table 1). The correlation between the two time series of annual anomalies remains about the same as that for the monthly anomalies for Emerald Basin, but the correlation for Avalon Channel improves to 0.7. Mason et al. (1998a) compared time series of annual anomalies for a number of areas and found the best correlation, 0.9, for surface temperatures on Emerald Bank.

Correlations Between Surface MCSST and Deeper Temperatures

Mason et al. (1998a) also explored the possibility of using the MCSST dataset as a proxy for sub-surface temperature anomalies. The correlation of the monthly and annual temperature anomalies for the MCSST dataset and for *in situ* observations for Avalon Channel decreased quickly from 0.39 at the surface to 0.18 at 50 m. The correlation for the annual anomalies decreased from 0.7 at the surface to 0.43 at 50 m. This behaviour is fairly typical for the east coast region, however, Mason et al. (1998a) found that the correlations were generally higher on the Newfoundland Shelf, somewhat smaller for the Scotian Shelf and smallest for the Gulf of St. Lawrence. Emerald Bank, with the highest surface correlations for the annual anomalies, also showed the highest subsurface correlation of 0.83 at 50 m. There is, therefore, some promise of using the MCSST data as indicators of subsurface temperature depending on location.

Summary

The MCSST dataset is useful in determining the annual cycle of temperature to within approximately 1°C in any single month over large areas of our region. The positive and negative temperature anomalies occur in broad continuous patterns in the region indicating consistency in MCSST data. However, if we assume that the *in situ* data are correct and use them as our standard (this was implicit in our earlier analysis), then comparisons indicate that at best we may be able to characterize about 40% of the monthly surface temperature anomalies. The situation is more promising when it comes to the annual temperature anomalies where tests indicate that we may be able to describe 35-80% of the surface variability (Mason et al. 1998a).

The *in situ* data are not without problems as even in the heavily sampled Avalon Channel and Emerald Basin, they have about 5 to 11 times fewer observations than the MCSST dataset. Moreover, these areas are about 10,000 km^2, thus spatial aliasing is a potentially greater problem for the *in situ* observations than for the MCSST dataset.

Our comparisons were made when a typical monthly (annual) surface *in situ* temperature anomaly in the region was 1.36°C (0.73°C). Thus, 1981-1996 represents a period of low surface temperature variability. In the past, a larger *in situ* surface temperature variability has been measured. Comparisons between the MCSST dataset and *in situ* observations should improve during periods of greater temperature anomalies, i.e. when the signal to noise ratio has increased. Finally, satellite data can assist in the interpretation of ships' measurements by broadening the coverage in some localities and also providing data for remote regions.

Acknowledgements

The MCSST data are provided at no charge by :

User Services Office
Physical Oceanography Archive Centre (PO.DAAC)
Jet Propulsion Laboratory
M/S 300-320
4800 Oak Grove Drive
Pasadena, CA 91109, USA

