A high-resolution satellite-derived sea surface temperature climatology for the western North Atlantic Ocean

Jorge M. Mesias\textsuperscript{a,*}, James J. Bisagni\textsuperscript{b}, A.-M.E.G. Brunner\textsuperscript{b}

\textsuperscript{a}Departamento del Medio Ambiente, Ilustre Municipalidad de Iquique, Tarapacá 369, Iquique, Chile
\textsuperscript{b}School for Marine Science and Technology, University of Massachusetts, Dartmouth, 706 South Rodney French Blvd., New Bedford, MA 02744, USA

Received 15 June 2005; received in revised form 25 September 2006; accepted 2 October 2006
Available online 29 November 2006

Abstract

Long-term and high-resolution (\textasciitilde{}1.2 km) satellite-derived sea surface temperature (SST) fields of a monthly mean time series for the 1985–1999 period, and a daily climatology have been calculated for the North West Atlantic Ocean. The SST fields extend from 78°W to 41°W in longitude, and 30°N to 56°N in latitude, encompassing the region off Cape Hatteras, North Carolina, to the southern Labrador Sea. The monthly mean time series, consists of 180 cloud-masked monthly mean SST fields, derived from a full-resolution NOAA/NASA Pathfinder SST data set for the 1985–1999 period. The satellite-derived monthly mean SST fields, as compared with in situ monthly mean near-surface ocean temperatures from buoys located in the western North Atlantic, yield an overall RMS difference of 1.15°C. The daily climatology, which consists of 365 fields, was derived by applying a least-squares harmonic regression technique on the monthly mean SST time series for the full study period. The monthly mean and daily climatological SST fields will be useful for studying inter-annual variability related to climate variability of SST over the study domain.

© 2006 Elsevier Ltd. All rights reserved.

Keywords: Pathfinder sea surface temperature climatology; Western North Atlantic Ocean

1. Introduction

Global or regional climatologies are useful in studies of seasonal, inter-annual and longer-term variability, playing a crucial role in climate-related oceanographic studies. Sea surface temperature (SST) estimates, derived from the advanced very high resolution radiometer (AVHRR) onboard NOAA’s polar-orbiting satellites, have been produced using multi-channel SST (MCSST) algorithms (McClain et al., 1985). However, because of known biases, especially during periods of high volcanic aerosols within the atmosphere, MCSST-derived values may have limited utility for climate change-related research. The NOAA/NASA Oceans Pathfinder AVHRR SST project was designed to fill this gap by providing an important AVHRR-derived SST data set suitable for climate change-related research. The Pathfinder SST algorithm has been developed at the University of Miami’s
Based climatology of Casey and Cornillon indicate products such as the Reynolds and the satellite-JPL Pathfinder climatology and other global domain. Although comparisons among the 9-km Stream North Wall that are included in our study optimal for areas like the frontal region of the Gulf spatial smoothing of 9 km, however, may not be topological pentads with the size of 9 km. The applied interpolation to daily satellite data, creating climatology that applied spatial and temporal Gaussian Pathfinder SST data using a processing methodol-
derived from the highest quality daily 9-km baseline periods (1986–1999 and 1985–1999), was applied using only satellite-derived SST data. The 9-km resolution (available at http://pathfinder.nodc.noaa.gov). Among other SST climatological products available to the research community with diverse spatial and temporal resolutions, is the global scale 1° Reynolds SST analysis (Reynolds and Smith, 1994, 1995); which was calculated from operationally derived near real time AVHRR SST data, the comprehensive ocean-atmosphere data set (COADS) and the UK Meteorological Office Historical observational SST data sets that include in situ measurements from volunteer observing ships (VOS), using an optimal interpolation technique with correction procedures to account for biases in the satellite data relative to the in situ measurements. Other climatological products are the 9, 18 and 54 km resolution data sets available from the Jet Propulsion Laboratory (JPL) (Vasquez et al., 1998), and the 9.28 km resolution global scale climatology by Casey and Cornillon (1999), which was calculated using only satellite-derived SST data. The 9-km JPL climatology; available for two different baseline periods (1986–1999 and 1985–1999), was derived from the highest quality daily 9-km Pathfinder SST data using a processing methodology that applied spatial and temporal Gaussian interpolation to daily satellite data, creating climatological pentads with the size of 9 km. The applied spatial smoothing of 9 km, however, may not be optimal for areas like the frontal region of the Gulf Stream North Wall that are included in our study domain. Although comparisons among the 9-km JPL Pathfinder climatology and other global products such as the Reynolds and the satellite-based climatology of Casey and Cornillon indicate that the JPL climatology performs in a statistically robust manner when using long-term independent in situ SST observations as a comparison set, the spatial smoothing together with the initial 9-km resolution may lead to problems in the vicinity of fronts.

