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Nearsurface Suspended Sediments at Monte Hermoso Beach, Argentina: II. Statistical Analysis[1]

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ABSTRACT

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The relation between nearsurface suspended sediment concentration (SSC), the climatological conditions, and the different zones of sample extraction at Monte Hermoso beach (Argentina) was studied statistically using analysis of variance (ANOVA). Multiple comparisons were tested by the Scheffé (S) method. Wind is a major factor in the distribution of SSC. In particular, interaction from survey C1 shows that offshore and inshore zones behave differently while the wind blew from the continent. The meteorological conditions determines the presence of an additive component of the variance between surveys.

ADDITIONAL INDEX WORDS: *Suspended sediments, statistical analysis, analysis of variance (ANOVA), Argentine coast.*

INTRODUCTION

In coastal environments the dynamic is dominated by the action of waves, tides, winds and the currents generated by them. Different energetic conditions produce the erosion, suspension, transport and deposition of sediments. In particular, in the high-energy nearshore zone suspended load transport is important. The turbulent movement generated in the fluid is the principal factor to maintain the sediment in suspension.

On the other hand, the analysis of variance (ANOVA) is a useful statistical tool to determinate actual differences among populations which, sometimes, are difficult to find from the original data. If previous knwoledge of the conditions is available, differences might be detected by *a priori* tests such as orthogonal comparisons. Otherwise only *a posteriori* tests must be employed to study the data.

Although multiple comparison tests have been used for more than 50 years in several areas (FISHER, 1935; NEWMAN, 1939; TUCKEY, 1951; SCHEFFE, 1953; DUNCAN, 1955), they only have recently been applied in geological studies of marine environments (*i.e.*, WELLS and LUDWICK, 1974). WELLS and LUDWICK (1974) made an analysis of the behavior of three well known multiple comparison methods: sum of squares simultaneous test procedure (SS-STP; GABRIEL, 1964); range simultaneous test procedure (Range-STP) or Tukey test (TUKEY, 1951); and the Student-Newnan-Keuls (SNK) procedure (NEWMAN, 1939). From their comparisons, they selected the SS-STP method because it produced less complex groupings. KOCH and LINK (1970) gave the same argument when they preferred Range-STP over the Scheffé or S-method (STEEL and TORRIE, 1981).

In the present study the S-method was employed for several reasons. The S-method is a very conservative test in the sense that have a large critical value for any contrast. So it is very difficult to find any differences between populations. Therefore, the detected differences might be accepted with reasonably good confidence. On the other hand, the method is very general in that all possible contrasts can be tested for significance. This is a relevant advantage over other methods (Tuckey, SNK, Duncan), which are only applicable to pairwise comparisons of means.

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The ANOVA and S-method have been applied to nearsurface fine (silt + clay) suspended sediment concentrations (SSC) obtained in the coastal area of Monte Hermoso beach (Argentina). In previous studies (CUADRADO and PERILLO, 1989; PERILLO and CUADRADO, 1990) differences in the SSC normal to the shore have been determined. Based on these studies, two major zones were defined: offshore and inshore (the latter includes the breaker and surf zones). The offshore zone normally has the lowest SSC, increasing during storm or large swell conditions. Sediment concentration increases toward the shore, being larger at the breaker zone. The purpose of this paper is to analyze statistically the SSC in relation to the different surveys, zones, and wind conditions.

DATA ANALYSIS

Detailed field and laboratory methods have been described elsewhere (CUADRADO and PERILLO, 1989; PERILLO and CUADRADO, 1990). However, a brief summary of data gathering is presented here. Five field surveys (C1 thru C5) were made from October 1983 to December 1984 at Monte Hermoso fishing pier (about 300 m long) (Figure 1). Water samples were taken from six positions every hour on the hour for about 10 hs in each survey with a weighted plastic bucket. The samples were stored in 1 1 (in 5 1 every three hours) clean, screw-capped plastic bottles. Laboratory procedures included calculation of sand and fine (silt plus clay) concentrations by vacuum filtering, and grain size and mineralogical determinations.