D. N. Gregory transferred the data from our database into the Regional DFO FoxPro® database.

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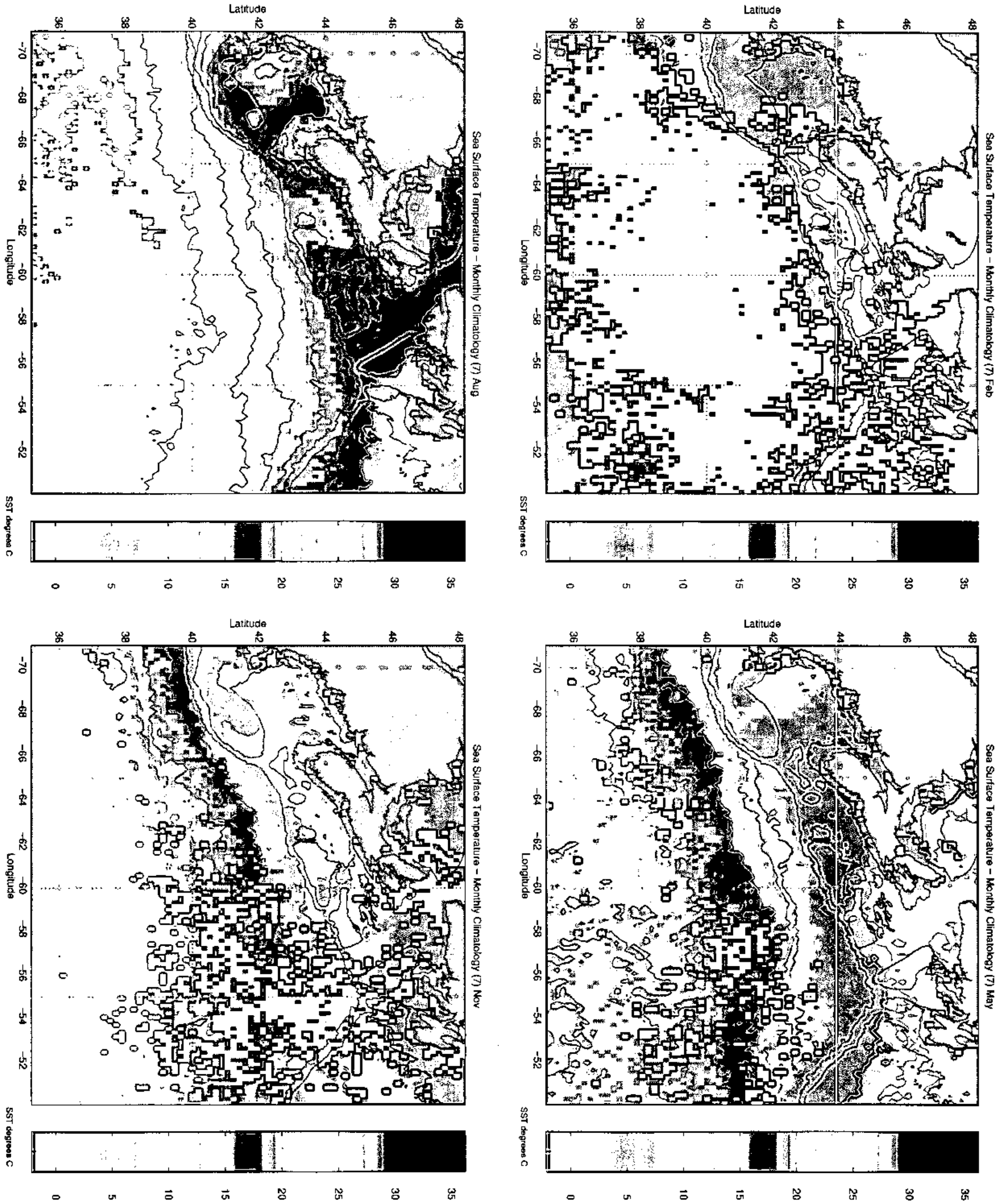


Figure 1. Long-term monthly average temperatures for February, May, August and November based on satellite observations. White areas are locations were less than 7 years of data were available. Selected temperature contours are shown in each panel; the 200 and 1000 m contours are shown in black.

