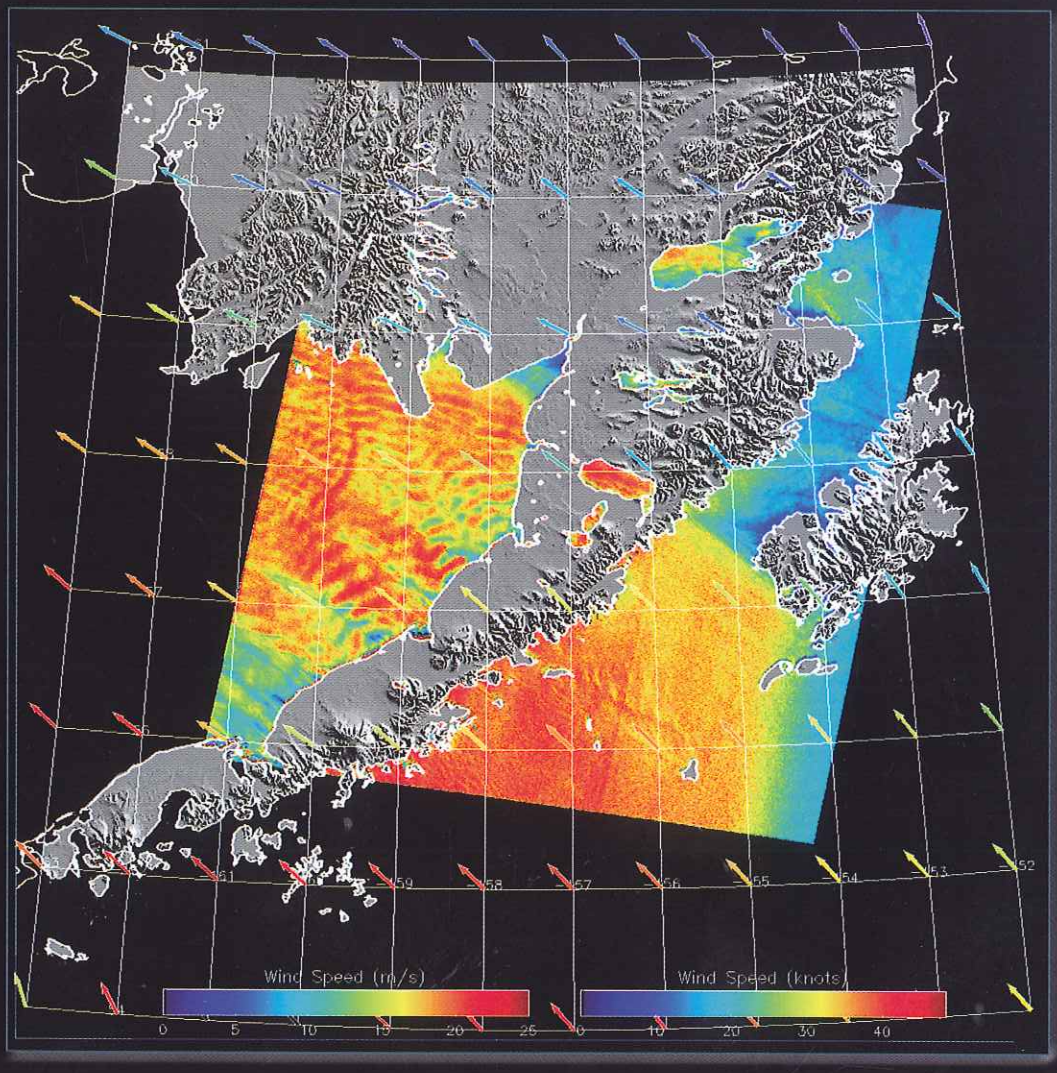
Official Magazine of the AMRS Association [www.waterobserver.org]
Spring 2004 / US$6.95

