AIRCRAFT AND IN SITU SALINITY AND OCEAN COLOR MEASUREMENTS AND COMPARISONS IN THE GULF OF MEXICO

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ABSTRACT

We report here on aircraft measurements made in May, 2007, with the NRL STARRS (Salinity, Temperature and Roughness Remote Scanner), and optical multi-wavelength radiance and irradiance sensors (Satlantic OCR-507 at SEA-WIFS wavelength bands). These measurements were made in conjunction with in situ measurements of sea surface salinity (SSS), ocean color, and fluorescence in the Atchafalaya River outflow from the R/V Pelican. In this work we demonstrate the ability of the aircraft optical and L-Band measurements to a) detect the location of salinity and color fronts as observed in the in situ measurements from the ship and b) provide context for the in situ measurements by providing synoptic measurements over a wider area than the ship was able to cover. A multilinear regression for salinity, based on three of the optical channels, provides an excellent qualitatative proxy for large scale salinity in the Atchafalaya plume region. We believe this is the first simultaneous use of L-Band and optical instruments to measure salinity from an aircraft.

Index Terms— Salinity, CDOM, Seawifs, Atchafalaya

1. INTRODUCTION

We are interested in the behavior of buoyant plumes in the nearshore region. The dynamics of these plumes are driven by wind and density contrasts. Salinity is often the dominant contributor to the density contrast of buoyant plumes. Rivers flowing into the coastal ocean carry freshwater as well as CDOM (Colored Dissolved Organic Matter). To the extent that CDOM, like freshwater, is conserved, CDOM concentration changes can serve as a proxy for freshwater dilution by mixing, and hence determine near-surface salinity in the coastal waters. However, because CDOM characteristics are determined by unique conditions in each watershed, the relationship of CDOM to salinity can vary for different rivers. Furthermore, the relationship between CDOM and salinity can vary temporally for a given river due to such phenomena as seasonal variation in rainfall, biological inputs, soil runoff, and vegetation [1]. Given these complications to using CDOM as a proxy for salinity measurement, the key opportunity provided by CDOM is that it can be remotely sensed on time and space scales that are infeasible for in situ salinity measurements. Satellite measurements of ocean color are available on 1 km or smaller, scales. By contrast, sea surface salinity is not yet being measured by satellite. The L-Band microwave satellites SMOS (Soil Moisture and Ocean Salinity) and Aquarius, to be launched in 2009 and 2010 by ESA and NASA, will have a SSS precision of 0.2 psu and resolution of approximately 100 km on monthly timescales. The coarseness of SSS resolution results in a coastal gap in the satellite measurements of SSS. If ocean color changes can be used as a proxy to determine salinity changes, the coastal gap may be reduced. Our observations can be used to predict salinity under prevailing conditions of clear weather and a large salinity contrast.

The remainder of the paper will describe the observations, with a limited discussion of the shipboard data, and then make a more detailed analysis of the predictions of salinity from the optics data. We conclude that these preliminary data show a best case for determining salinity from SEAWIFS optical observations from an aircraft. We believe this is the first report of simultaneous use of L-Band and optical instruments to determine salinity from an aircraft. The confounding factors of seasonal and river specific variation of freshwater sources (and their CDOM signatures) remain to be addressed.

2. OBSERVATIONS

The STARRS instrument has passive L-Band and C-Band microwave radiometers, for salinity and roughness detection, and IR radiometers for measuring SST. STARRS is mounted on a small twin engine aircraft (Piper Navajo). At a typical operating altitude of 2700 m, the swath of its six L-band beams is approximately 5 km. The swath lies across the airplane flight path and the six beams are oriented at ± 7, ± 22, ± 37 degrees from the vertical. C-band and IR instruments are nadir viewing. The L-Band radiometer determines salinity from the variation of ocean brightness temperature T_b, with

