Microwave Remote Sensing of Coastal Zone Salinity

Mark A. Goodberlet, Calvin T. Swift, Kevin P. Kiley, Jerry L. Miller and James B. Zaitzeff

Naval Research Laboratory, Code 7332, Stennis Space Center, MS 38666, USA
University of Massachusetts, Knobes Engineering Building, Amherst, MA 01003-4410, USA
College of William and Mary School of Marine Science, Gloucester Point, VA 23062, USA
Old Dominion University, Center for Coastal Physical Oceanography, Norfolk, VA 23529, USA
NOAA National Environmental Satellite Data and Information Service, Washington, DC 20746, USA

ABSTRACT


An operational airborne salinity remote sensing system is now available for coastal and estuarine studies with an accuracy of 1 ppt at 100 m spatial resolution. The system can perform area mapping at a rate of 100 km/hr from low altitude light aircraft. Called the Scanning Low-Frequency Microwave Radiometer (SLFMR), the system is designed to operate from a small single-engine aircraft. The system is composed of an 8-beam 1.4 GHz microwave radiometer, a 2-channel infrared radiometer, a Global Positioning Satellite (GPS) receiver for geolocation of the measurements and integral computer control. Working closely with personnel at the Virginia Institute of Marine Science (VIMS), the SLFMR was fitted to the VIMS U6-A DeHavilland Beaver aircraft. The first test flights of the SLFMR were completed in August 1993 over the Chesapeake Bay and coincided with extensive boat-based monitoring missions conducted by VIMS and Old Dominion University. Due to extensive Radio Frequency Interference (RFI) the 1993 test was not totally successful. The system was subsequently re-flown in 1994 over the Chesapeake Bay in a more friendly RFI environment. In this case, successful remote sensing measurements were made, which compared favorably with in situ data collected by VIMS. A final flight was conducted over Delaware Bay in an even more friendly RFI environment, and the data compared favorably with historical data compiled from ship surveys.

ADDITIONAL INDEX WORDS: Coastal salinity, Coastal ocean temperature, Coastal environments, littoral zone.

INTRODUCTION

In the late 1960’s, Sirohunian (1968) and Paris (1969) recognized that ocean surface microwave emission in the 1 to 3 GHz range had measurable sensitivity to changes in ocean surface salinity. A proof-of-concept system reported by Droppleman and Mennella (1971) consisted of a 1.4 GHz microwave radiometer and an 11 μm infrared radiometer. The system utilized a single fixed beam, was aircraft mounted, and able to observe the large salinity gradients existing near the mouth of the Mississippi river. In 1973, Thomann (1973) used a similar system to map ocean surface salinity in the Gulf of Mexico. This instrument could achieve acceptable measurement accuracy only by averaging the measurements over time periods from 12 to 16 seconds. This resulted in unacceptable spatial resolution due to smearing of the radiometer footprint caused by aircraft motion during the averaging time. The necessary technological improvements were available in 1977 to reduce averaging times below 1 second when the NASA Langley built system (Blume et al., 1978), (Blume and Kendall, 1982), consisting of a 1.4 GHz and 2.65 GHz radiometer, was used to map salinity levels in the Chesapeake Bay. Additionally, the salinity retrieval algorithm used by the NASA group benefited from the improved understanding of ocean surface emissivity developed by Klein and Swift (1977).

In the early 1970’s, tropical storm Agnes had a near catastrophic effect on the Chesapeake Bay shellfish industry when it significantly lowered salinity levels in the Bay with its prolonged and heavy rains. At the time, helicopters and boats were sent (at considerable cost) throughout the Bay to collect water samples which were used by marine biologists to understand the effects of the storm. It is interesting to note that development of the NASA Langley salinity mapper resulted from this incident as a rapid means of collecting ocean salinity and temperature data. Recently, renewed interest in studying the environment has resulted in new systems (Fumi Remote Sensing Centre, 1990), new ideas such as spaceborne salinity mappers (Skou, 1989), (Swift and McIntosh, 1983), and programs designed to encourage development in the field.