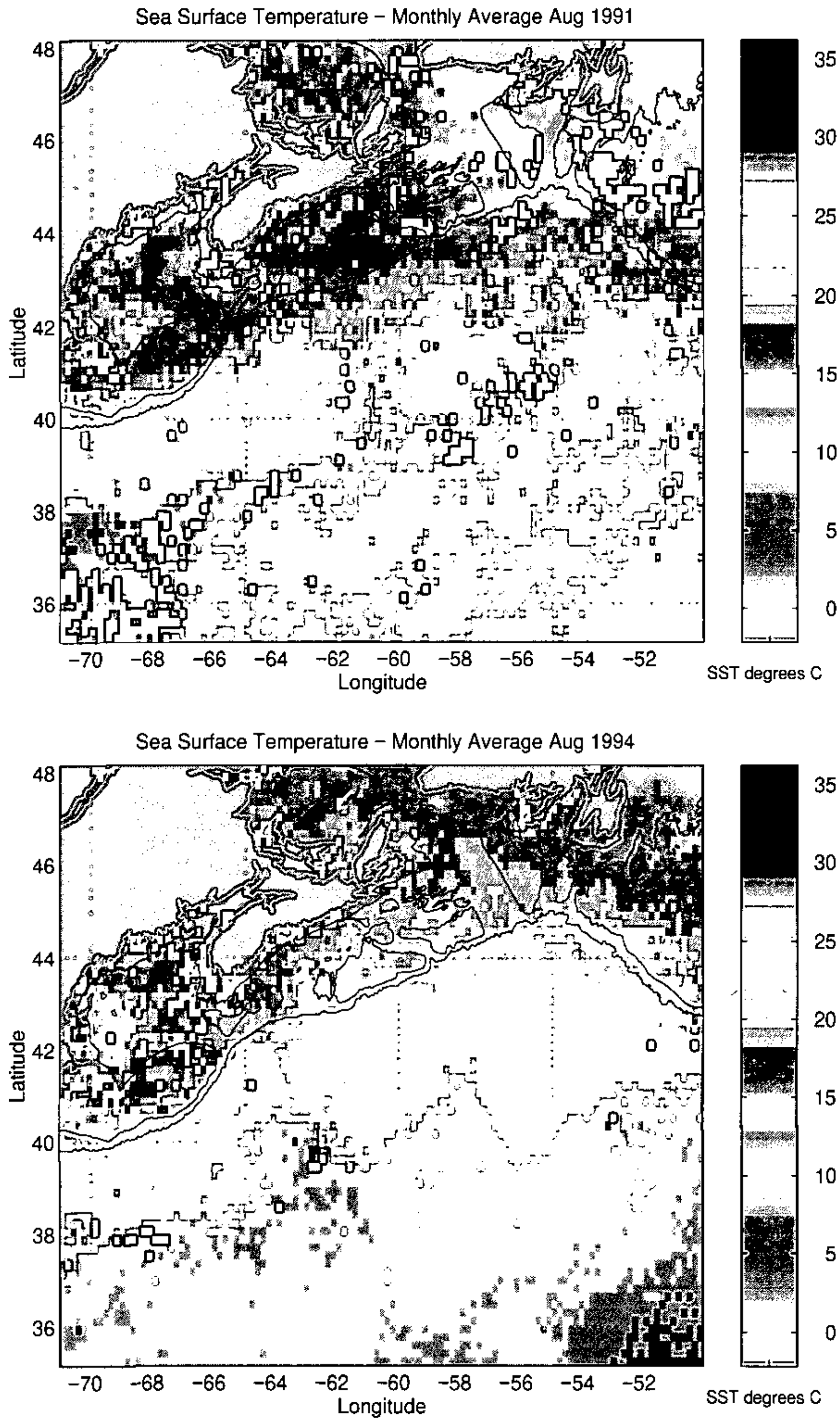


Figure 2. Sea surface temperature for the Scotian Shelf region and adjacent areas from satellite observations for August 1991 and 1994.