Only those samples of the first four surveys (C1 thru C4) gathered within 2 hs before and after high tide (−2, −1, HT, +1, +2) are utilized for the statistical analysis. This selection was based on the fact that beyond this tidal condition less than 3 samples were taken from each zone (offshore and inshore). Three was estimated as the minimum number of replicates for each hour and zone to give statistically significant results. Therefore, an ANOVA triple with 3 replicates was employed. The factors are: hours (5 levels), zones (2 levels), and surveys (4 levels). The latter is taken as a block since it is considered as a random factor. The experimental unit is the concentration of fine suspended sediments in mg/1.

The original data had to be transformed by the function square root due to the inhomogeneity of variances observed after applying the test of Bartlett (STEEL and TORRIE, 1981). Even after the transformation, the inhomoge-

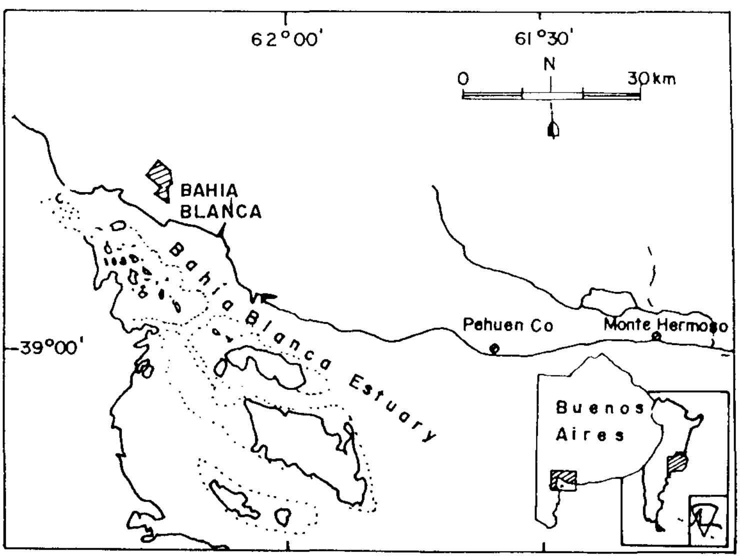

Figure 1. Location of the study area.

Table 1. *Analysis of variance triple for the transformed data by the function root square.*

Source of variation	SS	df	MS	F
A– hours	8.02	4	2.01	0.87 (ns)
B– zones	22.11	1	22.11	6.47 (ns)
C– surveys	167.49	3	54.50	102.08 **
A×B	1.28	4	0.32	3.02 (ns)
A×C	27.65	12	2.30	4.32**
B×C	10.25	3	3.42	6.40 **
A×B×C	11.64	12	0.96	1.82 (ns)
Within	42.71	80	0.53	

SS = Sum of squares, df = degree of freedom, MS = Mean Square and F = F-distribution percentage points. * = significant. ** = highly significant. ns = not significant.

$F_{0.95}(1,3) = 10.13$ $F_{0.99}(1,3) = 34.12$
$F_{0.95}(3,80) = 2.76$ $F_{0.99}(3,80) = 4.13$
$F_{0.95}(4,12) = 3.26$ $F_{0.99}(4,12) = 5.41$
$F_{0.95}(12,80) = 1.92$ $F_{0.99}(12,80) = 2.50$

neity of the variances is still present, but the F value for surveys is large (Table 1). It is important to take into account that, under heteroscedasticity, the true value of significance is usually greater than the apparent level. But even under homoscedasticity such high F value will also be rejected. Then, the ANOVA results presented in Table 1 indicate that there is a highly significant difference among the four surveys.

To confirm this result, the original data were analyzed by an ANOVA double with 3 replicates for each survey. The factors were hours and zones. The results are presented in Tables 2 through 5. In this case, the test of Bartlett showed that the populations are homoscedastic.

Only in survey C1 (Table 2) the ANOVA detected an interaction between both factors. Therefore, a series of comparisons was made to localize the actual differences. For the comparisons the S-method was utilized, thus we worked only with a global error.

