There are also of course isothermal boundary conditions on T at $z = -\delta_w$ in the water, and at $z = +\delta_{air}$ in the air, and an "isodensity" (constant relative humidity) condition on ϱ at $z = +\delta_{air}$.

The static solution for $\overset{(0)}{T}$, $\overset{(0)}{\varrho}$ of this problem is quite straight-forward, as given in Osborne [1964]. When it comes to taking into account the velocity terms in the diffusion type equations (equivalently, solving for $\overset{(1)}{T}$ and $\overset{(1)}{\varrho}$, after $\overset{(0)}{T}$ and $\overset{(0)}{\varrho}$ have been determined), the complications multiply rapidly. One would have to make sure that the air and water velocities inserted into these three diffusion equations are themselves compatible with their boundary conditions and diffusion equations, the hydrodynamical equations of the boundary layers, including viscosity. What choice to make here is not entirely clear, but there are at least two possibilities. 1, Choose velocities from a wave type solution (W. J. Harrison [1908]), or 2, choose velocities from a "stationary state" boundary layer solution (R. C. Lock [1951]). How much difference this choice would make, and the fact that momentum, thermal and vapor density boundary layer thicknesses are not exactly the same, we do not know. In any event, we suspect that the temperature perturbations which come out will be proportional to either the static drop or gradient through the water boundary layer primarily, since this part of the "air-water system" has by far the largest thermal capacity. This is admittedly only a guess. The temperature drop through the air layer can be much larger than the drop through the water layer, and there may well be a range of significant frequencies where this air temperature drop or the humidity drop, is the controlling magnitude. Only a detailed calculation could clarify these points. Another unexplored aspect is the failure of the continuous motion condition, when evaporation is taken into account. We suspect this effect would be appreciable only for very thin boundary layers and large evaporation rates.

References

Ballard, S. S. (Ed.), 1959: A collection of papers on infrared measurements. Proc. Inst. Rad. Eng.

Ewing, G., 1950: Slicks, surface films and internal waves. J. Mar. Res. **9**, 61.

Harrison, W. J., 1908: The influence of viscosity on the oscillation of superposed fluids. Proc. London Math. Soc. (2), **6**, 396.

LaFond, E. C., 1962: Internal waves. In: M. N. Hill (Ed.), The Sea. **1**, 731. New York.

Lamb, H., 1932: Hydrodynamics. 6th ed. Cambridge.

Lock, R. C., 1951: The velocity distribution in the boundary layer between parallel streams. Quart. J. Mech. and Appl. Math. **4**, 42.

McAlister, E. D., 1964: Infrared optical techniques applied to oceanography. 1. Measurement of total heat flow from the sea surface. 1st U. S. Navy Sympos. on Mil. Oceanogr., 17/19 June 1964. 219. U. S. Naval Oceanogr. Off., Wash.

Osborne, M. F. M., 1964: The interpretation of infrared radiation from the sea in terms of its boundary layer. Dt. Hydrogr. Z. **17**, 115.

Roll, H. U., 1952: Temperaturmessungen nahe der Wasseroberfläche. Dt. Hydrogr. Z. **5**, 141.

Sanderson, J. A., et al., 1963: Infrared target and background radiometric measurements. Concepts Units and Techniques, by Working Group on Infrared Background. Infrared Physics. **3**, 139.

Eingegangen im Februar 1965

UDC 551.466.2

Waves at Ocean Weather Ship Station "Juliett" (52°30′N, 20°00′W)

By L. Draper and M. A. B. Whitaker

Summary. Waves have been recorded in the North Atlantic by means of a Shipborne Wave Recorder on an Ocean Weather Ship. The recordings started in 1952, and although the ship divides its time between four stations, sufficient records are now available from each month at "Juliett" to allow a year's analysis to be made. The results of this analysis are divided into the four seasons, and give separately the characteristics of wave height, period and spectral-width parameter; the joint occurrence of height and period is also given.