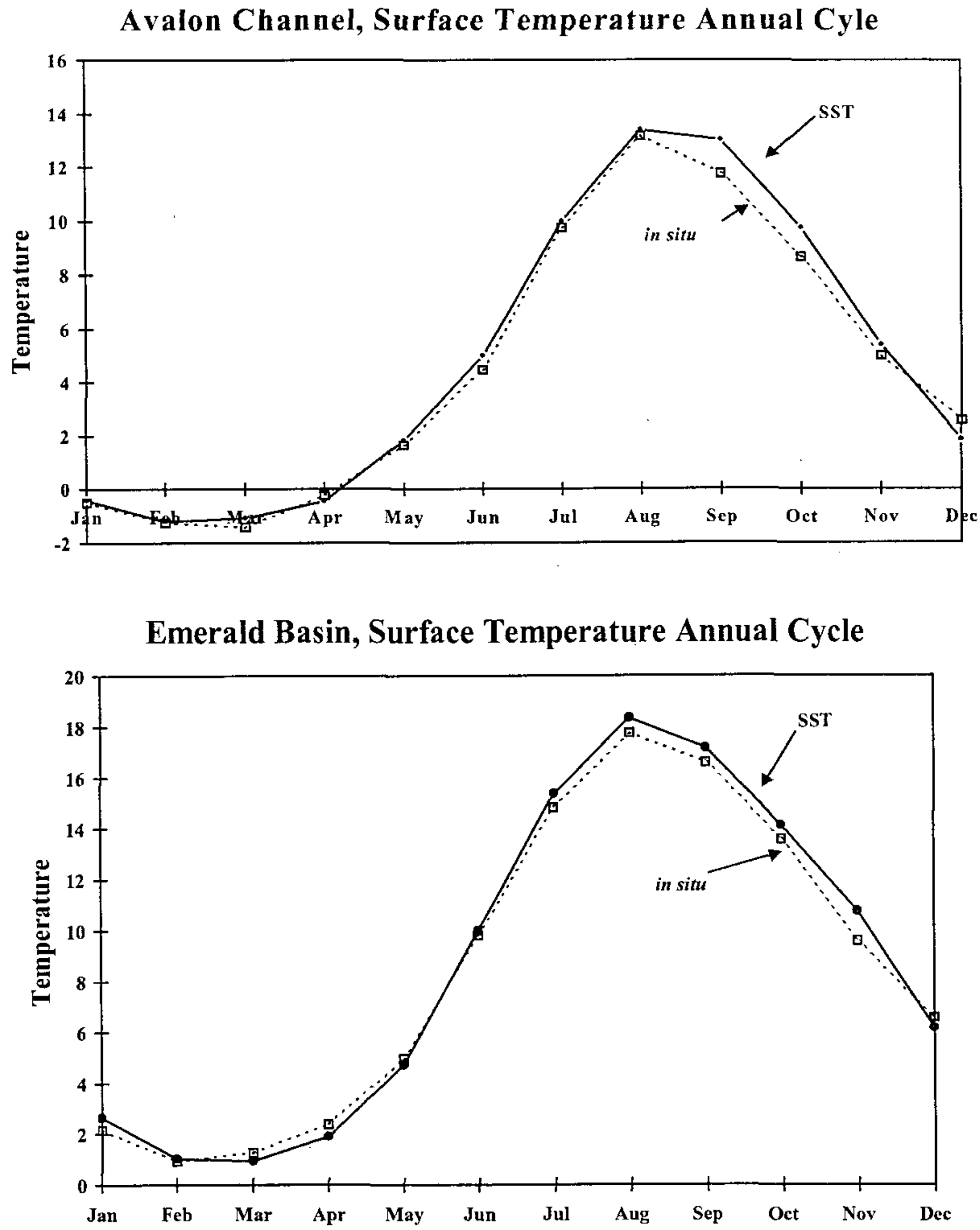
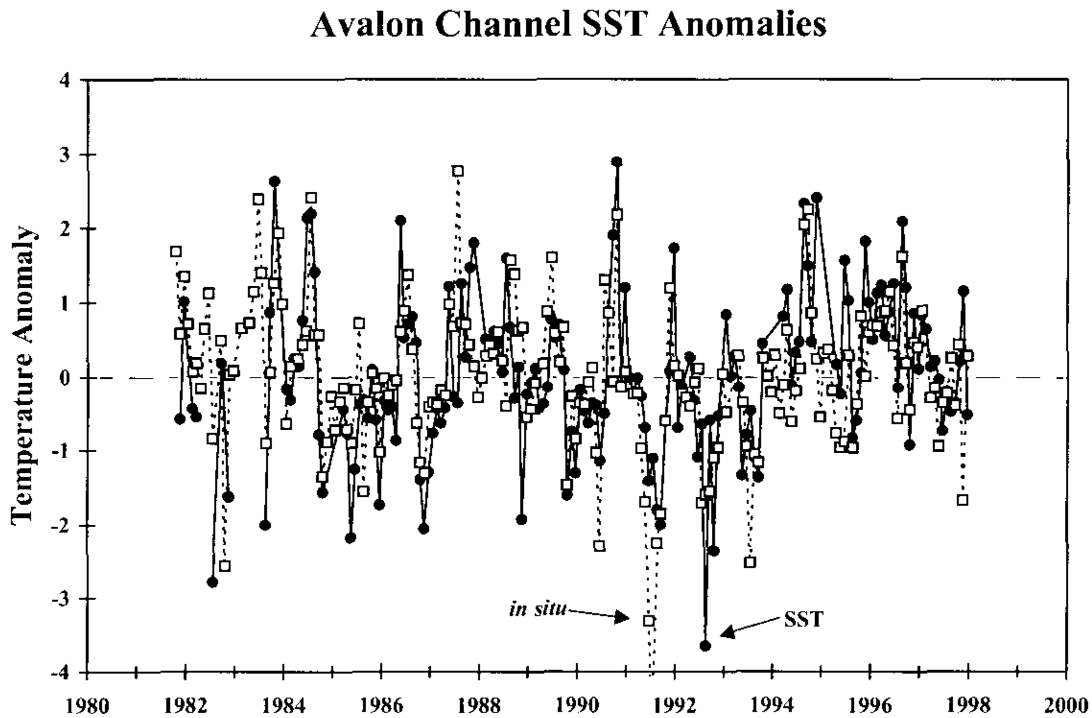


