AUTONOMOUS DEPLOYMENT OF SISTeR FOR AATSR VALIDATION

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ABSTRACT

The SISTeR (Scanning Infrared Sea surface Temperature Radiometer) is a validation radiometer designed to generate accurate in situ measurements of skin sea surface temperature (SST) in support of the ATSR series of satellite radiometers. The design and operation of the SISTeR instrument is outlined and recent developmental work to give the instrument operational autonomy is described. Finally, a new autonomous deployment on the M/S Color Festival is described and examples of the new data are given.

1. INTRODUCTION

The SISTeR is an in situ, chopped, self-calibrating filter radiometer for the measurement of skin SST. SISTeR has been deployed on ships eight times to date in support of the ATSR series of SST radiometers on the ERS and ENVISAT satellites and has consistently recorded high quality validation measurements. Platforms have included a ferry and small and large research vessels.

The SISTeR has always had some degree of autonomy. Once programmed, it will operate its mechanisms and generate a serial data stream without further intervention. However, as its optical system is, by necessity, open to the elements, the instrument has always been accompanied on deployments by support personnel, so that it can be sealed up when required, its operation checked and the data stream logged.

The need for operator intervention has limited deployment opportunities due both to the cost and availability of support staff and the availability of suitable platforms. In addition, the instrument has been vulnerable to changes in the weather, particularly at night when operators are less alert and rain showers are less immediately obvious. In the worst case, if the weather changes suddenly, the officer on duty can refuse physical access to the instrument, and it must take its chances until conditions change.

Over the past year, the SISTeR has been developed to address these operational deficiencies. In particular, it has been equipped with an electronically commanded weather door, an optical rain gauge and a GPS receiver, the latter to provide time stamps and positional information. The SISTeR code library has been completely rewritten to support these new features.

In the following sections, the basic instrument and its operation is outlined, the new autonomous features are introduced and a new deployment on the M/S Color Festival, a ferry operated by the Color Line between Oslo and Frederikshavn, is described.

2. SKIN SST MEASUREMENTS

The sea surface is very nearly black in the thermal infrared part of the spectrum (typically 98% or more near to nadir), so the infrared brightness temperature of the sea surface is closely related to the sea surface temperature. In addition, the penetration depth of thermal infrared radiation in water is very small (less than 10µm at 10.8µm) so infrared temperature information comes from the extreme surface, or “skin”, of the sea. The small radiative deficit in upwelling radiance from the sea surface, due to its non-blackness, is made up by cooler reflected radiance from the sky.

To correct for the radiance deficit, radiometric measurements for skin SST must include direct measurements of the sky at the complementary angle to the sea surface measurement, so that the sky term can be calculated out of the sea surface signal (Fig. 1).

Figure 1. Radiative measurements of the sea surface.

For a narrow band filter radiometer, SST can be calculated to a very good approximation by solving
\[ R_{up} = \varepsilon B(SST) + (1 - \varepsilon) R_{down} \]  

where \( \varepsilon \) is the emissivity of the sea surface and \( B(SST) \) is the black body radiance at the sea surface temperature, each integrated over the instrumental filter function and field of view, and \( R_{up} \) and \( R_{down} \) are the upwelling and complementary downwelling sea and sky radiances measured by the radiometer.

3. THE SISTeR INSTRUMENT

The SISTeR is a chopped, self-calibrating filter radiometer with infrared filters matching those in ATSR series of satellite radiometers (Fig. 2). Near to ambient temperature and with the 10.8µm or 12.0µm filter, radiometric noise is approximately 30mK for a 0.8s sample and radiometric accuracy is of order 20mK.

![Figure 2. The SISTeR radiometer.](image)

The SISTeR has three internal compartments (Fig. 3). Two, the foreoptics enclosure and electronics enclosure are waterproof. The third, containing two black bodies and the scan mirror mechanism, is isolated from the external environment by two apertures to the black bodies and by a baffle which rotates with the scan mirror and acts as a shutter.

![Figure 3. SISTeR optics and mechanisms.](image)

The foreoptics compartment contains a 2mm diameter pyroelectric detector, a six-position filter wheel, coaxial with a rotating two-bladed chopper and an ellipsoid mirror. The detector forms the field stop and the ellipsoid mirror, the aperture stop. An ellipsoid mirror was chosen as the primary optical element as, by placing the detector image at the exit aperture, the aperture can be made small and the instrumental exposure is reduced.

![Figure 4. SISTeR, opened at the calibration compartment.](image)

The two aluminium black body cavities in the calibration compartment (Fig. 4) are coated with Mankiewicz Nextel paint and have an emissivity exceeding 0.999. Each has an embedded four-wire 27Ω rhodium iron thermometer and a heater element wound onto the outside of the cavity where it is attached to an outer fibreglass shell, near to the cavity aperture. The air gap between cavity and shell is small to inhibit convection. The black body cavities are calibrated complete in a specialised facility at Oxford University, against a secondary standard thermometer traceable to the U.K. National Physical Laboratory.