While the JPL has produced reduced-resolution Pathfinder SST fields for the entire globe, using the UM/RSMAS algorithm (Vasquez et al., 1998); workers at the University of Rhode Island's, Graduate School of Oceanography (URI/GSO), have re-processed all full-resolution AVHRR/HRPT/LAC data collected off the US east coast for 1985–1999, using the UM/RSMAS Pathfinder SST algorithm, obtaining the inter-calibrated North West Atlantic Pathfinder data set SST time series (available at http://dods.gso.uri.edu/dods-3.4/nph-dods/Pathfinder/Northwest_Atlantic/1km/de-clouded), among other SST data sets. These data sets possess the highest spatial and temporal resolutions available from the original AVHRR data. Cloud-contaminated regions within each image were eliminated by automated flagging procedures (Cayula and Cornillon, 1996), resulting in one SST image for each day of the time series for the 1985–1999 period. A description of the image processing procedures can be found at http://rs.gso.uri.edu/avhrr-archive/archive.html/.

The Western North Atlantic Ocean (Fig. 1) is affected by one of the most extreme SST variations in the world (Molinari et al., 1997; Casey and Cornillon, 1999, 2001), and by strong climate fluctuations related to the basin-scale North Atlantic Oscillation (NAO) signal (Hurrell, 1995). This region includes the large coastal ecosystem that extends from Cape Hatteras to the eastern Scotian shelf, one of the 50 large marine ecosystems (LMEs) located around the coastal margins of the world’s ocean basins (Sherman and Skjoldal, 2002). This LME sustains a variety of commercially important marine species; yielding one of the most highly productive ecosystems in the world. In this ecosystem, fish populations mainly fluctuate due to strong climate-related changes and human exploitation efforts. After the collapse of pelagic species; such as herring (Clupea harengus) and Atlantic mackerel (Scomber scombrus) during the 1960s (Mayo et al., 1992), cod had become the most dominant component of the Gulf of Maine (GOM) and Georges Bank (GB) fisheries (Serchuk et al., 1994), until its steady decline during the past two decades; meanwhile, production of pelagic fish (e.g., herring,
mackerel) in the GOM, GB, and in the southern New England/Middle Atlantic Bight region has sharply increased since the 1980s, while groundfish (e.g., cod, haddock) production has sharply declined (Sherman et al., 2002).