Seegang bei der Station des Ozeanwetterschiffes „Juliett" (52°30′N, 20°00′W) (Zusammenfassung). Im Atlantischen Ozean wurde an Bord eines Wetterschiffes der Seegang registriert. Die Registrierung wurde im Jahre 1952 begonnen, und obwohl das Schiff die Beobachtungen an vier verschiedenen Stationen nacheinander durchführen mußte, stehen für jeden Monat genügend Aufzeichnungen von W. S. „Juliett" zur Verfügung, um eine Jahresanalyse der Beobachtungen vornehmen zu können. Die Ergebnisse der Analyse werden auf die vier Jahreszeiten verteilt und geben für jede die charakteristischen Eigenschaften von Wellenhöhe, Periode und Parameter der Breite des Wellenspektrums sowie die Beziehung zwischen Wellenhöhe und Wellenperiode an. Die Ergebnisse zeigen die Diagramme im Text.

Vagues de vent auprès de la navire station du navire météorologique «Juliett» (52°30′N, 20°00′W) (Résumé). A bord d'un navire météorologique dans l'Atlantique du Nord on a enregistré les mouvements de la mer agitée. On a commencé à enregistrer ces observations en 1952, et bien que le navire enregistrait successivement ces observations à quatre stations différentes on a pu recueillir pour chaque mois un assez grande nombre d'observations à bord du navire météorologique «Juliett» pour en faire l'analyse d'une année entière d'observation. Les résultats de cette analyse sont divisés par les quatre saisons; ils montrent les caractéristiques individuelles de la hauteur des vagues, de la période et du paramètre de la largeur du spectre ainsi que la relation entre la hauteur et la période des vagues. Les résultats en sont représentés sur les diagrammes dans le texte.

Waves have been recorded by Ocean Weather Ship "Weather Explorer" and then by her replacement, "Weather Reporter", on stations A, I, J, and K in the North Atlantic since 1952. The instrument used is the Shipborne Wave Recorder (M. J. Tucker [1956]). The ship is on station for about two thirds of the year and her time is fairly well distributed over the four stations. The National Institute of Oceanography now has an adequate number of records from every month in the year at station "Juliett" to allow an analysis to be made. In all, 1440 records have been used; for each month they were selected at random from the ones which were available. All records were of 12 minutes' duration taken at 3-hourly intervals. Only the records which were taken when the speed of the vessel was two knots or less have been used in the analysis because at higher speeds the apparent wave period is distorted. The method of analysis which has been used is that described by M. J. Tucker [1961]. This gives for each record:

a. H_1 The sum of the distances of the highest crest and the lowest trough from the mean water level,

b. T_z The mean zero crossing period,

c. T_c The mean crest period.

From these measured parameters the following parameters have been calculated, after allowing for instrumental response:

d. H_s The significant wave height (mean height of the highest one-third of the waves): this is derived from H_1 by using the relationship $H_1 = f \cdot H_s$ where f is a factor related to the number of zero crossings in the record (M. J. Tucker [1963]). The numerical value of f for a record containing 100 waves is $1 \cdot 60$ and for 50 waves $f = 1 \cdot 49$. These values of f are theoretical ones for a narrow band spectrum (D. E. Cartwright and M. S. Longuet-Higgins [1956]) and have been shown to be substantially correct for typical wide-band spectra of sea waves (Tucker [1963]).

e. $H_{max\,(3\,hours)}$ The most probable height of the highest wave which occurred in the recording interval (L. Draper [1963]).

f. ε The spectral width parameter which is calculated from T_z and T_c (Tucker [1961]). $\varepsilon^2 = 1 - (T_c/T_z)^2$.

The results of these measurements and calculations are expressed graphically and are divided into seasons:

Winter – January to March
Spring – April to June
Summer – July to September
Autumn – October to December.

Because of the uneven distribution of the records throughout the individual months it was found convenient to take a "month" to start on the 23rd of the preceding calendar month, e.g., Winter is based on records from December 23rd to March 22nd. This does not affect any conclusions drawn from the analysis.