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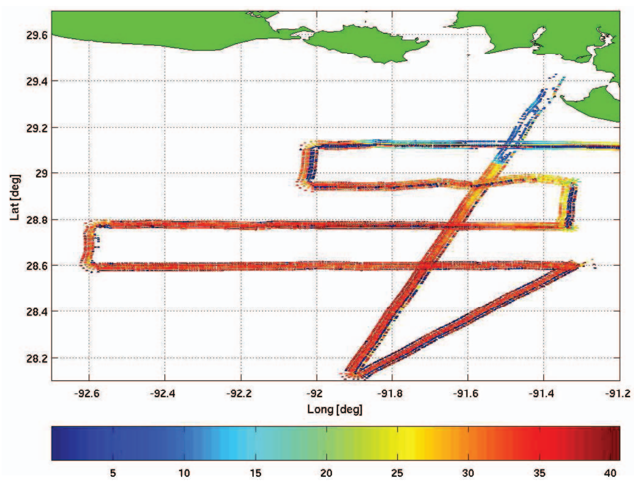
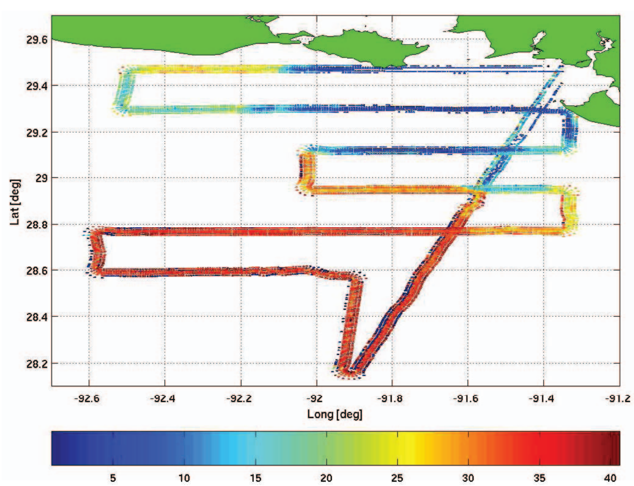
temperature and conductivity. Brightness temperature is proportional to emissivity, which is related to the complex index of refraction of the seawater and determined by the conductivity, hence indirectly the salinity. (See [2] for more information.) Further information on the STARRS instrument and data processing can be found at [3] and [4]. Daytime flights necessary for the optical measurements are non-optimal for STARRS L-band measurements since sun-glint can produce errors in the SSS measurement. Data from any beams contaminated from sun-glint were either discarded or a correction based on [5] was applied, depending on the severity of the sun-glint. At worst, only two of the six beams were adversely affected by sun-glint.



(a) Morning Flight



(b) Afternoon Flight

Fig. 1. Salinity maps from morning and afternoon on May 10, 2007. Noise from sun-glint is evident on the east side of the outbound leg in morning and on the west side of it in afternoon. These scans were removed in subsequent processing.

The optical sensors mounted on the top and bottom of the aircraft are multi-wavelength radiance and irradiance sensors (Satlantic OCR-507 with SEAWIFS wavelength bands: 412, 445, 492, 554, 670, 780, 864nm). The ratio of downward viewing to upward viewing (irradiance/radiance) optical response, at each wavelength, provides a rough measure of ocean reflectance in that band. Data for all channels was sampled at approximately 5 Hz and averaged to a 2 second sample interval. The optical data from each flight was processed using the ProSoft package from Satlantic, the instruments' manufacturer. Level 3a processing was used, which provides a value at each wavelength band of water leaving radiance (downward view, LT) and a value for reference downwelling plane irradiance (upward view, ES). (For more information on these terms, see the Prosoft 7.7 manual [6].) No atmospheric corrections have been applied to the data. The results we will show indicate that omitting such correction is not crucial to the analysis.

