A NOPP Partnership for Skin Sea-Surface Temperature

Peter J. Minnett
Meteorology and Physical Oceanography
Rosenstiel School of Marine and Atmospheric Science, University of Miami
4600 Rickenbacker Causeway, Miami, FL 33149-1098
Phone: (305) 421-4104 FAX: (305) 421-4622 E-mail: pminnett@rsmas.miami.edu

R. Michael Reynolds
Remote Measurements & Research Company
16 Locust Road, Brookhaven, NY 11719-9628
Phone: (631) 286-3072 FAX: (631) 286-8446 E-mail: michael@rmrco.com

Frank J. Wentz
Remote Sensing Systems
438 First Street, Suite 200, Santa Rosa, CA 95401-6338
Phone: (707) 545-2904 FAX: (707) 545-2906 E-mail: frank.wentz@remss.com

Andrew T. Jessup
Applied Physics Laboratory, University of Washington
1013 NE 40th Street, Seattle, WA 98105-6698
Phone: (206) 685-2609 FAX: (206) 543-6785 E-mail: jessup@apl.washington.edu

Edward J. Kearns
Meteorology and Physical Oceanography
Rosenstiel School of Marine and Atmospheric Science, University of Miami
4600 Rickenbacker Causeway, Miami, FL 33149-1098
Phone: (305) 421-4837 FAX: (305) 421-4622 E-mail: ekearns@rsmas.miami.edu

William J. Emery
Aerospace Engineering Sciences, University of Colorado at Boulder
Campus Box 431, Boulder, CO 80309-0431
Phone: (303) 492-8591 FAX: (303) 492-2825 E-mail: William.Emery@colorado.edu

Gary A. Wick
NOAA Environmental Technology Laboratory
325 Broadway, Boulder, CO 80305-3337
Phone: (303) 497-6322 FAX: (303) 497-6181 E-mail: Gary.A.Wick@noaa.gov

James A. Cummings
Naval Research Laboratory
7 Grace Hopper Ave., Monterey, CA 93943-5502
Phone: (831) 656-5021 FAX: (831) 656-4769 E-mail: cummings@nrlmry.navy.mil

Doug May
NAVOCEANO Code N32
1002 Balch Boulevard, Stennis Space Center, MS 39522-5001
Phone: (228) 688-4859 FAX: (228) 688-5577 E-mail: mayd@navo.navy.mil

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LONG-TERM GOALS

Sea surface temperature (SST) is an important parameter in many operational and research activities, ranging from weather forecasting to climate research. The goals of this project are to demonstrate the use of autonomous infrared radiometers that measure the skin SST to absolute accuracies that are useful for the validation of global SST fields derived from measurements on earth-observation satellites, to use these measurements to determine the accuracies of such remotely-sensed SSTs, and to demonstrate the use of skin SSTs in forecast models.

OBJECTIVES

As a result of the heat flow between the ocean and overlying atmosphere, the surface of the ocean is nearly always somewhat cooler than the water at a depth of a millimeter or more. The temperature difference across the thermal conductive layer at the sea surface is usually referred to as the skin effect the surface is called the thermal skin effect. During the day, solar heating may cause vertical temperature gradient in the uppermost several meters of the ocean, especially in conditions of low wind speed, which further decouple the bulk "SSTs," conventionally measured by thermometers at a depth of a meter or so, from the skin SST, which is the temperature that controls the exchange of heat, momentum and gases between the ocean and atmosphere. Furthermore, it is the skin temperature that gives rise to the signal measured by space-borne radiometers. Thus, the uncertainties in the satellite-derived SST fields determined by comparisons with sub-surface bulk temperature include a component due to the variability in the temperature gradients in the upper few meters, and across the skin layer. The objectives are to provide accurate skin SSTs using autonomous radiometers, to establish the accuracies of satellite-derived skin SSTs, and to demonstrate the changes, hopefully improvements, in the coupling between ocean and atmosphere in forecast models, and process models that help us understand the physical behavior of the skin layer.

The project is broken down into three components:

1. The deployment at sea, in an environment comparable to ships of the Voluntary Observing Ship (VOS) fleet, instruments for measuring the skin and bulk SST, and telemetering these measurements for use in an operational environment in near real time.

