SECCHI DISC AND SEA COLOUR OBSERVATIONS IN THE NORTH ATLANTIC OCEAN DURING THE NAVADO III CRUISE, 1964–65, ABOARD H.NETH. M.S. "SNELLIUS" (ROYAL NETHERLANDS NAVY)

by

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CONTENTS

I. INTRODUCTION

This paper discusses Secchi disc and colour scale observations made in the North Atlantic during the Navado III cruise, 1964–1965, aboard H.Neth. M.S. "Snellius". These simple measurements are useful for obtaining an impression of the transparency of the water within the survey area; however, they give no more than rough estimates over limited depths. Considerable secchi depths were expected in the Sargasso Sea and a disc of 1 metre diameter was therefore used in addition to the "standard" disc of 1 foot diameter, in accordance with JOSEPH's recommendation (1952).

II. OBSERVATIONS

Positions of stations and observed values are shown in figure 1. Corresponding data on wind, sea and swell are listed in the Appendix; special remarks on weather and state of the sea, recorded at the time of measurement, are listed for most stations, under "remarks".

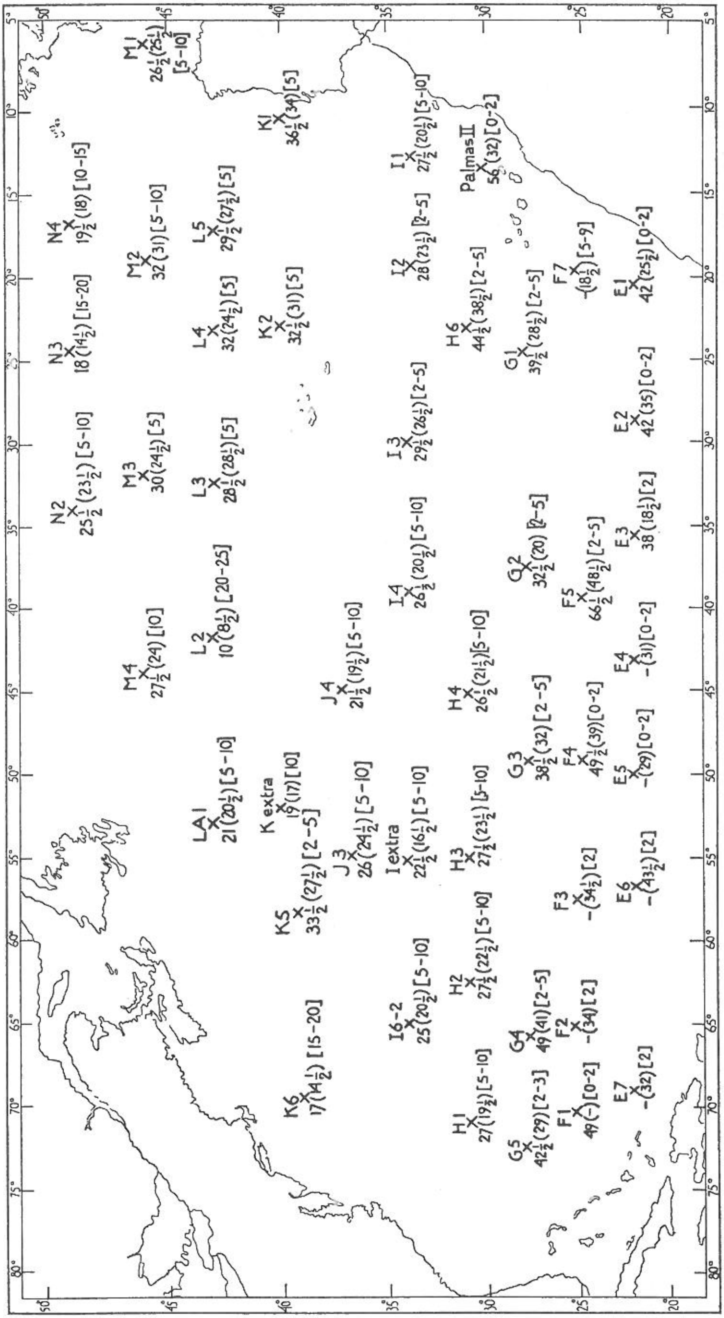

Fig. 1. Stations occupied by H. Neth. M.S. "Snellius" during the Navado-III cruise; the observed Secchi depth, disc diameter 1 meter (ditto, disc diameter 1 foot) [percentage yellow according to Forel scale].