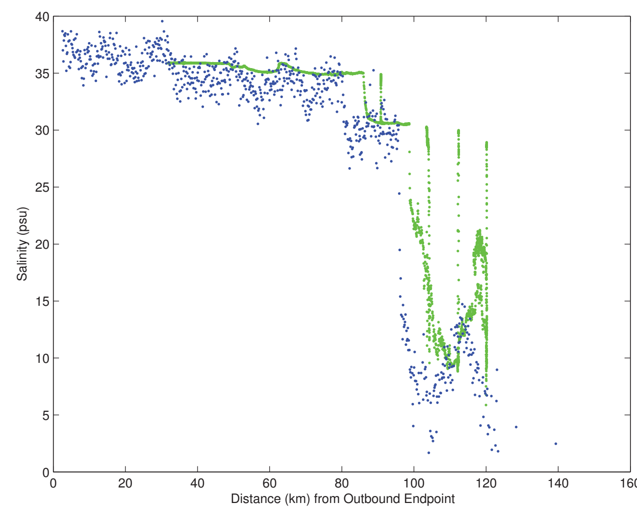
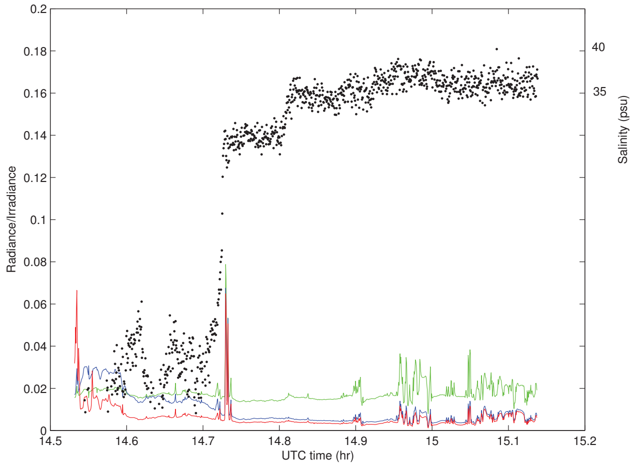
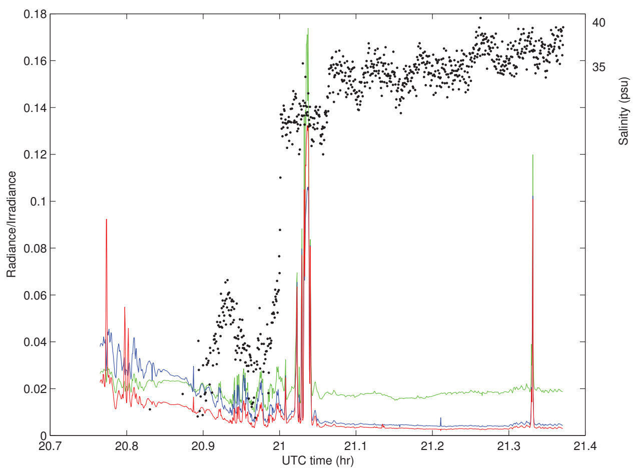


Fig. 2. R/V Pelican (green) and STARRS (blue) salinity along the outbound flight leg. STARRS data is from the afternoon flight. The ship was at the salinity front when the aircraft flew over it. The ship covered the distance shown in approximately 12 hours while the aircraft covered it in less than 45 minutes.

Two flights of 3 and 3.5 hours were made on May 10, 2007 while the ship was on the outbound leg of the flights. During the day the Pelican moved toward shore. Maps of salinity from STARRS are shown in Figure 1. To verify the quality of the STARRS salinity we compared it to the in situ salinity from the R/V Pelican. The STARRS system has significantly higher noise than the ship's thermosalinograph and various corrections are applied in order to calculate salinity. One particular difference between the shipboard and aircraft measurements is that the shipboard water intake for its underway sampling is at a depth of over 1 m, while the microwave measurement detects the brightness temperature (hence salinity) of the top few centimeters. Thus, if there is a very thin



(a) Morning Flight



(b) Afternoon Flight

Fig. 3. Optical channel values and salinity along the outbound leg for the two flights. (LT/ES) is shown for three wavelength bands: 445nm (green), 670nm (blue), and 780nm (red). The salinity (black dots) front and optical front coincide exactly.

fresh layer, it may not be detected by the ship. Underway and stationary ship salinity values also may differ due to the dynamics of the intake. These effects can be seen in Figure 2. In spite of the noise in the STARRS data, the agreement between ship's thermosalinograph and STARRS salinity is good. Many features, if not exact magnitudes, of the salinity along this leg match between the thermosalinograph and STARRS. Ship data from very close to shore, not shown here, do show very low (5-10 psu) salinities that are also observed by STARRS. However, those measurements were taken a day or more before the flights here. The speeds of the ship and aircraft are different, so they cannot sample the same location simultaneously. Thus, fronts may have moved slightly between sampling by the ship and aircraft.

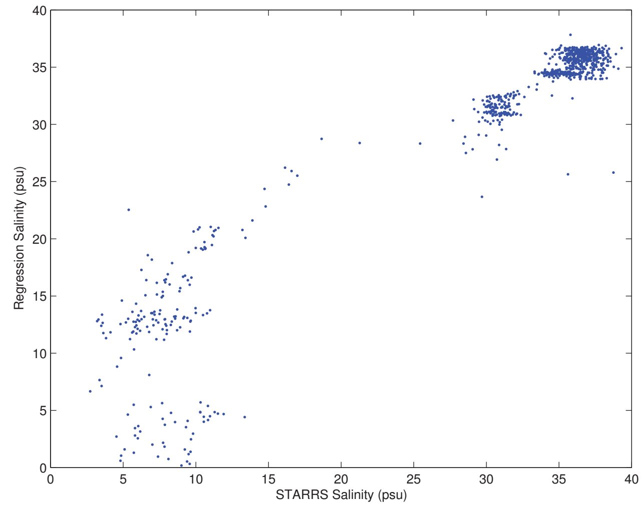


Fig. 4. Regression results for salinity based on the linear fit to (Band5/Band2) and (Band5/Band6) values along the outbound leg for the morning flight.