backscatter®

observing aquatic environments

NOAA's Satellite Oceanography Program



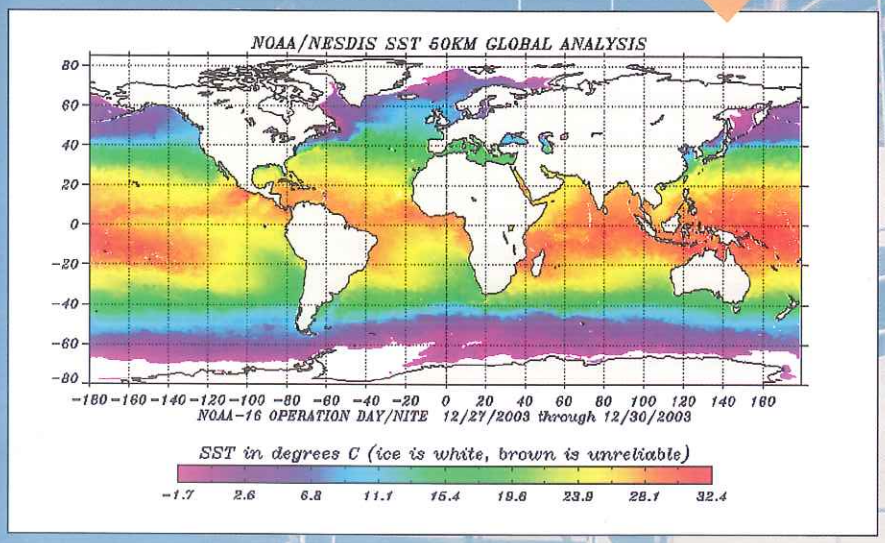
Satellite Remote Sensing and the NOAA/NESDIS Sea-Surface Temperature Science Team

Nicholas R. Nalli
NOAA/NESDIS, Camp Springs, Maryland

INTRODUCTION

Remotely-sensed sea-surface temperatures (SST) derived from the National Oceanic and Atmospheric Administration (NOAA) polar (POES) and geostationary (GOES) satellites continue to be an indispensable resource that directly supports NOAA's missions and strategic goals. Since the inception of satellite oceanography in the 1970s, NOAA/NESDIS has been an international contributor in the advancement of satellite-derived SST methodologies and operational products. These data are required by a number of users (NOAA internal and external), including the NESDIS CoastWatch/OceanWatch and Coral Reef Watch programs, NOAA and U.S. Navy forecasters, and the academic research community. Currently at NESDIS, satellite SST research is coordinated by the Oceanic Research and Applications Division (ORAD) SST Science Team within the Office of Research and Applications (ORA). The goal is to oversee and facilitate efficient, end-to-end satellite product development, beginning with research and continuing through the transition into NOAA operations. To achieve this, ORAD works closely with the NESDIS Office of Satellite Data Processing and Distribution (OSDPD), which assumes responsibility for operational implementation and maintenance. To facilitate cutting-edge research, ORAD also supports collaborations with academia. This article overviews the satellite SST research and development program at ORAD.

Figure 1. *Operational NOAA-16 AVHRR 50 km global SST 3-day composite analysis for the period 27–30 December 2003.*



THE PRESENT PROGRAM

NOAA/NESDIS is responsible for developing and maintaining operational environmental satellite data products and making them available for public access and distribution. Providing long-term data continuity, ORAD sustains and enhances the current POES and GOES infrared (IR) SST products. To better serve the user community, the ORAD SST Science Team works to develop and implement SST operational, near-real time products that meet user requirements in terms of absolute accuracy, precision, geographic coverage, and sampling resolution (spatial and temporal). These user-products include global analyses, CoastWatch/OceanWatch high-resolution coastal SST, and Coral Reef Watch monitoring products.