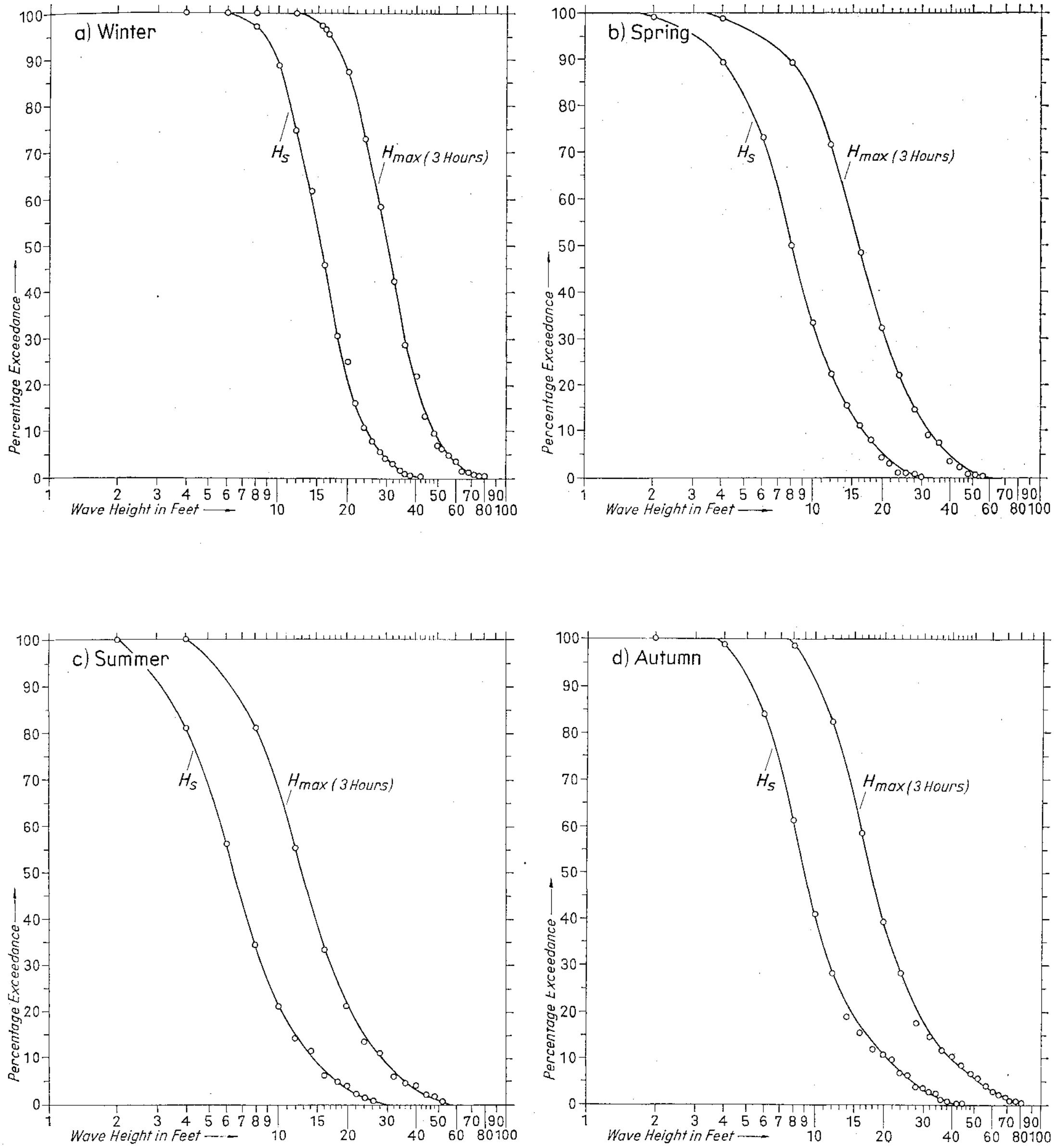

Fig. 1. Cumulative distribution of significant wave height and the most probable height of the highest wave in the recording interval

Fig. 1: For each season a graph is drawn showing the cumulative distribution of significant wave height H_s and of the most probable height of the highest wave in the recording interval, $H_{max\ (3\ hours)}$.

Fig. 2: The distribution of zero-crossing period is given for each season.

Fig. 3: The distribution of the spectral width parameter is given for the whole year.

Fig. 4: This is a scatter diagram relating significant wave height to zero crossing period.