This paper describes the development and test of a low-cost airborne salinity measurement system which can measure surface coastal ocean salinity and temperature. The system offers a new tool for scientists and coastal zone managers to study and interpret the physical and biological characteristics of estuaries and near-shore waters. Although surface vessels provide a means for conducting detailed local studies involving salinity and temperature, only aircraft observations...
will permit a synoptic picture. Moreover, only the relatively high speed of aircraft will permit an almost instantaneous picture which would normally be aliased by the tidal cycle if such maps were produced from ship measurements. Specifically salinity and temperature field maps are needed to understand coastal dynamics and to calibrate and validate numerical circulation models. Salinity is also important to adult, juvenile, and larval fish distribution, and for management of important species such as shrimp and oysters.

**METHODS**

**Theoretical Considerations**

Matter, when maintained at a physical temperature, \( T \), will radiate electromagnetic noise power by an amount which is quantitatively described by the Planck radiation law. If observations are made at wavelengths longer than approximately 0.3 cm, the Rayleigh Jeans approximation to the Planck formula is valid and the radiated power, \( P_R \), received by an instrument bandwidth, \( B \), can be expressed as (Ulaby et al., 1986),

\[
P_R = e k T B
\]

where \( k \) is the Boltzmann constant, \( T \) is the temperature of the emitter, and \( e \) is the emissivity. It is common practice in the field of microwave radiometry to ignore physical and system constants, and define the measurement of noise power through a quantity called the brightness temperature \( T_B \), which is defined by the following equation.

\[
T_B = e T
\]

The emissivity \((0 < e < 1)\) can be thought of as a figure of merit which defines the efficiency of radiation. If \( e = 1 \), the emitter is a perfect blackbody, and the only parameter that can be measured by remote sensing techniques is the radiating temperature. Therefore, all other geophysical information depends upon the emissivity. If it is assumed that the thermal radiator is a reasonably flat half-space, with a well defined boundary, such as the air-sea interface, then the emissivity can be calculated by solving the boundary-value problem of an electromagnetic wave incident upon the interface of the two dielectrics. If this is done, then the emissivity is given by,

\[
e = 1 - R
\]

where \( R \) is the Fresnel reflection coefficient. If the instrument views nadir, the boundary-value solution results in the following expression for the reflection coefficient.

\[
R = \left| \frac{n - 1}{n + 1} \right|^2
\]

The quantity, \( n \), is the complex index of refraction of the emitter, which is the square root of the relative dielectric constant. The complex dielectric constant of sea water has been studied in great detail, and an algorithm has been developed (Klein and Swift, 1977) which relates the dielectric constant to the conductivity of sea water and therefore its salinity. The dependence of the radiometric brightness temperature of sea water upon physical temperature and salinity is shown in Figure 1.

![Figure 1. Radiometric brightness temperature of the ocean plotted as a function of sea surface temperature and for the salinity values of 5, 15, 25 and 35 ppt.](image)

The influence of the conductivity is enhanced as the microwave frequency is reduced to L-Band \((i.e., \text{ frequencies in the neighborhood of } 1.4 \text{ GHz})\). This occurs because the imaginary part of the dielectric constant depends upon the ratio of the ohmic conductivity of sea water to the electromagnetic frequency. Thus, as the frequency becomes lower, the effects of the conductivity, hence the salinity become more pronounced. In other words, an L-band radiometer can be thought of as a remote conductivity meter. However, the conductivity also strongly depends upon temperature, therefore, some provision must be made to correct for the effects of sea surface temperature. Our choice is to use an infrared radiometer.