POES Infrared (IR) SST Products

NESDIS collaborates with the U.S. Navy in POES processing under a Shared Processing

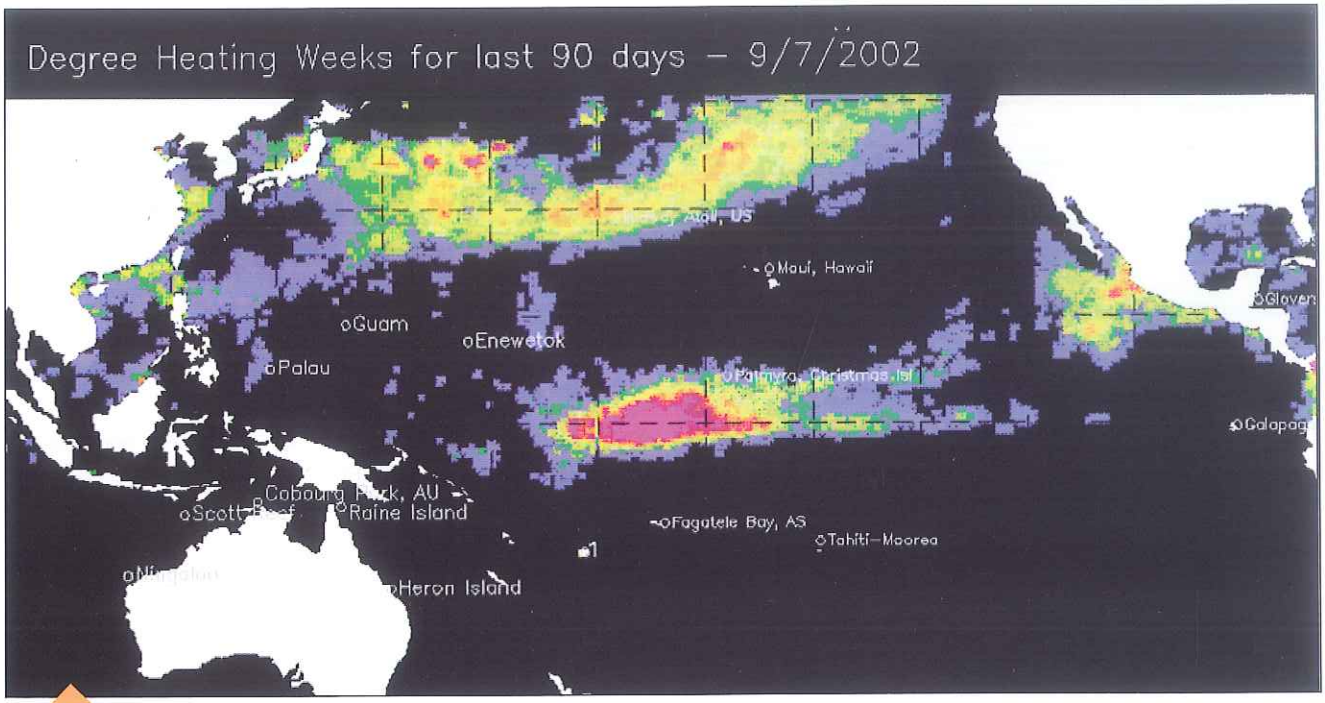


Figure 2. *NOAA's Coral Reef Watch Degree Heating Weeks product chart for the 90-day period prior to 7 September 2002.*

Agreement. NESDIS continues to develop and sustain the operational NOAA-16/17 AVHRR/3 SST equations which are based upon long-established statistical-empirical, multispectral methods that correct for atmospheric water vapor under cloud-free conditions. The algorithms include the well-known multichannel SST (MCSST) and nonlinear SST (NLSST) algorithms, as well as a new experimental aerosol-corrected SST (ACSST). Periodic validation and quality-monitoring of the operational equations are conducted, based upon monthly samples of AVHRR-buoy matchups. The AVHRR global retrieval precision currently is ~0.5 K. The retrievals form the basis for derived-products, including global analyses (e.g., Figure 1) and anomaly charts, which are, in turn, used for various user applications. One important application is NOAA's Coral Reef Watch (see Photo 1). Figure 2 shows the Degree Heating Weeks chart for 7 September 2002, a product indicating prolonged ocean thermal stress on corals. This chart, derived from the NOAA AVHRR SST analysis and available in near-real time, indicates a period of high thermal stress at the U.S. Midway Atoll, where the satellite SSTs exceeded the coral bleaching threshold for the extended period 1 August through 7 September 2002. Based upon the satellite SST indicators, NESDIS was able to issue an early Bleaching Warning to coral reef management authorities on 7 August 2002.