Table 2. *Analysis of variance for C1. (Abbrevations as in Table 1).*

Source of Variation	SS	df	MS	F
Hours	1877.04	4	469.26	8.86 **
Zones	660.82	1	660.82	12.48 **
Error	1489.95	4	372.49	7.04 **
Within	1058.88	20	52.44	
Total	5086.699	29		

$F_{0.95}(4,20) = 2.87$ $F_{0.99}(4,20) = 4.43$
$F_{0.95}(1,20) = 4.35$ $F_{0.99}(1,20) = 8.1$

Table 3. *Analysis of variance for C2. (Abbreviations as in Table 1).*

Source of Variation	SS	df	MS	F
Hours	224.43	4	56.108	1.64 (ns)
Zones	4.64	1	4.64	0.13 (ns)
Error	28.49	4	7.12	0.20 (ns)
Within	682.21	20	34.11	
Total	939.77	29		

The contrasts for the factor hours are:

L1: average SSC for −2 and +2 against the other hours.
L2: same as L1 for −1 against HT.
L3: same as L1 for −1 against +1.

The interaction contrasts are:

L4: average of the difference in SSC between the offshore and inshore zones for −2 against the same difference for the other hours.
L5: same as L4 for +2 against the average of the same difference for HT, +1 and −1.

The contrasts for the offshore zone are:

L6: the average SSC of −2, −1, HT and +1 against the values for +2.
L7: same as L6 for HT, −1 and +1 against the values for −2.

Finally, the contrast for the inshore zone include:

Table 4. *Analysis of variance for C3. (Abbreviations as in Table 1).*

Source of Variation	SS	df	MS	F
Hours	4684.08	4	1171.02	3.12 *
Zones	5625.22	1	5625.22	14.99 **
Error	2006.64	4	501.66	1.34 (ns)
Within	7505.39	20	375.27	
Total	19821.34	29		

Table 5. *Analysis of variance for C4. (Abbreviations as in Table 1).*

Source of Variation	SS	df	MS	F
Hours	3231.92	4	807.98	5.57 **
Zones	3178.58	1	3178.58	21.91 **
Error	1273.42	4	318.35	2.19 (ns)
Within	2901.01	20	145.05	
Total	10584.94	29		

Table 6. *Scheffé Contrasts. L is the contrast value, ci the coefficient of the contrast i, ni the number of elements in the sample, MS Li the Mean Square of contrast Li, and MSw the Mean Square within.*

Li	L	ci /ni	MS Li	F = MS Li / MSw
L1	12.59	5/36	1142.16	21.57 **
L2	− 1.13	1/4	5.13	0.09 (ns)
L3	− 2.94	1/3	25.84	0.49 (ns)
L4	35.09	10/12	1477.82	27.91 **
L5	6.90	8/9	53.56	1.01 (ns)
L6	−20.16	5/12	967.93	18.28 **
L7	−13.46	4/9	407.84	7.70 (ns)
L8	23.35	4/9	1227.10	23.18 **
L9	−23.20	4/9	1221.39	22.88 **

L8: the average SSC for HT, −1 and +1 against the values for −2.
L9: same as L8 for HT, −1 and +1 against the values for +2.

All contrasts were compared at 5% (*) and 1% (**) level of significance (table 6).

RESULTS AND DISCUSSION

The climatologic conditions are an important factor for the suspension of sediments in coastal areas (KOS'YAN and PAKHOMOV, 1979). Under storm conditions the concentration of suspended sediments is likely to increase in response to greater wave energy. The analyzed surveys were made in different wave and wind conditions, which are considered as randomly picked. A highly significant difference among them is shown from the large F value obtained from the ANOVA triple.

PERILLO and CUADRADO (1990) suggest that the fine SSC in Monte Hermoso beach is not a product of resuspension of bottom sediments, but the influx of Bahia Blanca Estuary waters. Therefore, in the present case the action of wave-generated turbulence (higher in storm conditions) keeps the small particles suspended for a longer time in the water column. A situation which is reflected in higher values of SSC.

The average SSC for each of the 5 hours at the two zones are presented in Figure 2. The marked distinction detected by the comparison of the four graphics, indicates the differences that exist among the surveys, which was also shown by the respective ANOVA (Table 1). The curves for C3 and C4 (Figure 2c and 2d) are not parallel although there is a lack of interaction between the two factors. This situation indicates the noisy characteristics of the data.

On the other hand, PERILLO and CUADRODO (1990) have shown that SSC behave differently in the inshore and offshore zones at Monte Hermoso beach. The difference is expressed numerically by a large F value for the factor "zones" in the ANOVA double (Tables 2, 4 and 5). The survey C2 is a special case since there are no differences between both factors (Table 3). This result was generated by the small range of SSC obtained during the survey (50 to 60 mg/1).