**Instrument Description**

The salinity mapping system is outlined in Figure 2. Its main component is a 1.4 GHz microwave radiometer called the Scanning Low Frequency Microwave Radiometer (SLFMR) which is capable of detecting changes in both ocean surface temperature and salinity. The other major components of the system are an infrared radiometer which provides an almost direct measurement of ocean surface temperature and a Global Positioning System (GPS) receiver used to geolocate measurements of the two radiometers. The infrared measurements of surface temperature are used to insure that surface temperature variations are not misinterpreted as salinity variations by the SLFMR. Salinity measurement accuracy depends upon the actual values of ocean salinity and temperature but for coastal United States waters is typically better than 1 part per thousand (ppt), or 1 practical salinity unit (psu).

The SLFMR has an electronically steered antenna beam
SIGNIFICANT FEATURES:
*} Null Feedback Radiometer Design
*} Constant Temperature Enclosure
*} Multiple Beam Array Antenna
*} Split-Window Infrared Radiometer
*} GPS Navigation
*} Utilizes Single-Engine Aircraft (U6A DeHavilland Beaver Class)
*} Automatic or Manual Operation
*} Immediate Post-Flight Data Reduction

APPLICATIONS:
*} Ocean Salinity and Temperature
*} Soil Moisture
*} Maps of River and Lake Ice Extent

Figure 2. The salinity mapping system at a glance.

and is capable of viewing any of six spots on the ocean surface which are located across the flight track of the aircraft (i.e. the system has scanning capability). Spot size (spatial resolution) depends upon aircraft altitude and speed but is typically 100 m for an altitude and speed of 350 m and 45 m/s respectively. The infrared radiometer has a beamwidth equal to that of the SLFMR but is nonscanning and measures ocean temperature over a spot located directly below the aircraft. A unique feature of the infrared radiometer is that two closely spaced channels are used to correct the surface measurement for the atmospheric component. This is the Split Window technique used in several NOAA satellites. The scanning capability of the SLFMR significantly improves the mapping rate over that of previous nadir only looking instruments. Mapping rate depends on aircraft speed and required spatial resolution. For a typical speed of 45 m/s and an altitude of 350 m, the SLFMR mapping rate is approximately 100 km/hr at 100 m spatial resolution. The flyback scan geometry of the electronically steered SLFMR beam is shown in Figure 3 where a sawtooth scan, used by instruments with mechanically steered beams, is shown for comparison. Note that the flyback scan results in more uniform sampling within the swath than the sawtooth scan.

Components of the system which must be placed outside the aircraft are housed in a thermally controlled and aerodynamically shaped enclosure measuring 0.2 m high by 1 m wide by 1.5 m long and weighing 52 kg. A photograph of the enclosure, mounted on the Virginia Institute of Marine Science (VIMS) aircraft is shown in Figure 4. Components of the system which are placed inside the aircraft include a power supply, an IBM-compatible computer which is used to control and acquire data from the SLFMR, an infrared radiometer and GPS receiver. The computer, GPS and power supply are mounted on an equipment rack measuring 0.7 m high by 0.5 m wide by 0.5 m long and weighing 32 kg. The infrared radiometer is also located inside the aircraft and views the ocean surface through a 0.15 m (minimum diameter) hole cut in through the underside of the aircraft. The infrared radi-
ometer measures 0.20 m high by 0.15 m wide by 0.08 m long and weighs 2.3 kg. The system operates from standard 115 V AC power and requires a maximum of 320 W during normal operation of which 200 W is allocated to the computer and another 70 W is allocated to thermal control of the SLFMR electronics. The system can be placed in a fast warmup mode during which it will require a maximum of 1600 W.

RESULTS

Ground Tests

The system was completed in June 1993, and the microwave subsystem was tested for stability and precision. Clear sky was used as a target because the associated brightness temperature is constant at L-band, and because it is a cold reference (approximately 6 K). The proximity of trees to the left side of the antenna scan also served as a partial check of the beam steering by the phased array antenna. A time series of one such test is shown in Figure 5, where radiometer digital counts are plotted as a function of hour of the day. In this curve, one division (10 counts) is approximately 1.6 K. Except for initial warm-up (0945–1045), and a dip between 1300 and 1430 hours corresponding to the passing of the sun thru the beam's sidelobe, the system does not drift by more than 2 K in a 5 hour period. Indeed, this drift is due to an internal temperature regulation problem, which can be corrected for in software through direct measurements of the internal temperature.