About one third of the measurements of Secchi depths were taken on the sunny side of the ship, because wind drift prevented measurements on the shady side; generally, this is noted in the Appendix. Time is given in g.m.t., but it will be clear from an inspection of the longitudes that all the observations were made between 07 and 17 o'clock, local time. Both maximum and minimum values of Secchi depths are given, *i.e.*, depth of disappearance and depth of reappearance of the disc.

The "yellow content" of the colour recorded in figure 1 is the mean value from four observations. For these observations the Secchi disc was lowered to one half the observed Secchi depth. The colour was estimated in the usual way by comparison with two colour scales consisting of coloured liquids in glass tubes (diameter 1 cm); one colour scale had the sequence according to Forel, the other according to Gazert (see SOWER, 1960).

III. ANALYSIS

The following interpretation may be made within the restrictions imposed by the limited data.

Maximum Secchi depths were obtained in the vicinity of the Sargasso Sea, although the highest value was found more eastward than expected. The rather isolated "islands" of low or high visibility in the Gulf Stream region and near the African coast are due to special local conditions, because not only the Secchi depth, but also the colour and the surface temperature of the water on these stations differ greatly from adjacent ones.

In general, the results agree with those recorded in the literature, *e.g.*, KRÜMMEL (1907), see Table I.

TABLE I

Secchi-disc observations in the North Atlantic Ocean (KRÜMMEL, 1907)

Position	*Disc Diameter*	*Secchi-depth (m)*
Sargasso Sea	2 m	56.5–66.5
Madeira	50 cm	42
Cape Verde Is.	50 cm	30

CLARKE (1939, 1941) and others have recorded Secchi disc readings of 18 to 41 m in various parts of the Sargasso Sea, while IVANOFF and WATERMAN (1958) reported Secchi depths up to 50 m south of Bermuda (diameter of the disc not given). RILEY (1957) gives a graphical record of Secchi depths measured at approximately weekly intervals over a two-year period at Ocean Weather Station E in the Sargasso Sea (35° N., 48° W.). These depths show marked seasonal fluctuations, ranging from about 8 m to 43 m, which indicated that this part of the Sargasso Sea is not always highly transparent. Further references are given by JOSEPH (1952), who gives a map of the distribution of the so-called "vertical extinction" coefficient in the North Atlantic, partly based on Secchi disc observations.

Secchi depths observed with the 1 foot disc will be denoted by S_f and those with the 1 metre disc by S_m. Several points have to be considered with regard to visibility of the two discs.

At the greatest observed Secchi depths (about 70 m for the 1 m disc and about 50 m for the 1 ft disc) the angles subtended by the discs greatly exceed the angular resolving power of the human eye, which is about one minute of arc. Consequently, for both discs Weber and Fechner's law is applicable throughout, according to which the contrast threshold of the human eye is independent of dimensions of the viewed object (unless the latter is too small or the general lighting conditions are very bad).

If the sea surface is perfectly flat the depth visibility limit of a disc results from decrease in contrast. Since this decrease is related to light-attenuating properties of the water and reflection of sunlight and skylight on the water surface, there is no reason for S_f and S_m to be unequal, according to Weber and Fechner's law. In practise, however, disturbance of water surface (ripples, waves) blur the image of the descending disc. This distortion may become so great that the image splits up, with components interspersed in the glitter pattern on the surface. In addition, small-angle scattering of light in water may contribute to reduced sharpness of the disc edge.

Both effects will be more significant for the small disc than for the big one, so that

$$S_f = pS_m \qquad \text{with} \qquad 0 < p < 1$$

It follows from the above considerations that the value of p should be highly dependent on the state of the sea, so that a certain relation between p and wind force may be expected. In fact, such a relation could be established (fig. 2).

For Beaufort zero the value of p is still less than one, since a perfectly flat surface never occurs. Even the obtained value 0.96, seems to be surprisingly high. This indicates that the effect of light attenuation on the value of p is relatively small.