Fig.. 3. Monthly mean temperatures (1981-1997) from satellite and *in situ* data for Avalon Channel and Emerald Basin.



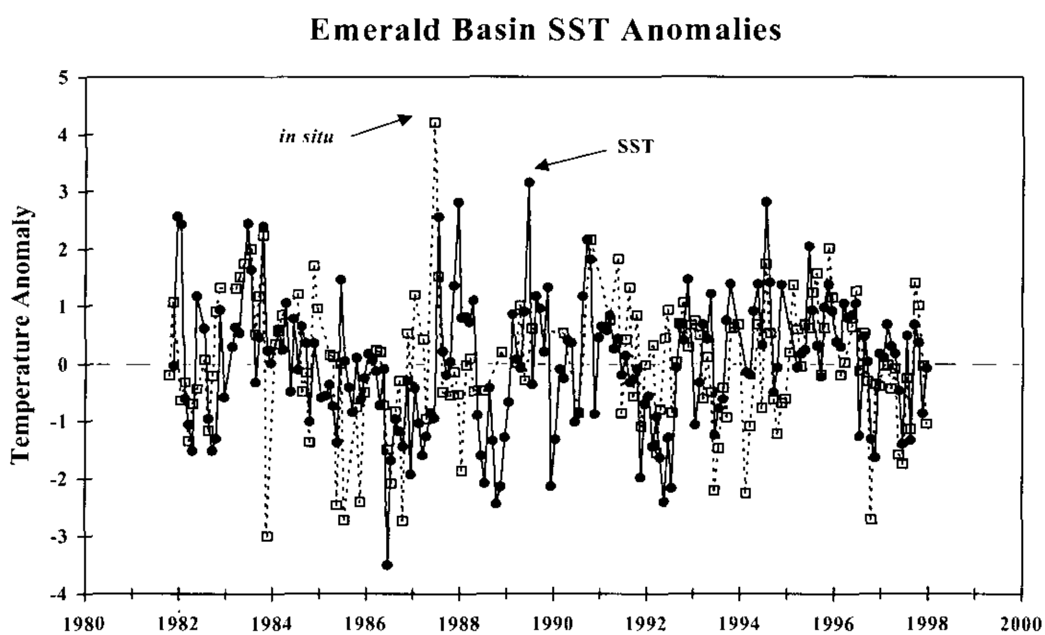
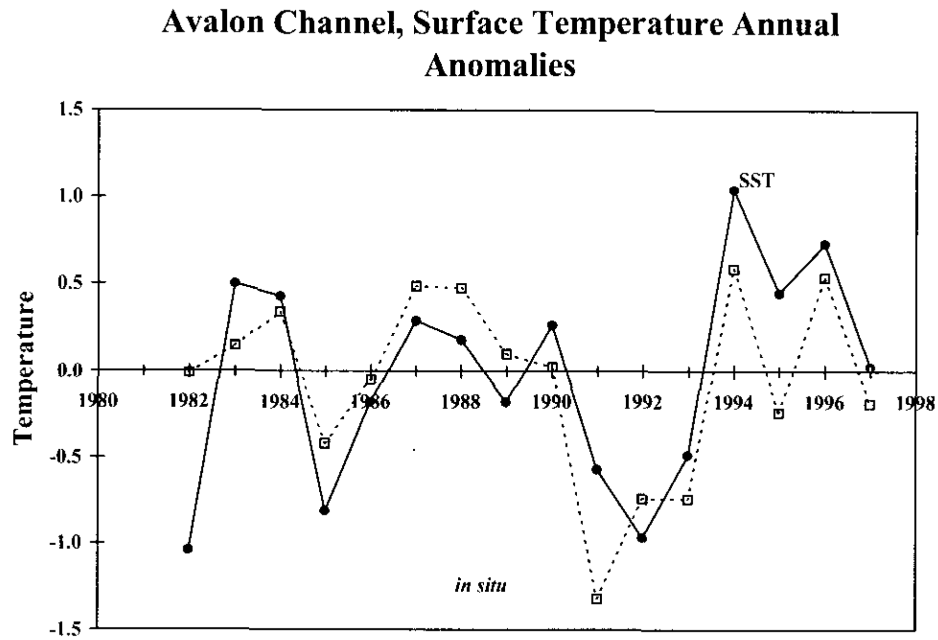