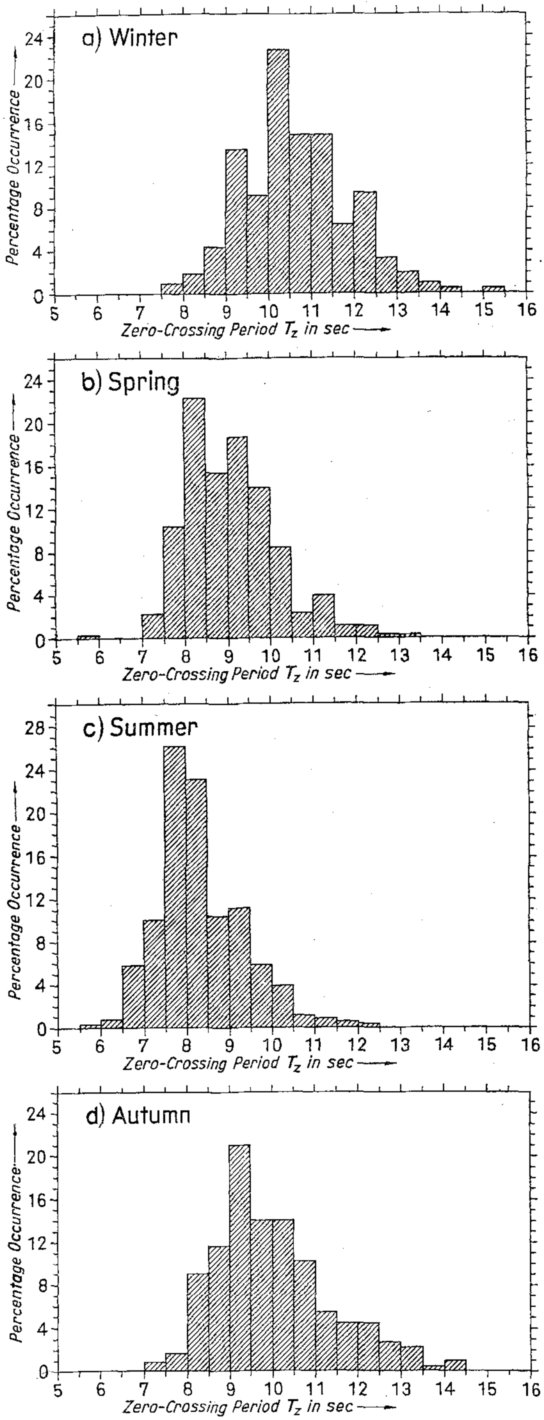

Fig. 2. The distribution of zero-crossing period

Discussion of results. From Fig. 1 it is easy to determine the proportion of time in which H_s or $H_{max\,(3\,hours)}$ exceeded any given height. For example, in the winter, the significant wave height exceeded 15 feet for 53 % of the time. Wave heights and zero-crossing periods are substantially higher in the winter months than in any other season. The seasonal variation in the spectral width parameter is fairly small; the mean is slightly lower in the spring and summer months than during autumn and winter. The scatter diagram of Fig. 4 relates the significant wave height to zero-crossing period. The numbers of occurrences are expressed in parts per thousand. For example, the most common wave condition was that with a significant height of between 4 and 8 feet and with a zero-crossing period of between 8 and 9 seconds which occurred for 132 thousandths, i. e. 13.2 % of the time. The rapid attenuation of the shorter waves with depth means that the pressure units, which are necessarily situated at about seven feet below mean water level, do not record waves which have a period of less than about five seconds; this is the cause of cut-off below that period. Higher waves are almost all associated with longer periods, but longer periods can also occur with lower wave heights which is the case when swell arrives from a distant storm.

A parameter which is sometimes of interest is the wave steepness, defined as the ratio of wave height/wave length; it may also be expressed as a decimal number. It should be noted that the steepness of a wave is not the same as the maximum slope of the water surface during the passage of a wave. Lines of constant steepness of $^1/_{20}$ and $^1/_{40}$ are drawn on Fig. 4 (in this case steepness relates to significant wave height/wave length calculated from the zero-crossing period). A fairly well-defined limit of steepness is observed at approximately $^1/_{18}$ (0.056). There is a theoretical limit for a progressive wave of $^1/_7$ (0.14); the steepest wave actually observed in this series of records had steepness of $^1/_{9.0}$ (0.11)) defined as maximum height observed (not significant height)/wavelength calculated from the zero-crossing period). This occurred with a wave 34 feet high and of 7.75 seconds zero-crossing period.