In the GOM and GB areas (Fig. 1); the water mass and circulation characteristics are influenced by two primary systems: (1) the southward flowing Labrador Current (LC) along the slope and shelf flowing into this system from the north, and (2) the Warm Slope Water (WSW) in the region north of the meandering Gulf Stream, which is the supplier of more saline slope water to the GOM through the Northeast Channel (Petrie and Isenor, 1985; Lazier and Wright, 1993; Sherman et al., 1988; Wiebe et al., 2002). From a basin-scale perspective, the LC
is directly forced by the Icelandic low-pressure system (the northern limb of NAO), while the WSW is further influenced by the latitudinal excursion of the Gulf Stream system and its low-nutrient warm core rings (Taylor and Stephens, 1980). The GS is thermally affected by the NAO in two different ways: first by the NAO-forced convection in the Labrador Sea (Dickson et al., 1996) and subsequent advection of Labrador Sea Water in the upper branches of the Deep Western Boundary Current (Pickart et al., 1999) in the slope waters south of the tail of Grand Banks; second via the LC at the Tail of the Grand Banks (Smith et al., 2001; Bisagni et al., 1996). Recently, Taylor and Stephens (1998) and Taylor and Gangopadhyay (2001) found a strong correlation between the basin-scale winter NAO index and the annual Gulf Stream North Wall index, with a time lag of two years. These findings and the possible basin-to-bank linkages alluded to above, motivate further investigation of the response patterns on the productivity and dynamics of marine populations in the North Atlantic Ocean induced by these signatures. In summary, further investigation of the relationships between SST changes and marine species variability is a high-priority research topic, for which, this study using satellite-derived data may be valuable.

In this study, we have developed both, a monthly mean time series and a daily climatology of SST fields, at full-resolution, using the North West Atlantic Pathfinder data set produced at URI/GSO for the 15-year period of 1985–1999. The main goal of this study is to construct satellite-derived SST fields for the area of the Western North Atlantic Ocean, based exclusively on Pathfinder-processed AVHRR data alone, giving us the advantage of producing full-resolution SST fields, without ‘smoothing’ and avoiding the problems introduced by the blending of satellite-derived and in situ data sets, as in the case of the Reynolds SST 1° analysis. The full-resolution daily climatology is calculated using a least-squares harmonic regression technique applied on the monthly mean time series of SST fields for the full 15-year (1985–1999) period. The SST fields from the monthly mean time series and the daily climatology will be available through the NOAA Coastwatch Program (at http://coastwatch.noaa.gov), for distribution to other environmental scientists in a NOAA Coastwatch-compatible format. Satellite-derived data can be a valuable tool for fisheries and ecosystem-related work when the limitations of the remotely sensed data are clearly understood and the research questions being posed possess the appropriate spatial and temporal scales.

2. Methodology

All day and night full-resolution (~1.2 km) cloud-masked North West Atlantic Pathfinder SST daily fields; obtained from URI/GSO in hierarchical data files (HDF) format, were loaded into a Matlab environment using the distributed oceanographic data system (DODS, now known as OPeNDAP) package to calculate the monthly mean time series and the daily climatological SST fields. The full study domain for the Western North Atlantic Ocean (78°–41°W, 30°–56°N) region; spanned by the satellite Pathfinder fields, that extends from Cape Hatteras in the south to the Labrador shelf area in the north, is depicted in Fig. 1. Because of the large size of the matrices (6144 × 6144), to make the calculations the full domain was partitioned into 16 small sub-domains. Through independent calculations for each sub-domain, the time series of monthly mean SST fields for the 1985–1999 period (180 months) was calculated using all day and night fields in each calendar month. The monthly mean SST fields were stored, together with the corresponding values of the number of SST values used to estimate the mean SST at each pixel. Only pixels where the number of values was greater than one are considered for the computation of the local mean; while pixels with just one observation value are excluded of the entire fitting procedure. The long-term and full-resolution monthly mean SST fields are, then, used to calculate, via a least-squares temporal harmonic regression technique, 365 full-resolution daily climatological fields, one for each yearday, which characterizes a typical annual cycle.