A significant interaction in the ANOVA double was observed only for C1. The two factors (hours and zones) have a certain level of dependence which may be explained by the change in the width of the zone of sediments (ZOS; see PERILLO and CUADRADO, 1990) associated to wind conditions. In C1, a rotation of the wind direction from north to south-southeast (due to a sea breeze phenomenon) was registered one hour before high tide, and returned to the original direction one hour after high tide. Within the period of three hours, the width of the ZOS reduced from more than 500 m to about 80 m.

The contrasts made for the factor hours (L1, L2 and L3) indicate the existence of a highly significant difference between the concentrations observed when the wind blew from the north (−2 and +2) and those associated to the SSE wind (−1, HT and +1) (Table 6). The interaction contrasts (L4 and L5) show a different behavior for both zones only for −2 as compared to the rest of the sampling period.

As both factors (hours and zones) are not independent, each zone was studied separately by means of an ANOVA simple (Table 7). The Mean Square within (MS_w) value of the ANOVA double (52.94) was employed to calculate the F values because it is the best estimator of the variance. In each zone differences in concentrations are highly significant at each sampling hour. To clearly define those differences, a series of *post facto* contrasts were made for the offshore (L6 and L7) and inshore (L8 and L9) zones. A highly significant increase was registered for the offshore zone at +2 when the wind returned to the north direction (L6). For the rest of the period, there are no differences for that zone (L7). For the inshore zone, the behavior for the periods with north and south-southeast winds are also distinct (L8, L9). But during

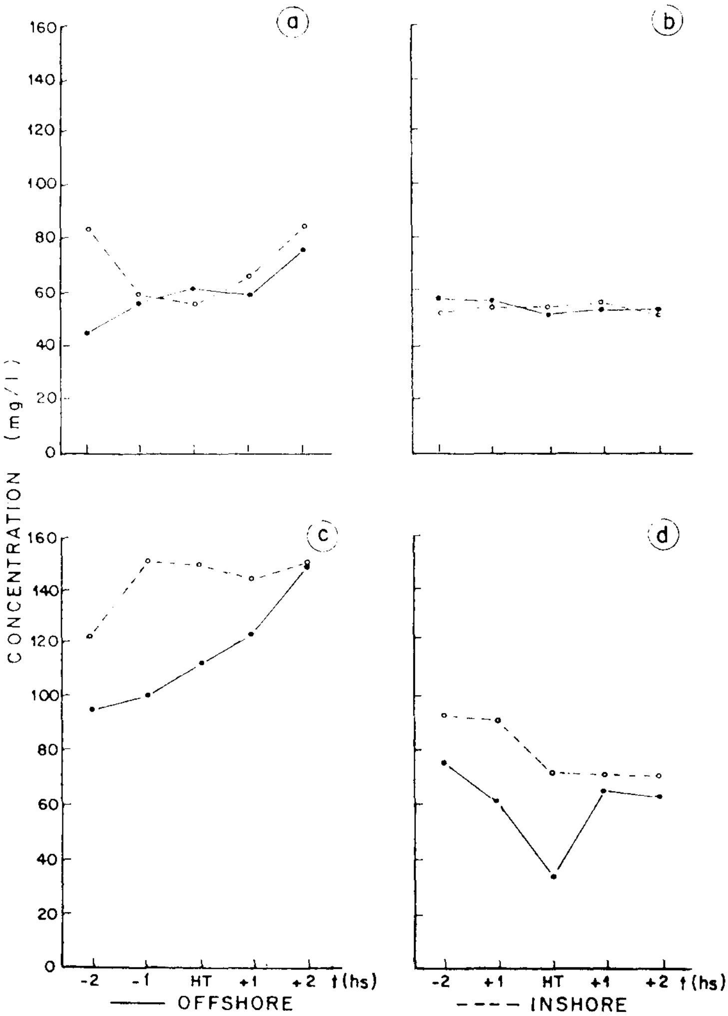

Figure 2. Suspended sediment concentration for the offshore and inshore zones during: (a) survey C1, (b) survey C2, (c) survey C3, (d) survey C4.