The time series shown in Figure 5 was also used to determine the instrument precision, or \( \Delta T \). The counts fluctuations translate to a radiometric \( \Delta T \) of 0.36 K, which is within the specifications needed to measure salinity with an accuracy of 1 ppt.

Description of Test Flights

In August 1993 all components of the salinity mapping system were installed on the VIMS aircraft and flown over areas in and around the southern portion of the Chesapeake Bay. The flights originated from the VIMS aircraft home base at Patrick Henry airfield in Newport News, Virginia. On 18 August a short flight was made to check mounting hardware and basic electrical circuits of the system. A 3 hour calibration flight was conducted on 19 August during the hours from 0830 to 1130 EDT for the purpose of overflying calibration points at Lake Drummond, the Chesapeake Light House, and the NOAA weather station on the third island of the Chesapeake Bay Bridge tunnel. In situ data were collected at these locations by Old Dominion University (ODU) and VIMS personnel. On 20 August between the hours of 0930 and 1230 EDT, the system was flown along lines in Hampton Roads in an attempt to map ocean salinity and temperature throughout the southern part and regions near the mouth of the Chesapeake Bay. On 20 August between the hours from 1500 to 1730 EDT, the system was flown along selective lines over which boats from both VIMS and ODU were making in situ measurements of ocean salinity and temperature. The purpose of the afternoon flight on 20 August was to acquire airborne and in situ measurements which were coincident in both time and space as a means of further calibrating/testing the salinity mapping system. The ODU and VIMS vessels used SeaBird, Inc. conductivity-temperature-depth (CTD) in-
Airborne Salinity Remote Sensing

SCANNING LOW-FREQUENCY MICROWAVE RADIOMETER

Figure 4. DeHaviland Beaver aircraft with the SLFMR mounted below (rectangular box under aircraft). The SLFMR measures 0.2 × 1.5 × 1.0 meters and weighs 52 kilograms. It scans through three pointing angles (see insert) on both sides of nadir, ±7°, ±22°, and ±39°.

Insruments to collect the in situ salinity data. These instruments were inter-calibrated at a common station on the eastern end of their respective transects. In addition, water samples were collected in conjunction with the ODU data and were analyzed on a high precision Guidline laboratory salinometer which was calibrated with IAPSO standard seawater. Observed salinities are accurate to within 0.003 ppt.

General performance of the system was good and no malfunctions either in hardware or computer software were encountered. The dual channel infrared radiometer, the GPS receiver and the system computer control all operated flawlessly. An example of the infrared results are shown in Figure 6, where we plot a comparison of the infrared temperatures with actual in situ measurements collected from boats. However, data collected by the SLFMR suffered from contamination by man-made Radio Frequency Interference (RFI). To illustrate the problem, a time series of digital counts vs hour of the day is shown in Figure 7. The significant interference during the first half of the mapping flight appears to correlate with the aircraft being in proximity to the three major airports in the Norfolk Virginia area. Although the strong interference appeared to cease as the aircraft collected data further North of the airports, the residual noise is still far too high to allow accurate salinity measurements (compare to Figure 5, where the y-axis has a different scale factor). The cause of this high noise level is not necessarily associated with the strong interference encountered at the beginning of the flight.