2.1. Harmonic regressions

The harmonic regression procedure is defined as it follows. At any given time \( t \) and pixel location, the local monthly mean SST value is given by

\[
T = A_0 + \sum_{n=1}^{N} A_n \cos(\omega_n t + \psi_n),
\]

where \( A_0 \) represents the climatological mean SST at each pixel; and \( A_n \) and \( \psi_n \) are the amplitude and phase of the harmonic function with frequency \( \omega_n \) at the same pixel; being \( n \) the number of cycles per
The harmonic analysis was implemented on a pixel-by-pixel basis in a Matlab environment, starting with the calculations of the monthly mean SST time series for each sub-domain. In Fig. 2 we show an illustration of the harmonic regression procedure as it is applied to four local time series of monthly mean-SST data, corresponding to areas affected with diverse cloudiness conditions: from minimum (Pixel 1, from sub-domain 09), moderate (Pixels 2 and 3, from sub-domains 11 and 12, respectively), to maximum (Pixel 4, from sub-domain 08) cloud coverage. For all cases, the final fit is obtained with the same number \( (N = 3) \) of significant harmonics, having high levels \( (\geq 50\%) \) of EV values, diverse SST value fluctuations, with STD values \( (\geq 3^\circ C) \) about different MT values. Pixel 1, of the cloud-free region from the Mid-Atlantic Bight area, off North Carolina shows a high mean SST value of \(~16^\circ C\), representing Gulf Stream Current warmer waters; Pixels 2 and 3 from the moderately clouded areas at the center of the study domain and the northern front of the Gulf Stream Current have relatively the warmest waters with mean SST values of \(~17^\circ C\) and \(~20^\circ C\), respectively, but moderate temperature fluctuations with STD values of \(~3.5\) and \(~6^\circ C\), respectively. The more clouded Pixel 4, from the tail of the Grand Banks of Newfoundland area, has a low mean SST value of \(~7^\circ C\), characteristics of waters that result from the mixing of cold waters of the LC with warmer waters (rings) that detach from the northern front of the Gulf Stream Current. For all pixels, the SST data eliminated as outliers were less than 10% of the overall data for the 1985–1999 period. The final fit at each pixel of the full domain was obtained with the same number of significant harmonics \( (N = 3) \), passing, everywhere, the significance F-test with a 95% level of confidence. This is not a result of limiting the maximum number of harmonic to \( N = 3 \), but rather a result of our strict procedure that recognize these as the only ones that are physically significant. Initial tests made with up to \( N = 5 \) harmonics to fit the data using (1) gave similar results than with \( N = 3 \) harmonics. This is a direct result from our procedure that derive the daily climatology from the monthly mean time series, as the monthly averaging calculations filter out higher order variabilities with shorter periods.

Fig. 3 shows the long-term mean SST field for the period 1985–1999, corresponding to the first term, \( A_0 \), in Eq. (1), showing surface waters with temperatures ranging between 0 and 30 \(^\circ C\), with
colder waters mainly at the regions of the Labrador Sea area, while regions with warmer surface waters are those of the meanders of the Gulf Stream current flowing toward the northeast. The apparent water temperature range (of 3–7°C) of the Flemish Cap area is a mixture of LC Water and North Atlantic Current Water. The general circulation in the vicinity of the Flemish Cap consists of the offshore branch of the LC, which flows through the Flemish Pass on the Grand Banks side and a jet that flows to the east, north of the Cap, which then flows southward (Loder et al., 1998; Ramp et al., 1985). To the south, the Gulf Stream current flows toward the northeast merging with the LC to form the North Atlantic Current, which influences waters around the southern areas of the Flemish Cap.

The highest water temperatures (apparently ranging between ~25 and ~30°C) are observed south of the Cape Hatteras area, corresponding to the northeastward-flowing Gulf Stream, reaching the southern areas of the Grand Banks off Newfoundland.

Figs. 4 and 5 depict the standard deviation (STD) and EV, respectively, of the Pathfinder monthly mean SST fields, obtained together with the calculation of our harmonic regressions. The map for the STD (Fig. 4) shows that the largest SST variations occur in the southern areas surrounding the Nova Scotia and Newfoundland regions. The EV map (Fig. 5) shows that our procedure in estimating the significant harmonic functions has successfully explained a large portion of the variability of the monthly mean SST data over
most areas of the study domain; except at some regions like that off Cape Hatteras, likely due to larger variability related to the separation of the GS current from the continental coastline, and some areas around the Gulf Stream North Wall, likely due to effects related to the NAO signal. The 365 climatological daily SST fields, one for each year-day, were then calculated using Eq. (1), but using only the significant harmonic functions determined for each pixel.