Because the records are taken at random from a series covering about ten years, it is reasonable to assume that they are representative of a typical year. The highest wave recorded

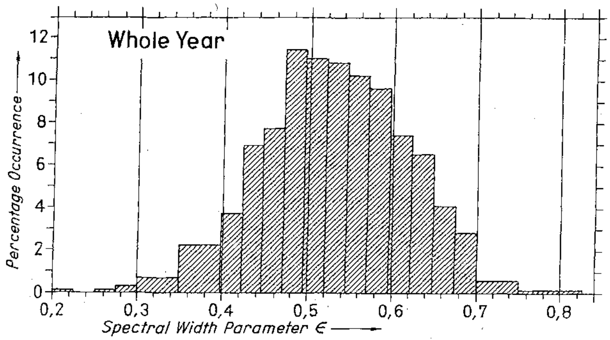

Fig. 3. The distribution of the spectral-width parameter

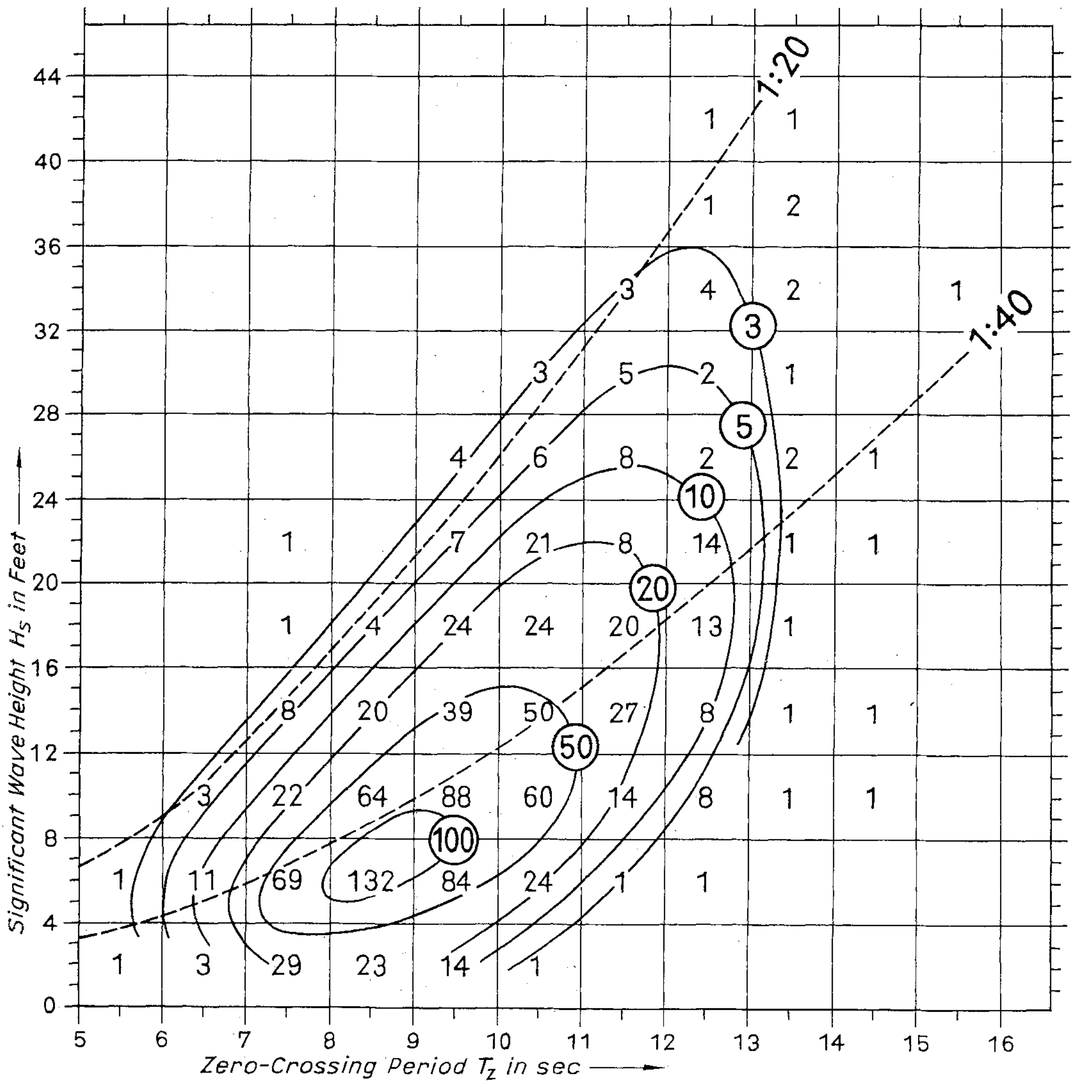

Fig. 4. Scatter diagram of significant wave height and zero-crossing period

by these vessels was one of 67 feet crest to trough on 12th September 1961 at station "Juliett". As far as we are aware this is still the highest wave which has ever been recorded by an instrument. It seems possible that the highest wave which was felt by "Weather Reporter" during that storm was about 80 feet high (L. Draper [1964]).

The wave measurements taken by the Weather Ships, and also by several Trinity House Light Vessels, have been used by Professor J. Darbyshire in the development of his wave forecasting technique. The method has also been expressed graphically and was published in 1963 (M. Darbyshire and L. Draper [1963]).

Acknowledgements. The authors wish to express their appreciation to the Meteorological Office for allowing their vessels to be used and to the Meteorologists and Electronic and Mechanical Engineers on the Weather Ships for the care they have exercised in taking the records and in ensuring the smooth running of the equipment. Without their continuing interest this information could not have been obtained.

References

Cartwright, D. E. and M. S. Longuet-Higgins, 1956: The statistical distribution of the maximum of a random function. Proc. Roy. Soc. Ser. A. **237**, 212.

Darbyshire, M. and L. Draper, 1963: Forecasting wind-generated sea waves. Engineering. **195**, 482.

Draper, L., 1963: Derivation of a "Design Wave" from instrumental records of sea waves. Proc. Instn. Civ. Engrs. **26**, 291.

Draper, L., 1964: Freak Ocean Waves. Oceanus. **10**, No. 4, 12.

Tucker, M. J., 1956: A Shipborne Wave Recorder. Trans. Inst. Nav. Archit., **98**, 236.