In normal operation, one black body is heated with a constant power increment and one is left unheated. Both black bodies track the ambient temperature, the warm black body at an increment of approximately 15K above the unheated black body.

![Figure 5. SISTeR filters and foreoptics window.](image)

The SISTeR filters match the ATSR infrared filters (Fig. 5) and have comparable shapes and out-of-band blocking performance.
4. SISTeR ELECTRONICS AND CONTROL

The SISTeR electronics are based on a small-format x86 XT-bus PC running DOS. All the instrument’s signal-processing and driver electronics are XT-compatible peripherals and all configurable features (scan mirror position, PSD phase and others) and data values (detector and thermometry counts, and others) are accessible at I/O addresses.

Every I/O address is shadowed by a named variable in a C library SISTeR.h and can be set or interrogated from within a simple C control program. The library also synchronises I/O transactions to a programmable measurement period (typically 800ms) and delivers a data packet containing all instrument data points to the instrument’s serial port at the end of each measurement.

5. SELF-CALIBRATION

As the SISTeR’s two reference black bodies are positioned at the end of its optical chain and the detector response is linear in radiance, external scene radiances can be calculated with the calibration equation:

\[
x = \frac{(S_{\text{scene}} - S_{\text{BB1}})}{(S_{\text{BB2}} - S_{\text{BB1}})}
\]

\[
R_{\text{scene}} = (1 - x) B(T_{\text{BB1}}) + x B(T_{\text{BB2}})
\]

Where \(B(T_{\text{BB1}})\) and \(B(T_{\text{BB2}})\) are the black body radiances, calculated from the black body thermometers and integrated over the instrumental filter response, and \(S_{\text{scene}}\), \(S_{\text{BB1}}\) and \(S_{\text{BB2}}\) are the signal counts recorded for views to the external scene and to each of the black bodies. Note that the radiometer optics are open to the elements because the radiometer cannot be sealed with a window – it would not be included in the calibration measurements.

6. AUTONOMY

The new requirement for autonomy has been addressed in three principal ways; defence against rain, GPS-derived time tags for the data stream, allowing reliable positioning of validation points, and protection against upsets (power outages and program crashes).

6.1. Rain Defence

An electronically signalled weather door has been designed for the instrument (Fig. 6). The door consists of a U-shaped plate with a soft neoprene foam face, which can be pressed over the front of the instrument to seal the calibration compartment. The door plate pivots on an axle which is driven through a final worm and gear drive by a geared motor. Limit microswitches on the axle define the range of movement through an H-bridge driver incorporated in the door mechanism.

Rain information is derived from an Optical Scientific Inc. ORG-815 rain gauge (Fig. 7). When automated operation is selected, a running mean of rain amount is compared with a threshold. When the threshold is exceeded, the door is closed and the scan mirror is turned inward to point at one of the black bodies until 5 minutes after the last rain is detected.

6.2. GPS

A Garmin GPS25LV 12 channel GPS receiver has been installed in the electronics compartment. The card generates an accurate (better than 1µs) timing pulse every second, followed by a serial string giving the pulse time and position. The PC’s system clock is used to interpolate the timing pulse to the times of the data frames, and the position data, along with its age, is recorded in every data frame.

6.3. Instrument Upsets

The SISTeR software library activates a watchdog timer whenever a control program is started. If the program crashes and the timer is not reset, the instrument reboots.
into the control program. Should the power fail, the instrument will also reboot into the control program as soon as it is restored.

All serial data generated by the instrument is logged to an Acumen Instruments DataBridge SDR serial data logger. Following power outages, the logger will also restart into logging mode. Data is logged into files on a flash card. New files are opened daily, or after power interruptions.

7. **SISTeR AUTONOMOUS DEPLOYMENT**

In collaboration with the Norsk Institutt for Vannforskning (NIVA), SISTeR has been installed very recently on the Color Line ferry M/S Color Festival (Fig. 8), operating daily between Oslo in Norway and Frederikshavn in Denmark.

![Figure 8. The M/S Color Festival.](image)

SISTeR is mounted above the starboard bridge wing (Fig. 7) and looks to the sea at 30° from nadir. The SISTeR calibration was checked before installation against a CASOTS calibration black body [1]. The radiometric temperature recorded by the SISTeR reproduced the thermometric temperature of the CASOTS cavity to within 10mK throughout the comparison temperature range.

8. **FIRST DATA**

Data from the first full day under way is summarised in Figs. 9 and 10. Fig. 9 shows the instrument position captured by the GPS receiver and Fig. 10, the skin SST retrieved from measurements of upwelling sea surface and downwelling sky radiances, along with the rain gauge output and the rain flag derived from the gauge signal.

![Figure 9. Route of the first day (Oslo – Frederikshavn).](image)

![Figure 10. Summary of first day’s SISTeR data.](image)

9. **ACKNOWLEDGEMENTS**

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10. **REFERENCES**