Although the harmonic regression calculations did include error estimations of the significant harmonic coefficients, they were uniformly near-null everywhere. So, it was estimated that most of the uncertainty in the final fits would be due to uncertainty in the monthly mean time series of SST fields, which will be mainly determined by the effective number of data used to calculate the local monthly mean at each pixel, mostly determined by its cloudiness conditions. Thus, a climatological mask was developed to discriminate between pixels with valid or non-valid SST values that can be applied to both the monthly mean and the daily climatological SST fields. The masking procedure was estimated upon the uses of the Nyquist frequency, assuming a dominant 12 months period of a seasonal cycle. Each local SST value at any pixel is considered valid, if (a) there are at least four hits (twice the Nyquist frequency) in the 12 months period, one for each month created by adding the hit files for January 1985 through January 1999, February 1985 through February 1999 and so forth; and, (b) those pixels had to be evenly distributed over the 12 months. Thus, for one specific pixel only two consecutive months can have zero hits; the third month must have a hit and so forth in order to be a valid SST value. The derived mask is illustrated in Fig. 6. Black areas correspond to pixels where SST values are considered non-valid, while white areas have valid SST values. At user’s discretion, then, this mask can be applied on the monthly mean and the daily SST fields. The areas most affected by
clouds are those to the east of Newfoundland and the Labrador Sea, which are cloud-covered almost year-round, except for the area over the southern branch of the LC, as it meanders southward around the Grand Banks off Newfoundland and Flemish Cap, which remains clear throughout most of the year. The oceanic areas that are least affected by clouds are those over the US continental shelf off the Middle-Atlantic Bight areas, and those from the center (mid-latitudes, around the atmospheric Azores High Pressure system region) of the study domain, and south of the northern front of the Gulf Stream.

2.2. Monthly mean and daily climatological SST fields

The maps in Fig. 7, depict monthly mean SST fields for year 1988, showing the positions of the main ocean currents in the region (the GS and LC currents), illustrate the intra-annual variability of SST for a year when the NAO index reaches its highest positive value in more than a century, suggesting the GS northern front has reached its more northward displacement (Brunner, 2002), and an apparent weakening of the LC. The year 1988 has been identified as the turning point of a climatic regime shift of large importance for ecosystem species that occurred in the North Sea (Reid et al., 2001; Scheffer et al., 2001). During this year there was a sharp increase in plankton biomass and alterations in deep water convection from the Greenland to the Labrador Sea, indicating changes in overturning activity (a key component of the global climate conditions today) in the North Atlantic Ocean, which are associated to changing conditions of the oceanic northward heat transport (Nunes and Norris, 2006), similar to those found for the sub-polar North Atlantic current gyre region in the late 1990s (Hakkinen and Rhines, 2004). The areas most affected by clouds are those east of the Newfoundland and Labrador Sea regions, during
most of the year, except the area over the southern branch of the Labrador Sea, as the LC meanders west and southward around the Tail of Grand Banks and Flemish Cap areas, which remains clear during most months of the year. The areas that are less cloudy are those over the US continental shelf off the Mid-Atlantic Bight area, and at mid-latitudes of the North Atlantic domain, south of the Gulf Stream. The dominance of a strong seasonal heating cycle is also apparent in the SST fields of Fig. 7, showing that the whole region has colder surface waters during winter months, and warmer surface waters during the summer months.