Fig. 4. Monthly mean temperature anomalies from satellite and *in situ* data Avalon Channel and Emerald Basin.



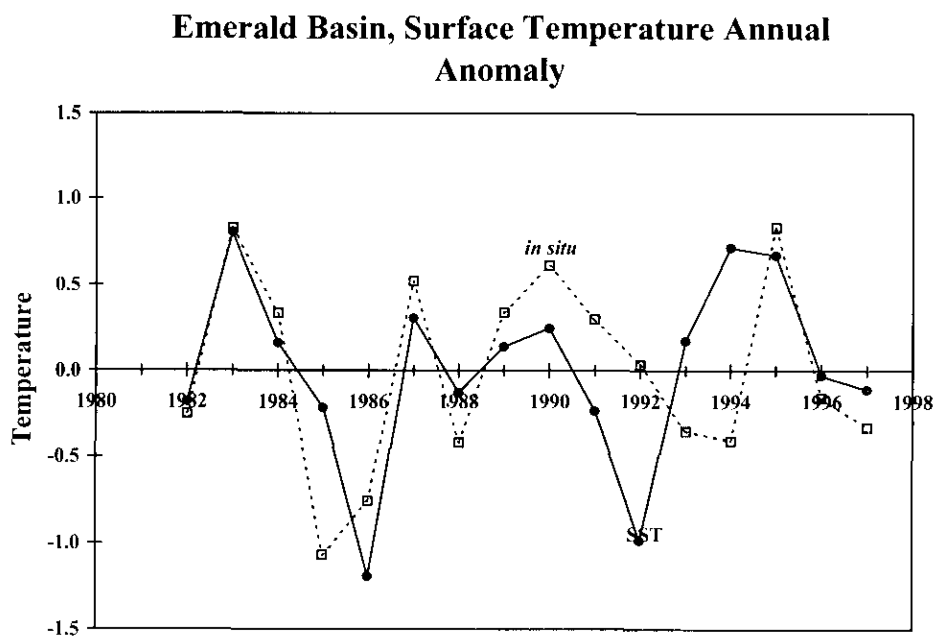


Fig. 5. Annual mean temperature anomalies from satellite and *in situ* data Avalon Channel and Emerald Basin.