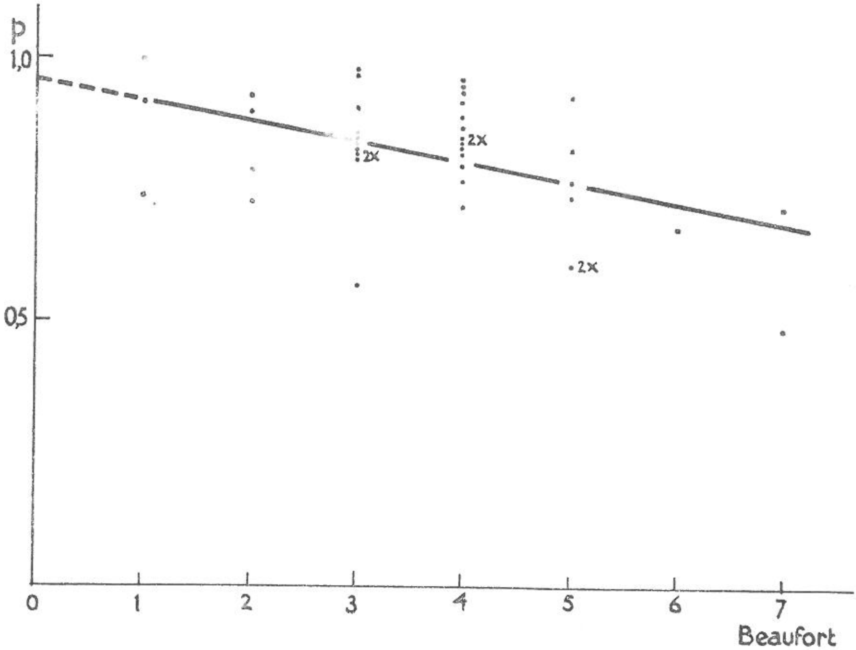

Fig. 2. Relation between Secchi depth observed with a 1-foot disc (S_f) and with a 1-metre disc (S_m), $p = \frac{S_f}{S_m}$ as a function of the Beaufort number. Assuming a linear relationship, a correlation coefficient of 0.47 is found from 41 observations.

For the majority of stations it is possible to calculate a corrected value S_f*, which corresponds to S_f/p, where p is only a function of wind force, according to Table II. In this way the mean effect of a roughened water

TABLE II

Wind force (Beaufort)	$p = \frac{S_f}{S_m}$
0	0.96
1	0.92
2	0.88
3	0.84
4	0.81
5	0.77
6	0.73
7	0.69

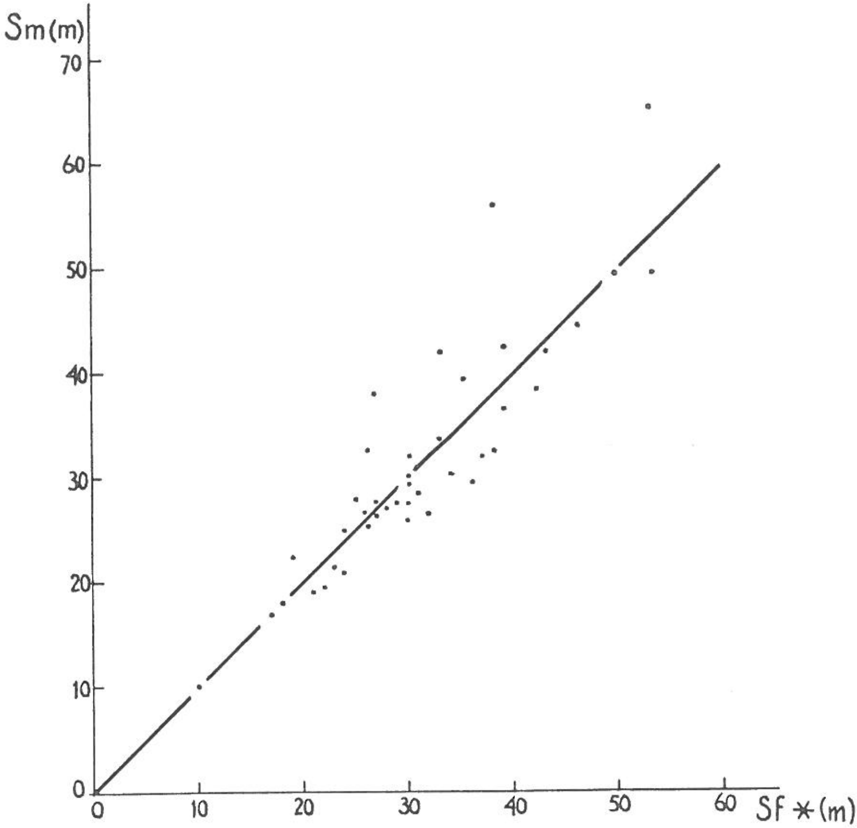

Fig. 3. Secchi depth observed with the 1 metre disc (S_m) against the same with the 1 foot disc, the latter corrected for the influence of wave action (S_f*).

surface on the visibility of the small disc is reduced to the same (order of) magnitude as the effect on the big disc, which is assumed to be negligible. As a check, the values of S_f* are plotted against the observed S_m in figure 3.