Taking advantage of the many advances in radiative transfer modeling in recent years, ORAD is moving toward radiative transfer model (RTM)-based skin SST retrievals for AVHRR/3. However, difficulties yet to be surmounted in this task for AVHRR include accurate specification of the filter spectral response functions (SRFs), bias-correction, RTM refinements and improvements, and finally validation of retrieved skin temperatures against *in-situ* buoy bulk temperatures.

GOES IR SST Products

SST derived from the GOES geostationary platforms benefits from enhanced temporal sampling frequency (up to once half-hourly versus four times per day sampling from two POES satellites). In regions of persistent cloud cover, GOES increases the likelihood of obtaining a clear-sky observation, as well as allowing the possibility of resolving the SST diurnal cycle. The current operational GOES algorithms are RTM-based. Because the GOES M-Q imagers were designed without a 12 µm channel, the algorithms must rely on the 3.9 and 11 µm channels. Unfortunately, the highly-transparent 3.9 µm shortwave IR (SWIR) channel is subject to solar contamination during daytime. Therefore, to compensate, the daytime GOES-12 RTM algorithm first screens regions of sun-glint and then accounts for diffuse solar contributions in the 3.9 µm channel. The GOES SST retrievals are used (along with POES) for NOAA's CoastWatch operational high-resolution SST product (Figure 3).

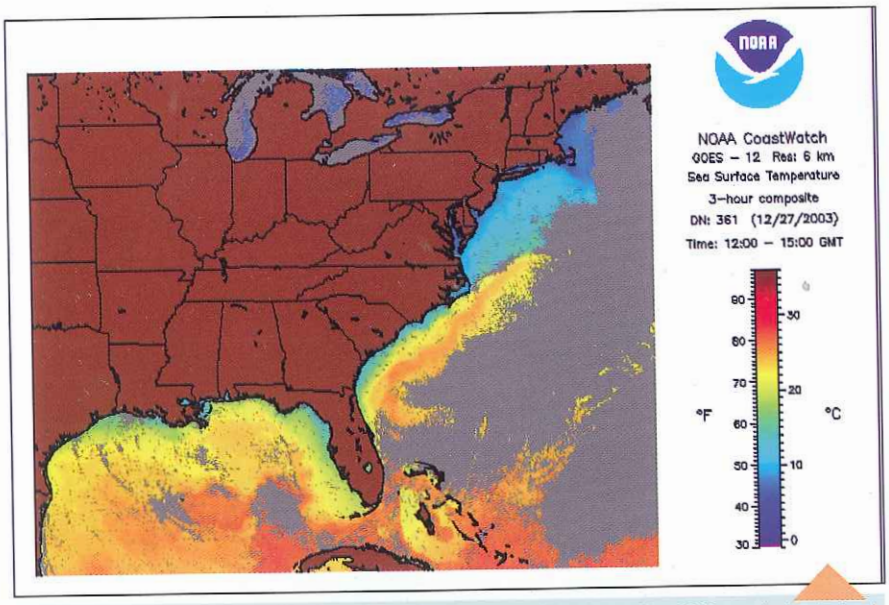


Figure 3. *NOAA's CoastWatch operational, 6-km, 3-hour composite SST product, derived from GOES-12 for the coastal waters of the Eastern U.S., 12:00–15:00 UTC, 27 December 2003. Gray areas denote regions of persistent cloud cover.*

