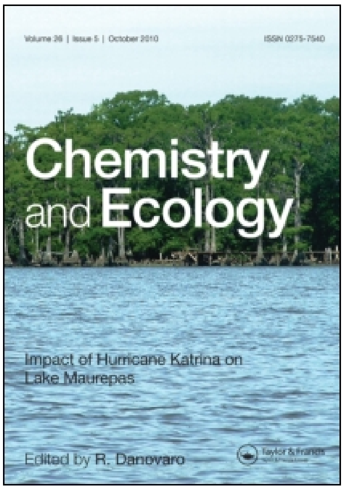

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John J. Tsai[a]; Hening Huang[b]; John R. Proni[a]
[a] National Oceanic and Atmospheric Administration, Atlantic Oceanographic and Meteorological Laboratory, Miami, FL [b] Hazen and Sawyer, Raleigh, NC

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ACOUSTIC OBSERVATIONS OF BOTTOM SURGE FROM DREDGED MATERIAL DISCHARGE IN THE OPEN OCEAN

JOHN J. TSAI,[1] HENING HUANG[2] and JOHN R. PRONI[1]

[1]*National Oceanic and Atmospheric Administration, Atlantic Oceanographic and Meteorological Laboratory, 4301 Rickenbacker Causeway, Miami, FL 33149;*
[2]*Hazen and Sawyer, P.C. 4011 West Chase Boulevard, Raleigh, NC 27607*

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Bottom surges generated from dredged material discharges in the open ocean have been observed using high frequency acoustic concentration profilers in several field studies during the past five years. The locations, water depths, bottom slopes, oceanographic conditions, and dredged material composition differed from study to study. Observed surges at three dredged material disposal sites may develop more than one surge peak for a single discharge. For water depths of the order of 10 m, surge height of the leading peak was estimated to be about one quarter of the water depth. For water of greater depth, of the order of 100 m, surge height reached 70 m, about 70% of the water depth. Surge height is established instantaneously when dredged material hits the bottom, and remains relatively constant as the surge advances horizontally. Total surge length reached 150 m for water depths of 10 m when measured from the impact point to the leading edge. For water depths of more than 100 m, the surge length reached more than 100 m. Length of the leading surge peak was as large as 45 m at this water depth.

Dimensional analysis was applied to relate the surge height of the leading surge peak to discharge parameters and oceanographic conditions. Results showed that the ratio of surge height to water depth was proportional to 1/10 power of the ratio of discharge volume to the third power of water depth.

KEY WORDS: Bottom surge, surge height, surge length, acoustic imaging, dredged material discharge, open ocean

INTRODUCTION

Negatively buoyant discharged material is considered to divide into three phases: convective descent, during which the material tends to fall as a cloud under the influence of gravity; dynamic collapse, occurring when the descending cloud either impacts the bottom or arrives at the level of neutral buoyancy at which descent is retarded and horizontal spreading dominates; and long-term passive dispersion, commencing when transport and spreading are determined more by ambient currents and turbulence than any dynamic character of its own (Brandsma *et al.*, 1976; Koh and Chang, 1973). For shallow water and weak density stratification, the plume hits the bottom before the onset of the dynamic collapse phase, and surges may be generated because of its impact with the bottom. Numerical models were used to predict plume behaviour when the bottom was encountered (*e.g.*, Army Waterways Experiment Station, 1993; Johnson *et al.*, 1988). However, few results were reported on the surges it generated. Basic questions on bottom surges from dredged material discharge concern their height and horizontally advanced distance. The dynamics at the moment of impact and plume spreading speed after the impact still are not known.

Dredged material disposal is of interest and concern to port authorities, environmentalists, dredgers, environmental regulators, and others. Studies of discharged dredged material plume behaviour, movement, concentration, and impact have made progress, but there is still a lack of good understanding of many fundamental issues. In particular, bottom surge formation occurring during disposal in open water due to the impact of dredged material on the ocean bottom is not well understood due, among other things, to lack of field data. However, the importance of bottom surges in ocean waste disposal is significant. For example, the surge may act as a secondary source of particulates because of resuspension of the bottom sediment from the impact of primary material with the bottom.

High frequency acoustic concentration profilers have proved to be effective in studies of dredged material discharges in the open ocean (Tsai *et al.*, 1992; Tsai and Proni, 1985; Kraus, 1991). Their use has been demonstrated in several disposal operations of different kinds of discharge, including dredged sediments, sewage sludge, drilling mud, and chemical wastes (Tsai, 1984). Acoustic studies indicate characteristics of discharged material, such as settling and dispersion rates, and depending on the type, density, discharge volume of material discharged, and ambient water conditions. When generated, bottom surge behaviour also depends upon the properties of the discharged materials, characteristics of the ambient water, and bottom geometry.