2. Using the skin temperature measurements to demonstrate the accuracy of the skin SSTs derived from a variety of satellite-borne radiometers, operating in both the infrared and microwave.

3. Demonstrating the use of the skin SST in an operational program as a pre-cursor to wide-spread use of the skin SSTs.

These are divided amongst the various partners in the project according to skills and existing facilities. Many of the activities leverage funds from other agencies to achieve these goals

APPROACH AND WORK PLAN

The approach has been to adopt the Infrared Scanning Autonomous Radiometer (ISAR; see http://www.gim.bnl.gov/instruments/isar/) and the Calibrated InfraRed In situ Measurement System (CIRIMS; Jessup et al., 2002) as the autonomous radiometers for use in this project. The ISAR was developed at the Southampton Oceanography Centre (SOC) in the UK and CIRIMS at the Applied physics Laboratory at the University of Washington, Seattle. The absolute accuracy of the two sets of radiometers is established by at-sea comparisons with the at-sea measurements of the Marine-

Atmospheric Emitted Radiance Interferometer (M-AERI; Minnett et al., 2001). The skin SST measurements are used to determine the accuracy of the SSTs derived from the infrared bands of MODerate-resolution Imaging Spectrometer (MODIS; Esaias et al., 1998) on the NASA EOS *Terra* and *Aqua* Satellites, and of the microwave measurements of the TRMM (Tropical Rainfall Measuring Mission) Microwave Radiometer (TMI), and the Advanced Microwave Scanning Radiometer for EOS (AMSR-E) on *Aqua*. Studies using the skin SST measurements, together with theoretical models, are undertaken to determine improved parameterizations of the skin effect for inclusion in models, and the consequences of using skin SST, as opposed to bulk SST, in process models focused on differences between skin and bulk SSTs are being used.

The key individuals leading the various components of the project are given in Table 1.

Table 1: Major partners and their roles in this project.

Partner	**Roles and Tasks**
P. J. Minnett University of Miami	Project lead, M-AERI deployments, absolute calibrations of sensors, AVHRR and MODIS analyses
R. M. Reynolds Remote Measurements & Research Co.	Instrument integration, at-sea deployments
A. T. Jessup APL - University of Washington	Instrument calibration, at-sea deployments
F. Wentz Remote Sensing Systems	Microwave SSTs
W. J. Emery University of Colorado	Bulk-skin models, regression skin SST analysis
G. A. Wick NOAA-ETL	Near-surface temperature models, GOES SST analysis
J. Cummings NRL Monterey	Application of skin SST to atmospheric forecast models
E. J. Kearns University of Miami	Telemetry expertise, host ships with established sensor suites
D. May NAVOCEANO	Operational applications

Future work will build on the achievements of the first year, including construction of the second ISAR, at-sea deployments of the ISAR, CIRIMS and M-AERI, validation of the various satellite-derived SST fields, modeling studies of the skin layer itself and of its effects on forecast models. A workshop will be held at the University of Miami to facilitate proper coordination of the project.

WORK COMPLETED

The first ISAR was constructed and tested at SOC early in the year. This was made possible by the generous contribution by the SOC of workshop facilities, technical support and of material from their stock. The ISAR was hipped to RMR Co where extensive software and electronics upgrades were made, and further functional tests were conducted. The ISAR was then delivered to RSMAS for calibration against the NIST-traceable and NIST-characterized Water Bath Black Body Calibration Source (Rice et al., 2004), as shown in Figure 1. The ISAR was subsequently mounted on an instrument support rig on the roof of the Marine Science Center at RSMAS for extended testing in a field environment. It was then installed on the *Explorer of the Seas* ((http://www.rsmas.miami.edu /rccl/; Williams et al., 2002) for comparison with the M-AERI for several weeks in the Caribbean Sea. A miniaturized SeaKeepers Control and Telemetry Module has been delivered to RSMAS for integration with ISAR 01. This will be done early in the second year of the project.

Two CIRIMS have been deployed continuously on the NOAA R/V *Ronald H. Brown* and the R/V *Thomas G. Thompson.* Both ships also have through-the-hull thermometers at depths of 2 and 3m. Data are transmitted back to land on a daily basis. These data, as well as all data collected under prior funding, are available on the CIRIMS web site (http://cirims.apl.washington.edu/).