Microwave (MW) SST Development

Due to the insensitivity of microwaves to clouds, aerosols, and water vapor, passive microwave-based retrievals are now receiving more attention. Recognizing these distinct advantages, ORAD has developed an experimental microwave (MW) SST retrieval algorithm for the TRMM microwave imager (TMI). The algorithm is based upon a statistical-empirical methodology that uses observations from the 10 GHz channel. The experimental TMI SST product is currently accessible in near-real time via NOAA's expanded OceanWatch program web page (Figure 4). Research has also begun on MW retrieval algorithms for the improved WindSat instrument. The WindSat frequency-array specifications are similar to the future National Polar Orbiting Environmental Satellite System (NPOESS) Conical Microwave Imager/Sounder (CMIS).

GOES-POES Blended Demonstration Product

An experimental POES/GOES IR blended analysis product has been developed at the Rutherford Appleton Laboratory (RAL) under contract for NESDIS. This blended product provides a methodology for future multi-instrument, multi-platform SST blending. Validation of the initial blended product began in January 2004.

Aqua/Terra

High spatial resolution (1.4 km) SST products from the Aqua/Terra Moderate Resolution Imaging Spectroradiometer (MODIS) are provisionally available through NOAA's CoastWatch. In anticipation of future observing systems, ORAD is investigating the potential of hyperspectral SST

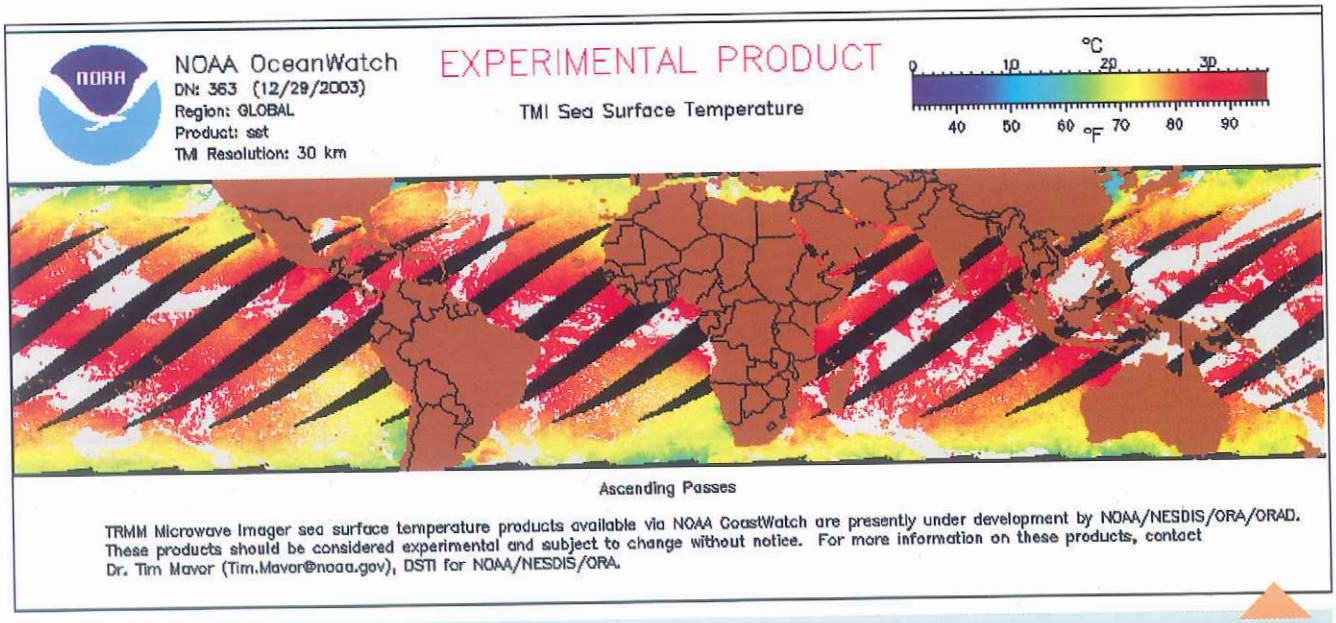


Figure 4. *NOAA's OceanWatch TMI microwave SST experimental product (0.25° latitude/longitude resolution) for 29 December 2003. Black areas are regions outside the sensor's observing swath, whereas, white areas are regions of precipitation.*