Bottom surges from dredged material discharges in the open ocean were observed at Townsville, Australia and reported previously by Wolanski *et al.* (1992). Surge heights were as large as 4 m in calm weather with negligible current. The dredger was stationary when discharge took place. Bokuniewicz (1985) also reported acoustic observations of bottom surges from dredged material discharge at two sites in the Great Lakes: one in Lake Erie and another in Lake Ontario. When the surges passed under a stationary 200-kHz fathometer, they showed the head of the surge passing under the transducer and reaching a thickness of 5 m about 40 s after the discharge. After the head of the surge passed the body of the turbid plume, it maintained a thickness of 2–3 m for several minutes. The concentrations of particulates was as high as 16 g l^{-1} at about 1 m above the bottom near the point of impact. The distance from the impact point reached about 120 m within the first 5 minutes. Bottom surges of more than 5 m in height and 130 m in length were also reported at Huangbaizuei dumpsite, Dalian, under different conditions (Huang *et al.*, 1993).

This paper will report only the acoustic observations of bottom surges generated due to the discharge operations in three field studies of discharges at different locations. Surge height and horizontal extent were estimated and compared with other reports (*e.g.*, Huang *et al.*, 1993). A dimensional analysis was applied to relate the observed surge height to water depth, buoyancy, and ambient current. Total surge length was estimated, and a similar dimensional analysis applied.

FIELD STUDIES

The high frequency acoustic system used in field studies of dredged material disposal has been developed and modified several times in the past ten years but its basic principle of operation remains the same. The system consists of two major units: one streamlined tow-body with 20 kHz and 200 kHz transducers towed about 1 m under the water surface when in operation, and one on-board acoustic unit including a dual channel acoustic transceiver and data storage components. The acoustic transceiver provides digital control of transmitter output pulse and receiver gain characteristics to allow accurate measurement of target echo levels. A precision low noise preamplifier is incorporated within the receiver to extend the system dynamic range and to allow measurement of very low backscattering levels. The pulse length range is 0.1–5 m/s and the repetition rate range is 8 to 1/2 per second.

Acoustic data can be recorded on thermal paper and displayed in real time during the field study. Alternatively, it can also be recorded on digital audio tape (DAT) and optical disks with a PC computer. These data represent the root mean square voltage in integer format at the output of the receiver and can provide a more detailed plume structure when processed in the laboratory to extract the acoustic backscattering intensity from the data. The acoustic intensity is assumed to be proportional to the particulate concentration, and contour plots of equal intensity levels will provide the detected sediment plume field. The concentration levels in these contour plots are shown in decibels and are equivalent to backscattering strength, which is proportional to the base-10 logarithm of acoustic intensity. For most dredged material disposal the discharge is released instantaneously by opening the bottom of the hopper. The research vessel with the acoustic system on-board then proceeds immediately to make continuous transects through the material cloud back and forth and keeps its tracks perpendicular to the proceeding direction of the hopper. It takes less than a minute for the material to reach the ocean bottom in shallow water. Therefore, acoustic observations of bottom surges occur during the first transect.

A particulate transport study of dredged material discharge in the vicinity of the Calcasieu Channel near Cameron, Louisiana, took place from August 19–28, 1991, by the Environmental Research Laboratory, Narragansett (ERLN) of the U.S. Environmental Protection Agency. Two acoustic systems from the Atlantic Oceanographic and Meteorological Laboratory of the National Oceanic and Atmospheric Administration (AOML/NOAA) were used in combination with other measurement systems to determine the degree of retention of particulates in the Ocean Dredged Material Disposal Site (ODMDS) during and immediately after disposal, and to investigate transport of particulates from the disposal area (Tsai *et al.*, 1994). Two ships, the S/V *Burrwood* and the R/V *Pelican*, each equipped with an acoustic system, tracked and monitored the waste plume and made longitudinal transects parallel and perpendicular to the dumping dredger, respectively, for each discharge. Each of the two acoustic systems had 20 kHz and 200 kHz frequencies, and acoustic data were recorded on digital tape and/or optical disks for computer processing after field operations. A total of eight discharges occurred during the five-day period. Material was released from a hopper dredge instantly when the scow was opened.

A second study called the 'Dredged Material Research Program' by the U.S. Army Corps of Engineers was conducted during August 18–September 2, 1989 in the Gulf of Mexico off Mobile Bay, Alabama. The AOML acoustic system was used for this study. Various volumes of dredged material up to 5,000 cubic yards were discharged into the open ocean to collect data on sediment plume dynamics for verifying and improving numerical simulation models of short-term fate, investigating and refining sediment plume monitoring procedures, evaluating acoustic instrumentation for measuring sediment plume dynamics, and collecting field data on coastal bottom boundary layer processes (Kraus, 1991). Even though only one vessel was used for the study, the acoustic plume tracking procedure was similar to that conducted in the Calcasieu Channel. There was a total of 18 discharges in various water depths, and all discharges were released, virtually instantly. The tracking ship made longitudinal or perpendicular transects to the waste plume immediately after each discharge, and acoustic data were recorded on tapes and disks for processing in the laboratory after field operations.