3. RESULTS

In Figure 3 the salinity front observed by STARRS is clear in the optical data for both flights. However, the sharp peak, by itself, indicates a front with large amounts of phytoplankton, but does not determine salinity. The 670 nm (Band5) band value changes most from the beginning of the line to the front, while the 780 nm (Band6) and 445 nm (Band2) bands change very little. We performed a linear regression between salinity and two variables determined from the optics. Thus

$$\text{salinity} = \mathrm{C_o} + \mathrm{C_1}x_1 + \mathrm{C_2}x_2 \tag{1}$$

We use the ratios (Band5/Band2 $= x_1$) and (Band5/Band6 $= x_2$) taken from only the outbound leg of the morning flight. This fit has an R_2 of 0.90 and is shown in Figure 4 for the outbound leg. The regression coefficients are then applied to the optics data set for both flights to predict salinity of the remainder of the morning flight as well as the entire afternoon flight. The results are shown in Figures 5 and 6. The qualitative agreement between the optics derived salinity maps is excellent for this case. The location of fronts that occur on other legs of the flights match well with those from Figure 1.

4. CONCLUSION

The freshwater outflow from the Atchafalaya basin was clearly visible from the ship and airplane during calm to moderate conditions. A few days earlier, conditions were rough enough to limit ship operations, so this suggests the outflow was strong enough to reform the front. Color fronts were also plainly visible from the ship and aircraft. However, not every color front is a salinity front, since turbidity fronts may have virtually no density or salinity contrast from one side to the other.

We have used the shipboard thermosalinograph to validate the STARRS salinity measurements and then the STARRS salinity data to generate a regression for salinity based on three bands of the optical data. Thus, we have demonstrated that the combination of STARRS and optical SEAWIFS observations can predict salinity in the nearshore region. This is the first report (to our knowledge) that uses both L-Band radiometer and optical instruments from an aircraft to determine salinity. This may also be a best case: the weather was clear, the salinity contrast in the region was very high, and the two flights were separated by only a few hours. In cases of different rivers as the source of fresh water, or even the same river at different times, more sphistcated analysis may be necessary to determine salinity over aircraft survey scales using optical data.

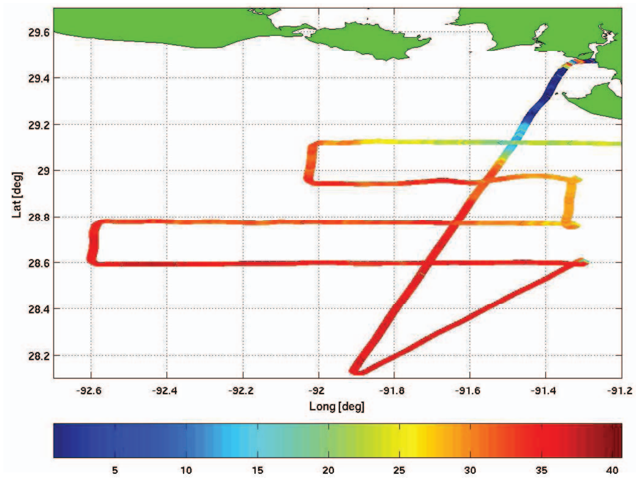


Fig. 5. Salinity map predicted by the optical data for the morning flight on May 10, 2007.

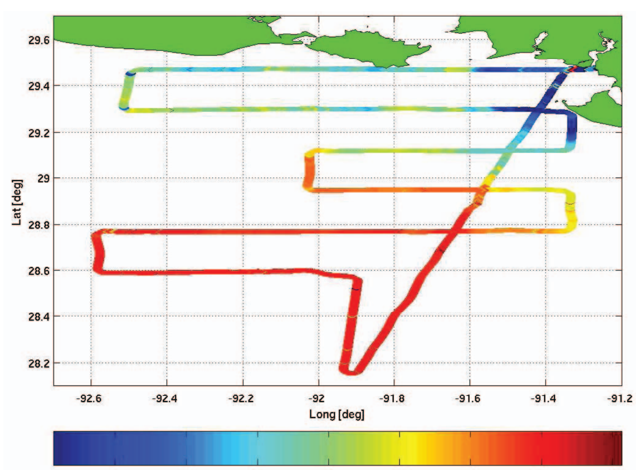


Fig. 6. Salinity map predicted by the optical data for the afternoon flight on May 10, 2007.

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