Figs. 8 and 9, illustrate the inter-annual variability of the winter and summer seasons, using January and July months as proxies, respectively, for the entire 1985–1999 period. The SST maps in Figs. 8 and 9, suggest that during winter (summer) seasons, the northeastern corner of the study domain present mostly cloudy (cloud-free) conditions, while surface water temperatures increase from low SST values during winter to high SST values during summer.

Maps of daily climatological SST fields (every 30 days) from mid-January, day 15, through mid-December, day 345, in Fig. 10, show the dominant seasonal heating cycle, with low winter temperatures during February and high summer temperatures during August, along with the spatial and temporal SST variability of the Labrador Current and Gulf Stream.

3. Comparison with in situ near-surface water temperature data

The scarce availability of long-term in situ SST measurements in the study domain, limited us to validate our SST fields by making a comparison of our monthly mean SST field time series with monthly mean values obtained from in situ data measured at approximately 1-m depth at 14 buoys, obtained from NOAA’s National Oceanographic Data Center (NODC), for selected locations from...
the Southern New England and Middle-Atlantic Bight regions, (Fig. 1), over an approximately 12-year period (1985–1997). The NODC data files were obtained from the F291 data set on CD-ROM containing meteorological and oceanographic data collected from moored buoys and C-MAN (Coastal-Marine Automated Network) stations operated by the NOAA National Data Buoy Center (NDBC). The results of the comparison between our SST monthly fields and the NODC buoy data are presented in Table 1. For each buoy location, the buoy time series of near-surface temperatures, \( N^* \), over the indicated period. The RMS value was calculated by collocated monthly buoy and monthly satellite SST differences. To be collocated the satellite SSTs must be defined within \( N^* \) pixels of the buoy position.

Although the comparison of our satellite-derived SST fields with the in situ data yields an overall RMS difference of 1.15 °C, RMS values less than 1.5 °C are found for the Mid-Atlantic Bight area (Table 1), where surface waters from the Gulf Stream predominate; while for the Southern New England region (Table 1), the RMS values are mostly greater than 1.0 °C, in a region where shelf waters from the Gulf Stream Current mix with waters from the LC, and the standard deviation is larger than those obtained for the Mid-Atlantic Bight area. Everywhere, only buoy data available within the 1985–1999 study period were considered for the comparisons with the satellite-derived monthly mean SST values. As it is indicated in Table 1, most of the buoys’ records available for the comparisons were limited within the 12-year 1985–1997 period, which is shorter than the 15-year
period used to calculate our monthly mean time series. This could partially explain why some of the RMS values are larger than others, even though comparisons are made for more than one pixel-to-one-buoy-location. Complementary explanations are due to high variability related with the latitudinal displacement of the Gulf Stream Current Front (Taylor and Stephens, 1980), or to anomalous warmer or lower SST values estimations due to higher or lower content of water vapor regimes used.

Fig. 7. Maps of monthly mean SST fields for year 1988, illustrating the seasonal variability of SST in the region domain.
Fig. 8. Maps of January (winter proxy) monthly mean SST fields for 1985–1999, illustrating the interannual variability of the winter season in the study domain.
Fig. 9. Maps of July (summer proxy) monthly mean SST fields for 1985–1999, illustrating the interannual variability of the summer season in the study domain.
by the Pathfinder SST retrieval algorithm, making difficult cloudiness determinations for pixels near cloudy regions (Vasquez et al., 1998; Casey and Cornillon, 1999). Since the Pathfinder algorithm does not explicitly identify sea ice (Casey and Cornillon, 1999), to which the higher-latitude Southern New-England region is more prone, it could also explain why the RMS values are larger for this area. Furthermore, comparisons have included records from C-Man stations (identified...
with numbers 1, 2, 4 and 12 in Table 1 and Fig. 1); which tend to increase temperature biases (with large RMS values), as they are mostly located on offshore towers and not in open ocean areas. If these C-Man stations are not included in the comparison, there is no significant decrease of the overall RMS temperature difference.