Another study was undertaken to investigate the short-term fate of discharged material into the designated Miami ODMDS before dredging of the Miami River and the Miami Harbor Turning Basin began (Tsai *et al.*, 1992). The designated ODMDS was also located in relatively deep water for discharge sites with a typical bottom depth of 140 m and was also located in the western boundary region of the Gulf Stream current off Miami, Florida. The mean current can be greater than 100 cm s^{-1} in the spring and summer. Transport, dispersion, and mixing of dredged material dumped into this area are affected by physical processes associated with the Florida Current. During the days of April 24–26, 1990, sediment plumes issuing from eight placement operations of dredged material from the Miami Harbor Turning Basin area were monitored continuously with the AOML acoustic system and an acoustic Doppler current profiler (ADCP) from RD Instruments. Conductivity-temperature-depth (CTD) measurements were taken and sediment samples collected from the dredging vessel with a sediment grab sampler. Bottom surges were observed acoustically even at this great depth.

The three field studies are summarized in Table I. The acoustic system on board the R/V *Pelican* during the Calcasieu Channel study had only one frequency (200 kHz). The acoustic system in the other two studies used both 20 kHz and 200 kHz frequencies. An ADCP from RD Instruments was used in the Miami Harbor and Mobile Bay studies and provided continuous ambient current data. An S4 current profiler from Inter-Ocean Systems was used for Calcasieu Channel study, but provided no usable information.

ACOUSTIC OBSERVATIONS

Calcasieu Channel Study

During three of the eight discharges in the Calcasieu Channel, extensive bottom surges were observed acoustically. A typical surge feature recorded on an echogram is shown in Figure 1 for discharge 5. This was detected from S/V *Burwood* while making its first transect perpendicular to the course of the dumping dredger as it moved very slowly and released the dredged material instantly. Detailed scattering strength plotted from the processed 200 kHz acoustic data of the same cloud are shown in Figure 2. The contour levels are in 6 decibel increments and represent particulate concentrations in depth and time (or horizontal distance) along the ship tracks. The main plume shown in Figure 2 had reached the ocean bottom but still was descending from the sea surface. Surge generated from the impact of the main cloud with the bottom was clearly seen at the early encounter with the ship and extended a total horizontal distance from the impact point of about 100 m based on the ship track during the acoustic transect. The surge is assumed to be generated on both sides of the plume. However, by the time the ship exited the main plume, the surge had almost disappeared. These bottom surges generally were not detected during the second transect of the same plume at a later time.

TABLE I Summary of field studies.

Study	Period of Study	Acoustic System			Total Number of Discharges	Water Depth Range (m)	Other Measurements			
		Frequency (kHz)	Pulse Period (m/s)	Repetition Rate (s^{-1})			CTD	ADCP	S4	RS
Calcasieu Channel	August 22–26,1991	200	0.1	4	8	11	Yes	Yes	Yes	Yes
Mobile Bay	August 22–31, 1989	200	0.1	4	18	6–12	Yes	Yes	Yes	Yes
Miami Harbor	April 24–26, 1990	20	0.5	2	8	130–240	Yes	Yes	No	No

CTD = conductivity-temperature-depth profiler from Sea Bird Electronics; ADCP = acoustic Doppler current profiler from R&D Instruments; S4 = S4 current meter from Inter-Ocean Systems; RS = Rosette sampling by General Oceanics.

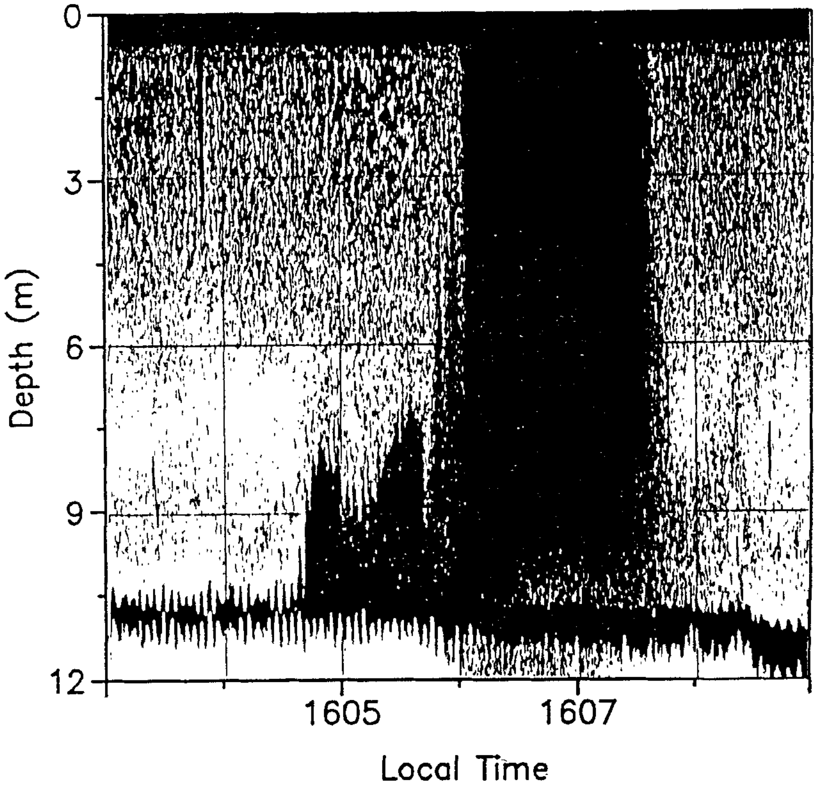

Figure 1 Echogram of discharge 5 observed by the S/V *Burwood* on August 25, 1991 at Ocean Dredged Material Disposal Site (ODMDS) in Calcasieu Channel, Gulf of Mexico.