Table 7. *Analysis of variance simple for the offshore and inshore zones separately. (Abbreviations as in Table 1).*

	SSamong	df	MS	F
offshore zone	1398.36	4	349.59	6.60 (**)
inshore zone	2466.27	4	619.77	11.71 (**)

Table 8. *Analysis of variance simple for the offshore and inshore zones separately only for the −1, HT, +1 hs.*

	SSamong	df	MS	F
offshore zone	50.85	2	25.43	0.48 (ns)
inshore zone	57.45	2	28.72	0.54 (ns)

the three hours with south-southeast wind both zones had similar conditions with no significant variations (Table 8).

The mentioned analysis and inspection of the original data show a marked reduction in the SSC in the inshore zone when the wind blew from the SSE. This was produced by a landward transport of "clear" offshore surface water by the wind, a phenomenon also described by COOK and GORSLINE (1972). As the wind returned to the north, the upwelling process associated to a practically null wave activity described by PERILLO and CUADRADO (1990) produced an increase in the SSC in both zones simultaneously.

CONCLUSIONS

The meteorological conditions determine the amount of suspended sediments in the different surveys. Specially the wind is an important factor which is related to the advection mechanisms, that is, the movement of a water mass containing previously suspended sediments.

Although the results from the ANOVA triple suffer from inhomogeneity of variances, the value obtained for the random factor "surveys" is so large that it can be considered as valid. There is an additive component of variance due to the different meteorological conditions found in each survey. They differ with an error less than 1%. The results obtained from the ANOVA double for each survey confirm those observed by the ANOVA triple.

Interactions were found only for C1 also with an error less than 1%, meaning that the inshore and offshore zones behaved diversely. During the sampling period a reduction of the SSC in the inshore as due to the influx of "clear" offshore water. The surficial landward flux was generated by wind drag. When the wind direction was from the south-southeast, both zones behaved similarly. As the wind shifted blowing again from the continent (north direction) the SSC increases in both zones, so the regions behaved the same within one hour. After the initial upwelling, typical inshore SSC were also found in the offshore zone, indicating a seaward flux of surficial water. The error involved in the determination of the variation of SSC for C1 was less than 5%. By means of the S-method we worked with a small global error, involving more than two comparisons.

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□ RESUMEN □

La relación entre la concentración de los sedimentos en suspensión cerca de la costa, las condiciones climáticas, y las distintas zonas de extracción de las muestras de agua en Monte Hermoso (Argentina) fue estudiada estadísticamente empleando análisis de la varianza (ANOVA). Varias comparaciones fueron realizadas con el método de Scheffé (S). Se determinó que el viento es el factor principal de la distribución de los sedimentos en suspensión. En particular, la interacción detectada durante la campaña C1 muestra que las zonas de costa afuera y cercana a la costa se comportan de manera distinta con vientos soplando del norte. Las condiciones meteorológicas determinan la presencia de una componente aditiva de la varianza entre las distintas campañas.

□ RÉSUMÉ □

Le rapport entre la concentration de sédiment en suspension (SSC) prés de la côte, le cadre climatique et les endroits de échantillonage ce sont etudié par la méthode statistique de variance pour les eaux côtiéres de Monte Hermoso (Argentine). D'ailleurs on a fait plusieurs comparaisons des donneés par la Méthode de Scheffé (S). C'est le vent le principal facteur qu'intervient sur la distribution de SSC. Les conclusions obtenues lors de la campagne C1 montrent different resultats de SSC au large par raport a la ĉote quant on est en face du vents d'origine continentale. Les conditions climatiques regnants pendant l'échantillonge introduisent une compossant additionnel a la variance.

□ ZUSAMMENFASSUNG □
Die Beziehungen zwischen der Konzentration oberflächennah suspendierter Sedimente, klimatischen Bedingungen und unterschiedlichen Entnahmestellen am Monte Hermoso Strand in Argentinien wurden mit Methoden der Varianzanalyse untersucht und anhand der Scheffé-Methode getestet. Die Konzentration der suspendierten Sedimente wird hauptsächlich durch den Wind beeinflußt. Spezielle Untersuchungen zeigen, daß sich uferferne und ufernahe Zonen bei ablandigem Wind unterschiedlich verhalten. Die meteorologischen Randbedingungen sind eine zusätzliche Einflußgröße für die Varianzbreite der Untersuchungsergebnisse.—*Reinhard Dieckmann, WSA Bremerhaven, FRG.*