The overall RMS temperature difference of 1.15°C, represents an acceptable difference, as compared with the estimated global bias of −0.09°C, with standard deviation of 1.45°C, of the difference between a WOA94 in situ data set and the Pathfinder 9-km climatology SST fields determined by Casey and Cornillon (1999). The overall RMS value is also of the same order of magnitude compared with the overall bias of about 0.2°C and a STD of about 1.0°C, obtained by Pichel et al. (2001) when comparing surface temperatures from buoys and NOAA/AVHRR—derived data for the Northeast US coastal region.

### 4. Discussion

Comparisons of the derived monthly mean SST fields with in situ data obtained from NODC buoys in the regions of the Southern New England and Middle-Atlantic Bight areas, indicate that the largest differences between the derived SST fields and the buoy data are obtained for regions where the Gulf Stream current shows its maximum variability. Limited availability of buoy data precluded us doing full comparisons with our derived monthly mean SST values. Because of the large differences in methodologies between our climatology and other available SST climatologies (e.g., JPL’s or that of Casey and Cornillon, 1999), we choose to leave a careful, detailed comparison between them to a future study.

However, given our careful approach to keep the full resolution of the original data, as well as the strict care to only include harmonic fits that have a true physical significance, we consider that we have developed monthly mean and daily climatological SST fields that will be very useful to study interannual variability of SST over the North West Atlantic Ocean, a region where SST variability studies are of high-priority because of a direct relationship between temperature and ecosystem variability, as related to climatic changes.

### 5. Summary and conclusions

High-resolution monthly mean and daily climatological SST fields for the western North Atlantic

### Table 1

<table>
<thead>
<tr>
<th>Buoy no</th>
<th>Buoy ID</th>
<th>Latitude (°N)</th>
<th>Longitude (°w)</th>
<th>RMS</th>
<th>N*/N*</th>
<th>Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>MDRM1</td>
<td>43 58’</td>
<td>68 07’</td>
<td>0.010</td>
<td>3/144/</td>
<td>January 85–December 97</td>
</tr>
<tr>
<td>2</td>
<td>MISM1</td>
<td>43 47’</td>
<td>68 51’</td>
<td>1.210</td>
<td>3/144/</td>
<td>January 85–December 97</td>
</tr>
<tr>
<td>3</td>
<td>44007</td>
<td>43 30’</td>
<td>70 06’</td>
<td>3.330</td>
<td>4/156/</td>
<td>January 85–December 97</td>
</tr>
<tr>
<td>4</td>
<td>IOSN3</td>
<td>42 58’</td>
<td>70 37’</td>
<td>1.470</td>
<td>4/156/</td>
<td>January 85–December 97</td>
</tr>
<tr>
<td>5</td>
<td>44013</td>
<td>42 24’</td>
<td>70 48’</td>
<td>3.770</td>
<td>3/156/</td>
<td>January 85–December 97</td>
</tr>
<tr>
<td>6</td>
<td>44005</td>
<td>42 42’</td>
<td>68 18’</td>
<td>0.317</td>
<td>4/126/</td>
<td>January 85–December 97</td>
</tr>
<tr>
<td>7</td>
<td>44028</td>
<td>41 24’</td>
<td>71 05’</td>
<td>3.970</td>
<td>4/28/</td>
<td>January 95–April 97</td>
</tr>
<tr>
<td>8</td>
<td>BUZM3</td>
<td>41 24’</td>
<td>71 00’</td>
<td>2.410</td>
<td>4/107/</td>
<td>January 86–December 97</td>
</tr>
<tr>
<td>9</td>
<td>44025</td>
<td>40 15’</td>
<td>73 10’</td>
<td>1.550</td>
<td>4/72/</td>
<td>January 92–December 97</td>
</tr>
<tr>
<td>10</td>
<td>44011</td>
<td>41 06’</td>
<td>66 36’</td>
<td>1.003</td>
<td>4/153/</td>
<td>January 85–December 97</td>
</tr>
<tr>
<td>11</td>
<td>44008</td>
<td>40 30’</td>
<td>69 24’</td>
<td>1.0250</td>
<td>3/156/</td>
<td>January 85–December 97</td>
</tr>
<tr>
<td>12</td>
<td>ALSN6</td>
<td>40 27’</td>
<td>73 48’</td>
<td>2.350</td>
<td>3/156/</td>
<td>January 85–December 97</td>
</tr>
<tr>
<td>13</td>
<td>44004</td>
<td>39 00’</td>
<td>70 00’</td>
<td>0.05</td>
<td>4/156/</td>
<td>January 85–December 97</td>
</tr>
<tr>
<td>14</td>
<td>44010</td>
<td>36 54’</td>
<td>75 42’</td>
<td>1.238</td>
<td>3/6/</td>
<td>January 95–June 95</td>
</tr>
</tbody>
</table>