Flights of April 1994

The Chesapeake Bay area was chosen as a demonstration site for a number of reasons. First, the VIMS aircraft could be locally deployed in order to save ferry costs. Second, the proximity of other VIMS research vessels and routine surveys conducted by ODU provided an avenue to obtain in situ measurements needed to corroborate the remote sensing data. Third, previous demonstrations by the nearby NASA Langley Research Center (Blume et al., 1978) identified salinity distributions that correlated well with historical surveys produced by traditional means. The radio frequency interference that was encountered in the 1993 mission was a complete and
unwelcome surprise, since RFI was not encountered by the NASA engineers who conducted their experiments in 1976 and in 1980. In view of this unexpected problem, a second mission was planned to identify potential sources of RFI, and to work around the problem to satisfy the remote sensing objectives. In discussions with the aircraft operations personnel, we determined that there were a number of transmitters on board the aircraft so that our first suspicion was that the aircraft was its own source. In order to systematically search for RFI sources, the SLFMR was set up on the ground adjacent to the VIMS aircraft at Patrick Henry Field. The antenna was pointed toward the sky, and the aircraft transmitters were turned on and off in sequence as the SLFMR system recorded data. The final test consisted of starting the aircraft engine to determine the level of induced ignition noise. Subsequent analysis of the SLFMR data failed to reveal aircraft self-induced RFI. We therefore concluded that RFI was generated by other transmitters located in the Hampton Roads area.

In order to further evaluate the RFI problem which plagued the initial SLFMR flights conducted during August 1993, a total of 6 flights were rescheduled during the period of April 1994. It was decided to select the week end as the prime data period under the assumption that sources of RFI would most likely occur during normal working hours. The initial airborne test was done on 22 April 1994, a Friday. This was a short flight from Newport News airport and over the York river. RFI was observed over the York river, which increased with increasing flight altitude. This behavior suggested that the source is a ground based instrument, possibly located in the vicinity of Norfolk, Virginia.

A data flight was then flown over the Chesapeake Bay on Sunday 24 April at a flight altitude of 500 feet. The flight track consisted of lines indicated on the map of the lower bay shown in Figure 8. Lines were chosen to be far north of Norfolk in an attempt to minimize RFI. In situ data was provided by a VIMS boat which sailed roughly along the SLFMR flight line, F-G as indicated in Figure 8. Only for the 24 April flight lines, F-G and H-I, was the RFI level low enough to allow reasonably accurate retrievals of salinity. Raw data are shown in Figure 9. It was very fortunate that this RFI quiet period coincided with SLFMR overflight of the VIMS boat. It
is interesting and also discouraging to note that at about 1000 EDT the RFI level jumped to an intolerably high level and remained there even though the SLFMR flight altitude stayed constant and the flight proceeded further north in the Bay and farther away from Norfolk. We suspect that at 1000 EDT an RFI source was turned on or perhaps the antenna of an already active RFI source was pointed in our direction.

Part of the data used to calibrate the SLFMR came from the VIMS in situ measurements made during this flight. The calibration done on this day was used to reduce the data from this flight as well as data from the flights of 26 and 27 April. The resulting SLFMR salinity retrievals are compared with measurements made by VIMS in Figure 10. The SLFMR salinity retrievals of Figure 10 represent a 9-point running average of the measurements made by SLFMR beam 1L. The single-measurement random retrieval error calculated from the data is approximately 1.5 ppt. This single-measurement accuracy was improved to less than 1 ppt by performing the running average used to display the data in Figure 10. Unaveraged retrievals of water temperature, which were made by the SLFMR system's dual-channel infrared instrument, are compared with the VIMS in situ measurements in Figure 11. The random and absolute single-measurement retrieval error for water temperature is well under 0.5 C.

In an attempt to escape the high and often unpredictable RFI levels in the Chesapeake Bay, the SLFMR was flown to Delaware Bay. The original plan was to fly directly east after takeoff from Newport News, Virginia and then up the eastern shore of the Delmarva peninsula while maintaining a distance of about 1–2 miles off shore. At Delaware Bay the flight would be determined by a set of 20 waypoints. However, upon arrival we found that unforecasted ground fog covered the Bay and much of the surrounding area. This fog extended vertically to an altitude of about 1500 feet and caused several problems. Firstly, the fog made it impossible for the infrared sensor to measure ocean surface temperature. Secondly, we experienced annoying but tolerable amounts of RFI at our flight altitude of 2000 feet and were prevented from flying lower to reduce the RFI level because of the fog. Thirdly, we...
had to “cut short” the flight when our plane ran low of fuel and we learned that the nearest fog-free airport for refueling lie far to the south in Salisbury Maryland. The actual flight lines flown on this day are superposed in the chart of the Bay shown in Figure 12. The presence of fog did not impact the L-Band measurements, since long microwave can “see through” the small droplets in the atmosphere. Since the fog prevented us from achieving infrared estimates of water temperature, historical water temperature data from May 1990 was used to perform the water temperature correction on the SLFMR microwave data.