A comparison of TMI and AMSR-E SSTs and in situ data has been conducted to give a base-line accuracy of the microwave satellite SST retrievals (Gentemann et al., 2004). The primary source of validation data used in this study are in-situ measurements collected from the existing network of fixed buoys, drifting buoys, and ship measurements available via the Global Telecommunication System. These data are compiled by the US Navy Fleet Numerical Meteorology and Oceanography Center, quality controlled, and available in near real-time from the USGODAE server in Monterey. A secondary validation data set consisting of additional delayed-mode, quality-controlled, calibrated, fixed buoy SSTs from the US National Data Buoy Center, the Tropical Atmosphere Ocean TRITON, and the PIRATA arrays, was compiled and further quality controlled by Remote Sensing Systems.

At the University of Colorado, the CIRIMS and M-AERI data were used in conjunction with infrared satellite imagery to derive a new algorithm for satellite skin SSTs. It is apparent that this brings improvements in accuracy relative to the regression algorithms calibrated against buoy measurements such as the US Naval Oceanographic Office (NAVO) operational SST product, the non-linear SST (NLSST; May et al., 1998). At NRL Monterey, atmospheric boundary layer single column experiments are being run with bulk SST to test the predictions of the skin SST by verifying them against the observed CIRIMS cruise skin SST values. These experiments will be used to improve the boundary layer formulation and parameterization in the COAMPS model.

RESULTS

The first ISAR was constructed and tested in the laboratory and in the field. Several problems were identified, to do with optical alignment and software instabilities. These have been rectified and the instrument is ready for deployment early in the second year of the project on the *Ronald H. Brown* along with CIRIMS and M-AERI.

The residual uncertainties in MODIS, TMI and AMSR-E skin SST retrievals are shown in Table 2. These are derived by comparison with M-AERI skin SSTs (and also those from CIRIMS in the case of AVHRR). The accuracies of the MODIS, infrared retrievals are marginally better than those of the AMSR-E microwave measurements.

Table 2. Residual uncertainties in satellite derived skin SSTs.

	Day	Night	Day and Night
NOAA-14 AVHRR (11µm)	0.02 ± 0.52 K	0.02 ± 0.64 K	
NOAA-14 AVHRR (4+ 11µm)		0.01 ± 0.57 K	
Terra MODIS (11µm)	0.027 ± 0.490 K	-0.065 ± 0.405 K	-0.027 ± 0.443 K
Terra MODIS (4µm)		-0.030 ± 0.353 K	
Aqua MODIS (11µm)	-0.074 ± 0.425 K	-0.103 ± 0.370 K	-0.034 ± 0.402 K
Aqua MODIS (4µm)		-0.074 ± 0.341 K	
Aqua AMSR-E			0.00 ± 0.55 K

IMPACT AND APPLICATIONS

National Security

Improved accuracy of remotely sensed oceanographic variables, especially in the coastal regions, and the improved model predictions that will result, will improve National Security.

Quality of Life

Increased population density the coastal margins of the USA renders more people susceptible to the dangers and disruptions of severe storms. Improved accuracy of remotely sensed oceanographic variables and the improved model predictions that will result, will improve the quality of life of coastal inhabitants.

Science Education and Communication

Students and post-doctoral scholars at the several universities are involved in this project. New, two-way data transmission and instrument control protocols are being developed.

TRANSITIONS

There are no transitions to report. These will take place later in the project.

RELATED PROJECTS

The objectives and activities are related to those of the NOPP-funded project "Multi-sensor Improved Sea Surface Temperature for GODAE." (PIs Gentemann and Wick). The at-sea measurement program benefits from support from NASA: "Sea Surface Temperature from MODIS" (PIs Minnett and Brown); "Trans-Oceanic Measurements for EOS Aqua Validation" (PI Minnett). The modeling components are connected to Activities supported by the US Navy. This research benefits from connections to several European projects, particularly those focused on the validation of the Advanced Along-Track Scanning Radiometer on the ESA satellite *Envisat*.

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