N* is the number of pixels surrounding the buoy location, used to calculate the RMS values. N the number of monthly buoy’s data used to calculate the RMS values.

Period the Span Period of the buoy’s record used to calculate the RMS values.

Buoy no the Buoy’s number as identified in Fig. 1.

Buoy-ID the Buoy’s identification as in the NODC/F291 data set.

Locations are shown in Fig. 1 with encircled red numbers, as per column Buoy no.
region (78°W–41°W and 30°N–56°N), were calculated from the cloud-masked North West Atlantic Pathfinder data set for the 1985–1999 period. The daily climatological SST fields were derived using a least-squares harmonic regression procedure applied to the previously calculated monthly mean time series of 180 SST fields over the 15 year study period. The monthly mean and daily SST fields were derived following a procedure that enabled us to keep the full resolution (~1.2 km) of the Pathfinder SST data set. Comparisons of the derived monthly mean-SST fields with buoy data for the southern New England and Mid-Atlantic Bight regions indicate that the largest differences between the climatological fields and the buoy data are for regions where the Gulf Stream displays its maximum variability. Given the full-resolution character of our monthly mean time series and daily SST fields, they will be useful for studying inter-annual variability of SST over the study domain, a region where SST variability studies are of high-priority because of its direct relationship to ecosystem variability, such as studies of the migration patterns of pelagic fish that are strongly affected by temperature.

We are confident that our SST fields will be useful for examining inter-annual variability of SST over the western North Atlantic Ocean, related to climate variability and may be applicable to a wide variety of ecosystem variability studies. In particular, we believe that our climatology is especially suited for studying the migration patterns of pelagic fish on the continental shelf area that extends from the Tail of the Grand Banks in the north to Cape Hatteras in the south (Sherman et al., 1988), such as examining the relationship between inter-annual variability of SST and Atlantic mackerel (Scomber scombrus) distribution along the US east coast from Cape Hatteras to the GOM, where annual mackerel migration are controlled by near-surface temperature pattern changes (Garrison et al., 2000, 2002), SST monthly maps for year 1988, illustrate changes in overturning conditions in the North Atlantic Ocean that are associated to climate global warming changes. Further studies monitoring these changing conditions are of primary importance to evaluate the changes in the generation of deep-waters, during a period of present active global warming changes. It is important to develop local and long-term time series of sea surface fields (temperature, salinity and so on) that allows good validation studies of climatological products like those presented in this study.

Acknowledgments

Support for J.M. Mesias and J.J. Bisagni was from the NOAA/NESDIS Ocean Remote Sensing Program under NOAA Grant NA06EC0242. A.M. Brunner acknowledges the support of NSF Grant OCE-0118363. We would like to thank Dr. Peter Cornillon, University of Rhode Island, Graduate School of Oceanography for providing the SST data and support on the installation of the Distributed Oceanographic Data System (DODS) package. J. M. Mesias also would like to acknowledge to Mr. Sergio Rosales, for help in the preparation of figures.

References