An interesting feature of this bottom surge was the presence of two surge peaks from the same discharge plume. As seen in Figure 2, the first or early concentration peak had higher peak concentration values than the second peak. The vertical heights of both surge peaks were 2.9 m and 3.3 m, respectively.

The time between the end of the first transect and the beginning of the second transect was about 4 minutes. The surge disappeared in less than 7 minutes because it took about 3 minutes for the ship to complete the first transect. This was true only on the assumption that the surge was generated on both sides of the plume to equal extent when the material cloud impacted the ocean bottom. It is not quite clear that this was the case, but bottom surge was observed from the second ship, the R/V *Pelican*, during the longitudinal transect following the dumping dredger.

An example of a surge observation from the R/V *Pelican* for discharge 4, following a longitudinal transect to the dredger, is shown in Figure 3. Because of material leakage before and after release, material clouds of much lower concentration were detected near the main plume. However, the surge in the main plume was still clearly distinguishable from the surrounding clouds. Horizontal advancement extended more than 100 m and the leading surge length was about 25 m. Vertical heights reached 3.0 m for the first peak and 5.5 m for the second peak. The surge was observed when

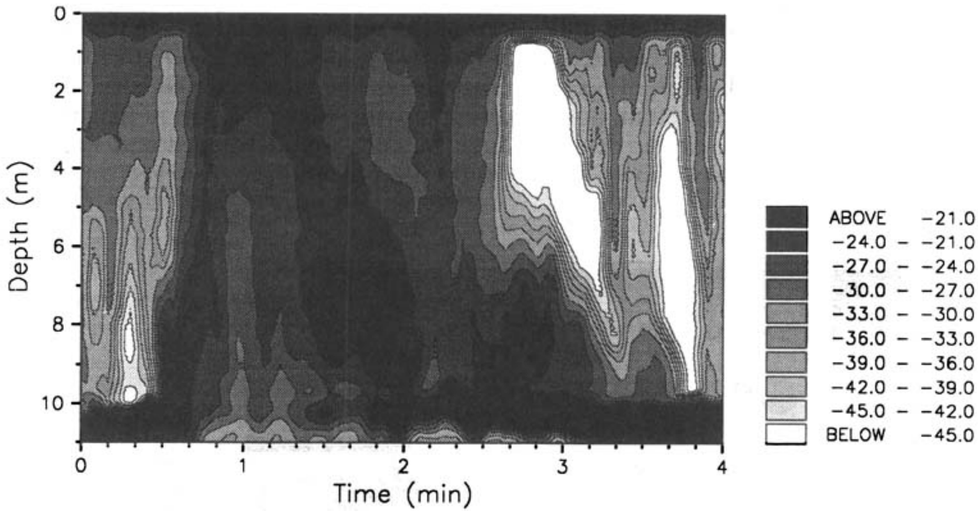

Figure 2 Contour plot of acoustic scattering strength in decibels for the same discharge in Figure 1.

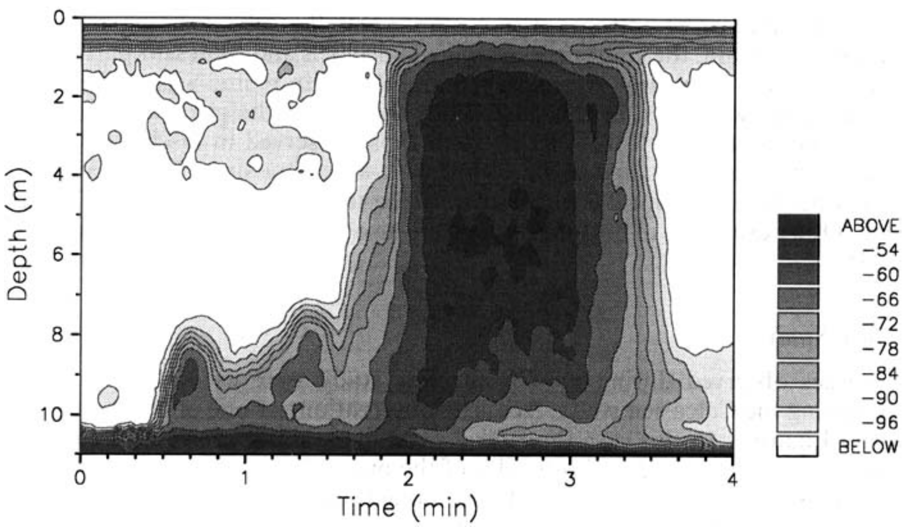

Figure 3 Contour plot of acoustic scattering strength in decibels for the same discharge in Figure 1 when observed by the R/V *Pelican*, making transects perpendicular to the S/V *Burwood*.