Tucker, M. J., 1961: Simple measurement of wave records. Proc. Conf. Wave Recording Civ. Engrs., Nat. Inst. Oceanogr. p. 22. Also printed in Dock Harb. Author. **42**, 231.

Tucker, M. J., 1963: Analysis of records of sea waves. Proc. Instn. Civ. Engrs. **26**, 305.

Eingegangen im Dezember 1964

UDC 551.46.083:551.463.22

Über Messungen der Schallgeschwindigkeit in der Nordsee

Von W. Düing und P. H. Koske

Zusammenfassung. Es wird über Messungen der Schallgeschwindigkeit berichtet, die auf einer Fahrt des F. S. „Meteor" während der Zeit vom 12. bis zum 23. September 1964 in der Nordsee durchgeführt wurden. Es wird eine Apparatur zur kontinuierlichen Messung von Schallgeschwindigkeit, Temperatur, Salzgehalt und hydrostatischem Druck beschrieben. Die Ergebnisse von fünfzehn Stationen in der nördlichen und mittleren Nordsee und von einer Station im Skagerrak werden dargelegt und diskutiert.

On measurements of sound velocity in the North Sea (Summary). The velocity of sound was measured on board of research vessel "Meteor" during her cruise in the North Sea from September 12th to September 23rd, 1964. The apparatus used for the continuous determination of sound velocity, temperature, salinity, and hydrostatic pressure is described. The results obtained at fifteen stations in the northern and central parts of the North Sea and at one station in the Skagerrak are reported and discussed.

Sur des mesures de la vitesse du son dans la mer du Nord (Résumé). L'article actuel traite les mesures de la vitesse du son executées à bord du navire de recherche «Meteor» pendant son voyage en mer du Nord à partir du 12 jusqu'au 23 septembre 1964. On décrit l'appareillage qui permet de mesurer d'une manière suivie la vitesse du son, la température, la salinité et la pression hydrostatique. Les résultats obtenus à quinze stations hydrographiques dans la partie du nord et la partie centrale de la mer du Nord et à une station hydrographique dans le Skagerrak sont présentés et discutés.