retrievals from the Aqua Atmospheric IR Sounder (AIRS) instrument. High spectral resolution has noted advantages for multispectral SST retrieval. Future hyperspectral systems (e.g., GOES-R) are anticipated to have spatial resolution comparable to today's AVHRR.

THE FUTURE

While SST retrieval is now considered a "mature" science, the challenge remains for NESDIS to meet stringent user accuracy requirements (~ 0.1 K rms) through the use of new instruments and retrieval algorithms. Future SST products from NESDIS will be derived from RTM-based retrieval algorithms to provide a means for more rigorous, systematic and accurate products. This approach will maximize the benefit from these data for both the operational and climate research programs.

Existing Programs

NESDIS will phase out long-established, statistical-empirical products in favor of RTM-based algorithms that optimize accuracy and provide reliable error estimates, including those from residual clouds, aerosols, and water vapor. NESDIS operational SST products will be supported by NOAA-K, -L, and -M, and beyond by NOAA-N/N' (to be launched in afternoon orbits tentatively in 2004 and 2008, respectively). The morning satellites MetOp-1 and -2 are to be launched and operated by EUMETSAT. Coordination between NOAA and EUMETSAT will be necessary for developing and sustaining SST products from both morning and afternoon POES platforms.

GOES RTM SST retrievals and cloud detection algorithms will be refined and applied to GOES-9 and -10, the Multi-functional Transport Satellite (MTSAT), and Meteosat Second Generation (MSG) and then merged to derive a geostationary SST analysis product with near global coverage. Retrospective GOES hourly data (beginning in 1994) will be reprocessed to derive a high-resolution GOES SST climatology.

MW SST products will continue development, including assessment of empirical and RTM-based approaches for optimal results from WindSat. MW retrievals have several advantages over IR, including insensitivity to atmospheric water vapor, aerosol, and clouds. Thus, they provide a vast improvement in spatial and temporal sampling frequency. However, MW retrievals are limited by smaller signals at coarser spatial resolution, sensitivity to sea state, precipitation, and land contamination near coasts.

Ultimately, the NESDIS goal is to develop and implement multi-platform, optimally-blended SST products that incorporate the strengths of IR, MW, geostationary, and polar orbiting observing systems.

Improved Validation and Skin-Bulk Effects

RTM-based retrieval algorithms obtain a surface skin temperature; whereas, buoy-measured bulk temperatures are typically obtained at ~1 m depth. The skin and *in-situ* buoy temperatures can differ significantly, thereby limiting validation efforts seeking to establish accuracies on the order of 0.1 K. Radiometric, as opposed to *in-situ*, ground truth will be necessary for accurate, rigorous validation. Investments are needed to develop such systems for sustaining and enhancing the RTM-based retrieval products of the future and for characterizing and modeling the skin-bulk temperature profile for optimal numerical model assimilation. Examples of radiometric ground-truth observing systems include the University of Washington Calibrated IR In-situ Measurement System (CIRIMS), shown in Photo 2, and the University of Miami Marine Atmospheric Emitted Radiance Interferometer (M-AERI). ORA plans to participate in a number of oceanographic research cruises involving M-AERI and CIRIMS over the next several years.

Satellite SST Climatologies

For climate applications, Pathfinder AVHRR reprocessing efforts at NESDIS have resulted in the 20-year AVHRR Pathfinder Atmospheres (PATMOS) data set. These data, which includes marine aerosol retrievals, have been used to derive a demonstration daytime, aerosol-corrected, SST climatology product. New AVHRR (and GOES) reprocessing efforts are underway at NESDIS to improve upon known limitations of the PATMOS data set, contributing a more stable SST record useful for inter-annual and long-term climate analyses.