R/V *Pelican* was making a transect perpendicular to the transect of the S/V *Burwood*; the simultaneous observations of the same discharge plume therefore constituted strong evidence of the symmetric configuration of the plume. However, some material apparently remained suspended in the water column near the bottom for an extended period of time as observed during the later transects. At about the same location or at least at the same side of the plume, the surge was observed as a dispersed layer of suspended material. The difference in corresponding contour levels between Figures 2 and 3 was due to a level off-set of the two acoustic systems.

A second observation of bottom surges from the S/V *Burwood* is shown in Figure 4 for discharge 8. Again, the contour levels were in decibels and represent particulate concentration levels. The surge was enlarged and the main plume was at the right. Three surge peaks were seen in this case. Both the vertical height and horizontal length from the impact point were larger than those observed in discharge 5. The total surge length was estimated to be 150 m with a leading surge length of 46 m and vertical heights of about 2.9 m for two of the three peaks and 5.5 m for the third peak. Other examples of bottom surges were also observed and are summarized in Table II.

Mobile Bay Study

Bottom surges observed during the Mobile Bay study were as evident as those observed during the Calcasieu study. Acoustic observations of one of the discharges is shown in Figure 5. In this case the R/V *Pelican* made a transverse transect, and bottom surges were observed on both sides of the main plume. The surge, observed easily before the ship entered the main plume, looked smaller because it was detected about 2 minutes earlier. Entrainment of discharged material with the ambient water in the water column during the convective descent phase is clear. The strong slopes of the plume boundaries from the surface to the bottom and increased width of the plume at the ocean bottom indicate that the entrainment was substantial. Horizontal spreading was also evident from indications of the surge at the later time (right side of the plume). The earlier detected surge had two peaks: 15 m in length for both peaks and 3.4 m and 4.2 m in height, respectively. The later detected surge had a total length greater than 80 m, and a leading moving edge of 3.3 m in height and 22.5 m in length. The earlier detected surge was not well developed and was not included in Table I. Not shown in the figures are other surges observed on either

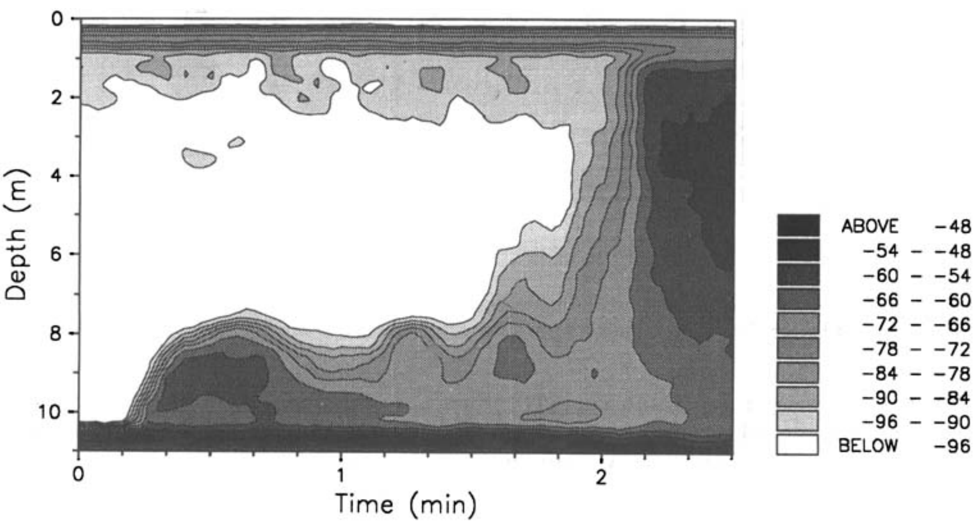

Figure 4 Contour plot of acoustic scattering strength in decibels for discharge 8 observed by the S/V *Burwood* on August 26, 1991 at the same disposal site of Figure 1. Bottom surge with three peaks is shown at the left, and a small part of the main plume is shown at the right.

TABLE II Summary of discharge parameters and characteristics of leading surge peak.