Plotted in Figure 13 is the 9-point running averaged values of salinity calculated from the data collected by SLFMR beam 1L along the flight track F-F2-T shown in Figure 12. Figure 13 also shows the May 1990 historical values of salinity for points along the SLFMR flight track. The single-measurement salinity retrieval random error calculated from the raw data ranges from approximately 1.5 ppt in the RFI quiet northern parts of the Bay to approximately 3 ppt near the Bay mouth.

**DISCUSSION AND CONCLUSIONS**

After the RFI problems encountered by the SLFMR over Chesapeake Bay in August of 1993, one may wonder why we attempted to fly in that area again. Although we were quite sure that a ground based RFI source was located in the Norfolk area, we suspected that at 15 or 20 miles from Norfolk the August 1993 SLFMR measurements were corrupted not by the Norfolk RFI but by RFI generated onboard the VIMS aircraft. In particular, we believed that the aircraft’s radar transponder, which utilized frequencies just 200 MHz away from the SLFMR operating band, could be generating low level RFI. Furthermore, if the radar transponder were a source of RFI, then the problem could be solved simply by
turning off the transponder. The first set of SLFMR ground and flight tests conducted on 22 April concluded that neither the VIMS aircraft nor the instruments it carried were a significant source of RFI.

A very disturbing characteristic of the Chesapeake Bay RFI is its time dependence (see preceding description of the 24 April 1994 flight). This fact made flight planning difficult and we were very fortunate to get good SLFMR data during the brief period of time that the aircraft was over the area in which VIMS was collecting in situ data. Without the data collected during this short RFI quiet period, we would have been unable to accurately calibrate the SLFMR.

A comparison of the time series of salinity derived from the SLFMR and the accompanying VIMS in situ data was shown in Figure 10. The average difference between the two measurements was less than 1 ppt, after applying a 9 point running average to the SLFMR measurements. This was the target accuracy which we expected to achieve based upon the earlier survey conducted by Blume et al. (1978). The ultimate value of the remote sensing data will be the wide area mapping capability. As an illustration of the potential value, Figure 10 shows an apparent dip in the salinity near longitude 76.26°, which is evident in both VIMS and SLFMR data. There is, however, a phase difference, which may be a consequence of a spatial shift in sampling, as suggested by the two tracks shown in Figure 14. Note that there is only one point when the two tracks are actually co-incident. When placed in a high flying scanning mode, the SLFMR has the potential of producing maps to enhance the spatial distribution of such features and gradients. Better coincidence with in situ data can also be achieved by overlaying boat tracks on the salinity map.

The 26 April flight took the SLFMR over the full length of the Delaware Bay where RFI levels were found to be significantly reduced below those in the Chesapeake. Therefore, we suspect that RFI levels in the Chesapeake are unusually high compared to other potential mapping sites having a reduced military presence. None of the RFI encountered during our flights affected the ability of the salinity mapping system's infrared instrument to measure ocean surface temperature. Under clear sky conditions the ocean temperature retrieval accuracy for the infrared instrument usually exceeded 0.5 C.