Now we have two quasi-independent values of the Secchi depth at almost every station, but generally these values are not identical. In a few cases S_m is much greater than S_f, probably because S_m was measured with a considerably greater wire angle than S_f. Since the wire angles were not given in the original "remarks", no corrections could be applied for it directly.

However, the effect of the wire angle can be minimized by taking the mean of the two values, *viz.*,

$$S = \tfrac{1}{2}(S_m + S_f^*)$$

where S is considered to be closest to the true value of the Secchi depth.

In the Appendix the colour of the seawater is expressed in percentages yellow, according to the Forel scale. As a rule the colour of clearest water has the lowest yellow content. When $100/S$ (S in metres) is plotted against Υ, percentage yellow, (fig. 4) the points show a certain amount of scatter due to inexactness of the observations. However, the observed correlation $100/S = 0.26\ \Upsilon + 1.9$ is satisfactory. This is a purely empirical relationship valid only for the area investigated. For comparison the values found by LUKSCH for other areas (JOSEPH, 1952) are also given in figure 4.

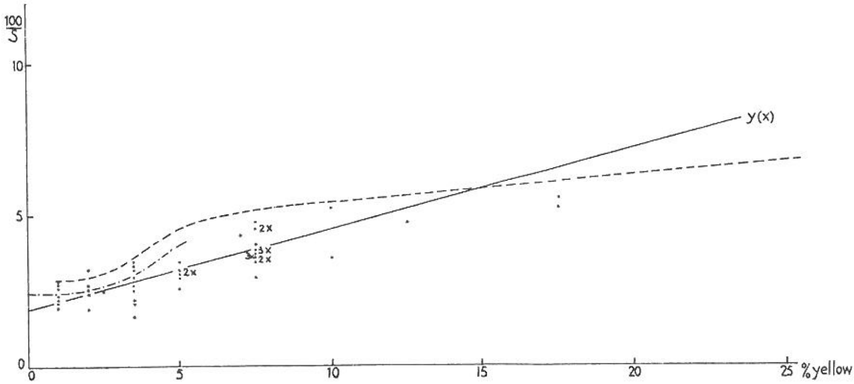

Fig. 4. Reciprocal averaged Secchi depth against mean yellow content (according to the Forel Scale) for the North Atlantic (———). $\frac{100}{S} = 0.26\ \Upsilon + 1.9$, S in metres, Υ in % yellow, correlation coefficient 0.88 from 49 observations.

- - - - - - Red Sea, -·-·-·-·- Mediterranean and Aegean Sea, both according to LUKSCH.

IV. DISCUSSION

The data given in this paper provide a rough indication of transparency patterns of surface water of various parts of the southern North Atlantic. Since this part of the cruise extended from December 1964 to September 1965 the transparency values can only be considered representative for the particular season in which they were recorded (compare the observations of RILEY, 1957); so, they must be interpreted carefully.

The correction for wave action, as given here, is a rough one and must be considered as a first approximation. Of course, the influence of the water surface could be avoided to some extent by observing the Secchi disc through a tube ending below the water surface, but this was not attempted. It is tempting to try to correlate our values of Secchi depth and colour with results of underwater light measurements and with the spectral transmission of different water types, both known from literature. (JERLOV, 1951, 1961). However, in view of the totally different methods of measuring, seasonal differences, etc., it seems best to refrain from such an attempt. Furthermore, TIMOFEEVA (1966) remarked: "It was found that this depth (of disappearance of a standard white disk) depends not only on the value of the extinction coefficient, but on the share of dispersion in the general weakening of light".

AKNOWLEDGMENTS

We like to express our thanks to officers and crew of H. Neth. M.S. "Snellius" for collecting the observations, especially to the senior officer A. Kamp, Royal Netherlands Navy.

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SUMMARY

During the Navado III cruise of H. Neth. M.S. "Snellius" in the North Atlantic, 1964–'65, observations on water transparency and-colour were made by means of Secchi discs of different diameter and a Forel scale. The influence of wave-action on the visibility of the Secchi disc is calculated in an approximative way. A fair relationship is found for the observed secchi depth and the corresponding percentage yellow in the Forel colour-scale.

RÉSUMÉ

Pendant son voyage appelé Navado III dans l'Océan Atlantique du Nord (1964–'65), S.M. "Snellius" a fait des observations sur la limpidité et la couleur de l'eau au moyen des disques de Secchi de diamètres differents et d'une échelle de Forel. Il se trouvait possible de calculer approximativement l' influence des ondes sur la visibilité du disque. Il y a un rapport assez bon entre la profondeur que nous désigne le disque de Secchi et le pourcentage de jaune sur l'échelle de Forel.