Date	Time	Ship*	Depth H(m)	Current U_a(cm/s)	Density ρ_o(g/cm^3)	Rate V_o(m^3)	Buoyancy B_o(m^4/s^2)	L_a(m)	H/L_a	V_o/H^3	Length L_s(m)	Height h_s(m)	h_s/H	L_s/H
8–24–91	182820	B	10.0	10**	1.30	3300	8893	943.0	0.011	3.300	70	2.8	0.280	7.0
8–24–91	182930	PC	10.0	10**	1.30	3300	8893	943.0	0.011	3.300	110	3.0	0.300	11.0
8–25–91	160420	B	10.2	10**	1.20	3400	5831	763.6	0.013	3.204	100	2.9	0.284	9.8
8–26–91	173400	B	10.3	10**	1.30	3400	7048	839.5	0.012	3.111	150	2.9	0.282	14.6
4–26–90	113120	S	130.0	36	1.34	523	1205	96.4	1.348	0.00024	100	40.0	0.308	0.85
4–26–90	141800	S	140.0	58	1.34	404	931	52.6	2.661	0.00015	120	70.0	0.200	0.86
8–26–89	215721	PM	12.0	13	1.33	4281	9621	754.5	0.016	2.477	85	3.5	0.292	7.1
8–27–89	221340	PM	12.5	15	1.33	3400	7731	586.2	0.021	1.761	80	3.3	0.264	6.4
8–31–89	180335	PM	9.2	–	1.34	4281	9862	–	–	5.498	68	2.9	0.315	7.4
9–13–89	132900	X	33.5	15**	1.25	500	882	108.0	0.169	0.0133	130	5.5	0.164	3.9

*B = *Burwood* in Calcasieu Channel study; PC = *Pelican* in Calcasieu Channel study; PM = *Pelican* in Mobile Bay study; S = *Sea Explorer* in Miami Harbor study, X = unknown vessel in Huangbaizuei dumpsite study.
** = estimated.

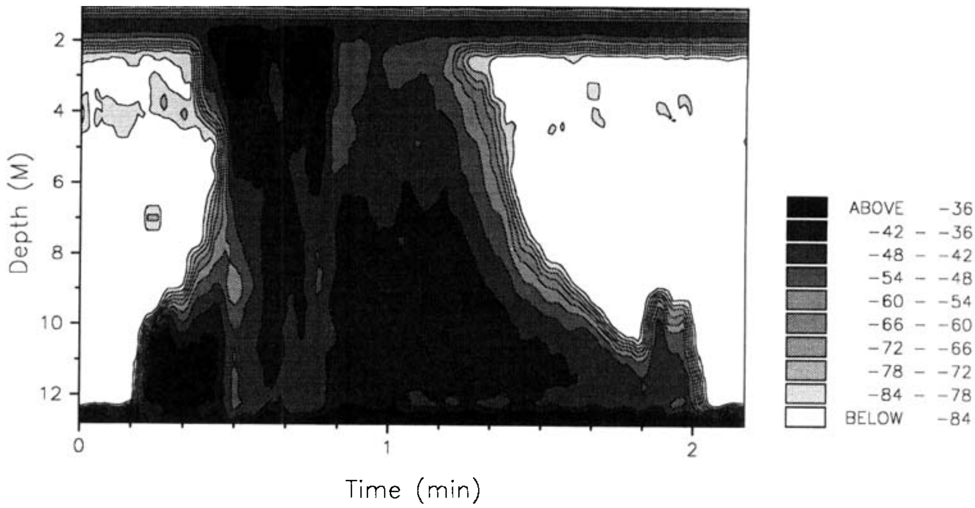

Figure 5 Contour plot of acoustic scattering strength in decibels for the discharge on August 27, 1989 at the National Beam Demonstration Project Site of Mobile Bay, Alabama.

one or both sides of the plume boundaries. However, some were detected when the vessel entered the plume, and some when the vessel moved out of the plume. The observations are also summarized in Table II.

Miami Harbor Study

Two discharges observed by the S/V *Sea Explorer* at the Miami ODMDS demonstrated that acoustic detection of bottom surges can be accomplished at relatively great depths. One of these discharges is illustrated in Figure 6. At 130 m depth, the surge was still well formed, with a height of 40 m, and indicated a strong horizontal advancement of 100 m. The plume is strongly shifted to the left, suggesting the presence of ambient currents. The averaged current was about 36 cm s^{-1} as determined from the ADCP measurements. Another observation at 140 m depth showed surge height up to 70 m and total length up to 120 m (Tsai *et al.*, 1992). The ambient current measured by an ADCP on board the S/V *Sea Explorer* indicated an averaged value of 58 cm s^{-1}. These data are also included in Table II.

ANALYSIS

In this study we use dimensional analysis (Fischer *et al.*, 1979) to relate the surge height of the leading peak and the surge length described in the previous section to discharge characteristics and environmental conditions.

Considering an instantaneous discharge of a volume of waste material from a barge, the height of the surge formed after the waste cloud impinged on the ocean bottom may be written in a functional form as follows:

$$h_s = f(H, V_o, B_o, U_a, U_*) \quad (1)$$

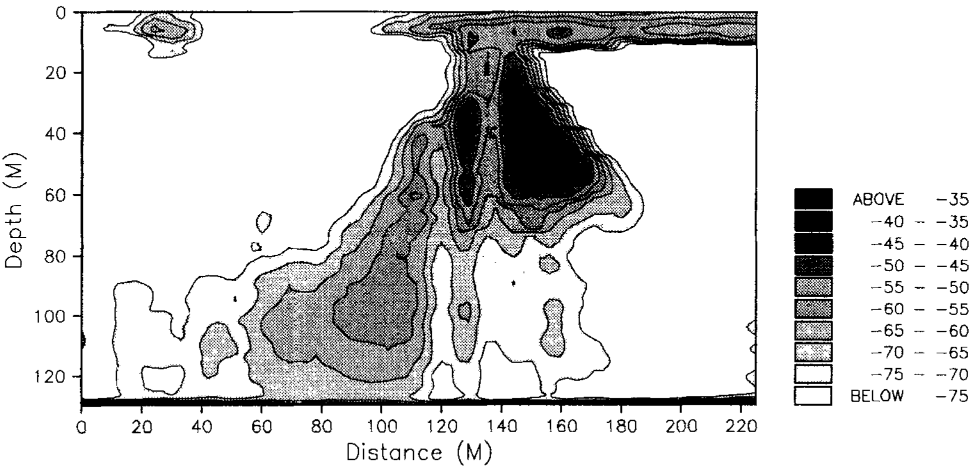

Figure 6 Contour plot of acoustic scattering strength in decibels for the discharge on April 26, 1991 at the Ocean Dredged Material Disposal Site off Miami, Florida.

where h_s is the surge height; H is the discharge depth, which should be measured from the bottom of the barge to the ocean bottom; V_o is the volume of the discharge; B_o is the buoyancy of the discharge ($B_o = V_o g_o'$, where $g_o' = (\rho_o - \rho_a)/\rho_a \cdot g$ is the reduced gravitational acceleration, ρ_o is the density of the discharge, ρ_a is the density of the ambient sea water), U_a is the ambient current speed; U_* is the bulk friction velocity which may characterize the drag forces on the surge. A flat bottom is assumed.

Equation 1 can be rewritten in a non-dimensional form:

$$\frac{h_s}{H} = f\left(\frac{V_o}{H^3}, \frac{H}{L_a}, \frac{H}{L_*}\right) \qquad (2)$$

where $L_a = B_o^{1/2}/U_a$ and $L_* = B_o^{1/2}/U_*$ are characteristic length scales. For $H/L_a \ll 1$, ocean current has no significant effects on the behaviour of the descending cloud and the surge. This is similar to the case of stagnant water. On the other hand, for $H/L_a \gg 1$, the descending cloud as well as the bottom surge will be strongly affected by the ambient current. Some of the H/L_a values for the field tests are listed in Table II. It is seen that for the Miami Harbor study, H/L_a is 1.348 and 2.661, and thus greater than 1. Therefore, currents are expected to have an influence on the descending cloud and the bottom surge. This can be seen from acoustic records (Figure 6) that indicate the cloud and surge are asymmetric and may be caused by the ambient current. For the remaining tests, however, H/L_a was about 0.02, or two orders of magnitude smaller than the Miami Harbor study case. For these cases the behaviour of the descending cloud and bottom surge is expected to be similar to that in stagnant water, and H/L_a term can be dropped from Eq. 2.

The value of H/L_* is not available because the friction velocity, U_*, is unknown. In fact, U_* is expected to reflect the effects of all resistant forces on the bottom surge. Based on turbulent boundary theory, U_* may be related to the advance speed (U_{surge}) of the bottom surge as:

$$U_* = U_{surge}\sqrt{c_d/2} = \sqrt{\tau/\rho},$$

where c_d is the drag coefficient, τ is the bottom shear stress, and ρ is the fluid density. Typical c_d values are in an order of 10^{-3}. Therefore, U_* is typically at least one order less than U_{surge}. An average value of U_{surge} is estimated as 0.46 m/s from the field data of Bokuniewicz *et al.* (1978) and 0.20 m/s from Johnson *et al.* (1988). If it is assumed this value applies to our cases, then U_* should be an order of 0.05 m/s. Thus, we also have $H/L_* \ll 1$. In such a situation, the term H/L_* can also be dropped from Eq. 2. Equation 2 then simplifies to:

$$\frac{h_s}{H} = f\left(\frac{V_o}{H^3}\right) \tag{3}$$

The data for h_s/H and V_o/H^3 from the field tests are shown in Table II and the lower half of Figure 7. It is seen from Figure 7 that a correlation between h_s/H and V_o/H^3 is suggested. The data may be regressed using a power law of the form:

$$\frac{h_s}{H} = a\left(\frac{V_o}{H^3}\right)^b \tag{4}$$

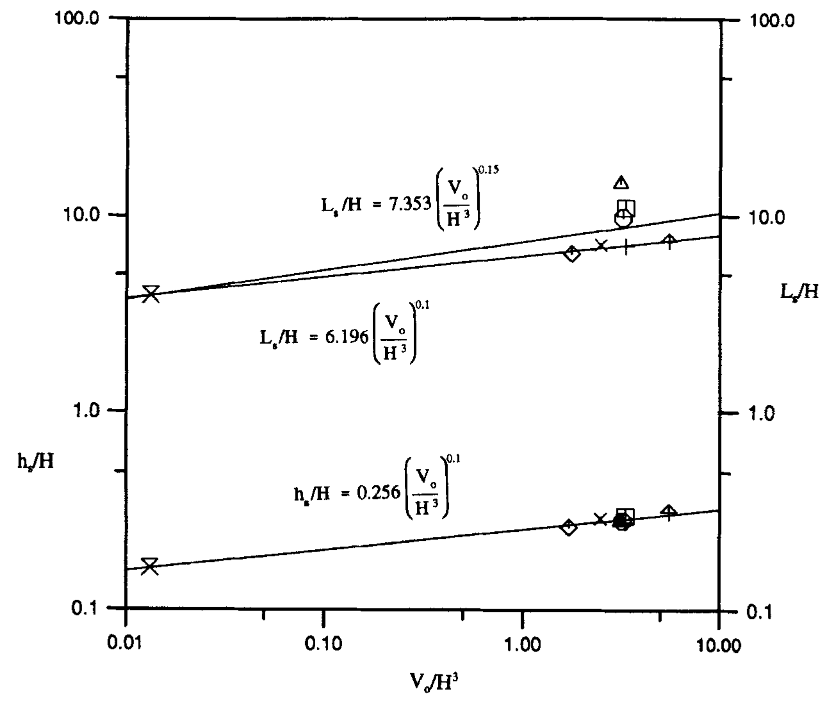

Figure 7 Bottom surge heights of leading peaks (lower curve) and surge lengths (upper two curves) from eight different dredged material discharges vs. the ratio of discharge volume and cube of water depth. Data were taken from Table II. Each symbol (see text) represents both surge height and length for a particular discharge. The two upper curves for surge length represent one regression for all data from eight discharges and the other for only data from five discharges.

where a and b are experimental constants. The values a = 0.256 and b = 1/10 were deduced from the data in Table II and are shown in Figure 7.

Horizontal distance advanced by the surge from the impact point of the discharged material with the bottom is a more complicated matter than the vertical height. First, acoustic detection of the plume is not an instant snapshot of the cloud, but a continuous process as the vessel makes transects. The time lag at the detection of both plume boundaries was at least 2 to 3 minutes. If a surge was not well developed when the vessel was crossing it, the length would have been underestimated. Secondly, the impact point was difficult to determine, resulting in uncertainties in the determination of surge length. The surge lengths or widths, L_s, defined as the horizontal distance from the impact point to the outmost boundary, are listed in Table II and also plotted in Figure 7. It can be seen that the L_s/H values for the Miami Harbor study in Table II were one order smaller than the rest of the data; these values were not plotted in Figure 7.

By the same dimensional analysis for surge height, we can derive the same power law of Eq. (4) for surge length as follows:

$$\frac{L_s}{H} = c\left(\frac{V_o}{H^3}\right)^d \tag{5}$$

Using all data in Table II, we found c = 7.353 and d = 0.15 as shown in Figure 7 The power dependence of V_o/H^3 is 0.15 for the surge length instead of 0.1 for surge height. However, when the three highest values of L_s/H are excluded, both surge length and surge height have the same power dependence of V_o/H^3. One of the three exceptional values was from observations by the R/V *Pelican* when it made longitudinal transects of the plume after the dredger discharged the material while moving slowly. This was the only data available when the surge was detected. The other L_s/H value that did not follow a 1/10 power law dependence of V_o/H^3 was from the Calcasieu Channel study where two and three peaks in one surge were observed. Both lines of L_s/H were plotted in Figure 7, one for all eight available data sets that followed 0.15 power law and the other for the five data sets that followed the 1/10 power law.

Dimensional analysis indicates that the waste clouds with bottom surges will have a total width of $2L_s$ at the bottom for stagnant water. When a current exists, the surge length will be smaller than observed values, and the total actual cloud width will be between L_s and $2L_s$. For instance, total cloud width for the Mobile Bay study would be about twice the surge length L_s, or 150 m, because the current was relatively small. Total cloud width for the Miami Harbor study would be only slightly larger than the surge length, or about a little larger than 120 m, because the current was relatively large.

SUMMARY

Acoustic study of dredged material discharge provides an understanding of plume transport, mixing, dispersion, and also measurements of surge height and length when material hits the bottom. For water depths of 9.2 m to 12.5 m, the observed vertical height of the leading surge peak was about 2.8 m to 3.5 m. These values fall within the range of surge height reported by Wolanski *et al.* (1992). For water

depths of 130 to 140 m, the observed surge height of the leading peak was 40 m to 70 m. Surge height was established upon impact of material on the bottom and remained relatively constant as it advanced horizontally.

Surge length, measured from the plume centre or impact point at the bottom, reached 150 m (Figure 4) for water depths of 10 m. The length of the leading surge peak was as large as 45 m when there was more than one peak in the surge. For water depths of more than 100 m, surge length reached 120 m. These observations agree with the report by Bokuniewicz (1985).

Dimensional analysis indicates that the ratio of surge height to water depth was proportional to 1/10 power of the ratio of discharge volume to the third power of water depth for negligible ambient current. Surge lengths followed the same dependence on discharge volume and water depth in some, but not all cases.

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