As shown in Figure 1, the sensitivity of the SLFMR raw microwave measurement (brightness temperature) to changes in salinity depends upon water temperature (decreasing sensitivity with decreasing water temperature) and salinity itself (decreasing sensitivity with decreasing salinity). Additionally, for decreasing water temperature, the SLFMR microwave measurements become increasingly sensitive to changes in water temperature, making it more difficult to separate the salinity signature from the water temperature signature. The theoretical single measurement SLFMR salinity retrieval accuracy under the April conditions we encountered (salinity = 12 ppt, water temperature = 14 C), is calculated to be 1.5 ppt. In contrast, the calculated salinity retrieval accuracy is 0.7 ppt for typical summer conditions (salinity = 20 ppt, water temperature = 25 C), in the same area. The SLFMR achieved the theoretically predicted salinity retrieval accuracy of 1.5 ppt during the April 1994 flights. However, we wish to emphasize that early Spring conditions in the Chesapeake Bay are not the conditions under which the SLFMR makes its most accurate measurements. Under cold water and low salinity conditions, the salinity retrieval accuracy of 1 ppt can be achieved by averaging several single-footprint measurements. The cold early Spring weather also makes it more difficult for us to maintain good thermal control of the SLFMR electronics. Although we are able to correct the April 1994 data for small drifts in the physical temperature of key electronic components, this forces us to rely on the accuracy of such a correction. Operating the SLFMR in warmer weather makes this thermal problem much less of a concern.

Part of the data used to calibrate the SLFMR came from the VIMS in situ measurements which coincided with the 24 April 1994 flight data. This was the only calibration done for the SLFMR and was used to reduce the data from all 6 flights. Since the absolute accuracy of the salinity retrievals from the flights of 24 and 26 April appears to be good, we conclude that the SLFMR has reasonably good long term calibration stability.

The six SLFMR beams are pointed at angles of 7, 22 and 39 degrees away from nadir on both the left and right side of the flight track. The larger the SLFMR beam pointing angle, the more sensitive that beam's measurements are to RFI coming in from the horizon. The increased sensitivity to RFI coupled with the fact that their measurements are also more sensitive to the rolling of the aircraft makes salinity retrievals of the 3L and 3R beams less accurate than those of the 1L and 1R beams. More in situ data are needed to accurately assess the reduced accuracy of the outboard beams and to further tune the calibration for all 6 beams. We were not able to make large area maps of salinity during these flights because of the limited number of flight hours allocated and the fact that RFI forced us to fly at low altitude. Since the SLFMR swath width for a flight altitude of 500 feet is only
950 feet and the SLFMR flight lines were parallel but separated by 2 miles, the data were presented in this paper using line plot format.

L-Band radiometers are extensively used for airborne remote sensing measurements of soil moisture (Levine et al., 1994). Those instruments have successfully generated images of the brightness temperature of terrain without any corruption by RFI except in the Norfolk area. We are now pursuing other opportunities to fly the SLFMR in other coastal regions which presumably will not suffer the degree of RFI experienced in the lower Chesapeake Bay. If such RFI can be avoided, and we are optimistic that it can, salinity images can be produced over a wide area in a relatively short time period. These images should be very useful to scientists involved in coastal zone modeling and biological assessments.

ACKNOWLEDGEMENTS

We wish to acknowledge the support of the following people and organizations: Vic Delnore (Lockheed-Martin), Richard Harrington (ODU) and John Bombaro, John Stark and Gene Barr of Rick Aviation for design and fabrication of the SLFMR-to-aircraft mount. Sam White (VIMS) who piloted the VIMS aircraft and assisted with flight planning. Livio Poles and Ed Martin of the U.S. Air Force Rome Air Defense Test Facility who assisted with SLFMR antenna pattern measurements. Jim Bernotas of Amherst Machine who fabricated and helped design the SLFMR enclosure. Steve Snyder and Sam Wilson of VIMS who provided in situ measurements of salinity and water temperature in Chesapeake Bay. Vic Klemas (University of Delaware) who provided salinity and temperature data in Delaware Bay. Joycee Davis of VIMS who allowed the SLFMR to operate during her 27 April 1994 fish net survey.

LITERATURE CITED