NPP/NPOESS Era and Beyond

After NOAA-N', the current NOAA POES series will be phased out by the NPOESS program. The NPOESS series will carry a new Visible Infrared Imager Radiometer

Photo 1. *Al Strong, SST Science Team investigator and coral specialist, observing recovery of corals in Palau following 1998 severe bleaching event.*

Suite (VIIRS), an instrument comparable to the Aqua/Terra MODIS. NPOESS will also have a hyperspectral IR instrument, the Cross-track Infrared Sounder (CrIS) as well as the CMIS microwave instrument. These instruments will enhance SST retrieval capabilities over the current POES/GOES. The NPOESS Preparatory Project (NPP) satellite, scheduled for launch late in 2005, will facilitate the transition from the current NASA Aqua/Terra and NOAA POES to the NPOESS era. NESDIS will work to provide independent quality assurance of the NPP SST EDRs developed by the NPP/NPOESS contractor. Likewise, looking beyond GOES M-Q, the GOES-R Hyperspectral Environmental Sounder (HES) and Advanced Baseline Imager (ABI) will provide advanced capabilities for SST retrievals from geostationary platforms.

SUMMARY

In support of NOAA's mission and strategic goals, NESDIS plays a leading role in developing, implementing, and distributing operational satellite-derived sea-surface temperature (SST) products. These data are freely available in the public domain, serving users in the government, academic, and private sectors. Within NESDIS, remotely sensed SSTs are provided via the CoastWatch/OceanWatch and Coral Reef Watch programs.

NESDIS satellite SST research is coordinated by the ORA/ORAD SST Science Team, with direct collaboration from OSDPD and from academia. NESDIS satellite SST data products described in this paper are accessible on the World Wide Web; some URLs are provided below. ■

Photo 2. *The University of Washington Calibrated IR In-situ Measurement System (CIRIMS) installed above the pilot house (left center) on the starboard side of the NOAA Ship Ronald H. Brown while in Pensacola, Florida during November 2003. Photo courtesy of Pablo Clemente-Colon.*

Near real-time SST imagery:
http://www.osdpd.noaa.gov/PSB/EPS/SST/SST.html
Retrospective SST data:
http://www.saa.noaa.gov/cocoon/nsaa/products/welcome
CoastWatch/OceanWatch data:
http://coastwatch.noaa.gov/
Coral Reef Watch satellite coral monitoring:
http://orbit-net.nesdis.noaa.gov/orad/coral_bleaching_index.html
Monthly GOES frontal probability data:
http://manati.nesdis.noaa.gov/tmi/fronts

ACKNOWLEDGEMENTS

The ORAD Sea Surface Temperature Science Team is managed by Dr. Eric Bayler, Chief of the Oceanic Research and Applications Division, and is supported by the NESDIS Ocean Remote Sensing (NORS) Program. Supplemental funding has been provided by the NESDIS Office of Systems Development (OSD), Product Systems Development and Implementation (PSDI), the GOES I-M Product Assessment Program (GIMPAP), and the Joint Center for Satellite Data Assimilation (JCSDA) Science Development and Implementation (JSDI). The views, opinions, and findings contained in this report are those of the authors and should not be construed as an official National Oceanic and Atmospheric Administration or U.S. Government position, policy, or decision.

SST Team Members: Nick Nalli (leader), Felipe Arzayus, Paul Chang, Pablo Clemente-Colon, Andy Harris, A. Ignatov, Richard Legeckis, Xiaofan Li, Gang Liu, Eileen Maturi, Tim Mavor, Ralph Meiggs, Bill Pichel, John Sapper, William Skirving, Al Strong, (also C. Merchant and S. MacCallum University of Edinburgh, Scotland)