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APPENDIX

station	date	position N. ° ′	position W. ° ′	g.m.t.	seehi-depth 1 m-disc	seehi-depth 1 foot disc	% yellow	surface tempera-ture °C	Wind Beaufort	Wave height Sea	Wave height Swell	Observation sunny side	Observation shady side	Remarks
Palmas II	2–12–'64	30 20	14 30	15.15	56	32	0–2	26.0	3	2	6			
E1	5	22 00	20 35	17.30	41–43	25–26	0–2		5	2	4			
E2	7	22 00	28 35	19.00	41–43	34–36	0–2		4	2	0			
E3	9	22 00	35 30	19.00	36–40	17–20	2		7	3	5			completely clouded
E4	11	22 05	43 00	18.00		30–32	0–2		6	2	6			
E5	13	22 00	49 55	19.00		28–30	0–2		4	2	6			
E6	15	21 45	56 40	18.00		43–44	2		5	2	4			
E7	18	22 00	69 00	20.00		31–33	2		3	1	3			
F1	16–1–'65	25 10	70 20	15.00	47–51		0–2		4	2	6			
F2	18	25 15	65 15	18.00		33–35	2		5	2	5			
F3	21	25 10	57 25	12.00		33–36	2		3	1	6	×		bright
F4	23	24 55	49 15	16.45	48–51	38–40	0–2		2	0	3			partly clouded, no sun on ship
F5	26	24 50	39 25	13.30	64–67	47–50	2–5		1	0	6		×	
F7	30	25 10	19 45	08.30		17–20	5–9	19.6	7	2	4		×	heavy swell, rough sea
G1	18–2–'65	28 10	24 25	12.00	39–40	28–29	2–5	19.8	4	2	4	×		semi-transp. layer of clouds
G2	21	28 05	37 25	12.30	31–34	19–21	2–5		5	4	2			completely clouded, drizzle, rough sea
G3	24	27 45	49 15	14.15	37–40	31–33	2–5		5	3	5			completely clouded, drizzle, rough sea, subsurface cu
G4	1–3–'65	27 45	65 55	14.00	48–50	40–42	2–5		3	1	3		×	bright
G5	3	28 00	72 40	14.45	42–43	28–30	2–3		6	3	4	×		bright, rough sea, wind rips
H1	14	31 00	71 00	14.45	26–28	19–20	5–10		7	4	5			completely clouded, rough sea
H2	20	31 05	62 40	13.00	27–28	22–23	5–10		3	2				semi- transp. layer of clouds
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		4	2	5			partly clouded, no sun on ship, rough sea

H6	30	30 55	23 15	12.00	44–45	38–39	2–5		3	2	6		×	bright, partly clouded
I1	9–4–'65	33 55	12 55	09.30	27–28	20–21	5–10	17.1	5	1	2			completely clouded
I2	11	33 50	19 20	18.00	27–29	23–24	2–5	18.2	4	2	3		×	bright, partly clouded
I3	14	34 05	30 10	12.00	29–30	26–27	2–5		2	2	3	×		semi-transp. layer of clouds
I4	16	34 10	39 00	12.00	26–27	20–21	5–10		5	2	5	×		semi-transp. layer of clouds
I extra	20	34 10	55 20	18.00	22–23	16–17	5–10		2	0	2		×	bright
I6–2	22	34 00	65 00	20.30	24–26	20–21	5–10		3	2	3	×		bright, partly clouded
J3	17–5–'65	36 45	55 00	12.00	25–27	24–25	5–10		4	1	5	×		semi-transp. layer of clouds
J4	20	37 25	45 05	18.00	21–22	19–20	5–10	19.6	3	1	1			completely clouded
K1	2–6–'65	39 55	10 35	12.00	36–37	33–35	5		2	1	2		×	bright, partly clouded
K2	4	40 05	23 00	10.00	32–33	30–32	5		4	1	4		×	bright, partly clouded
K extra	11	40 03	52 07	12.00	18–20	16–18	10	18.9	4	1	2			dense fog
K5	12	39 35	58 20	19.00	33–34	27–28	2–5		3	2	4	×		bright
K6	15	39 13	69 18	12.00	16–18	14–15	15–20		3	2	3	×		bright, partly clouded
LA–1	20	43 05	53 10	18.00	20–22	20–21	5–10	21.7	3	1	2	×		bright
L2	27	43 10	41 50	18.00	9–11	8–9	20–25	14.6	4	2	4			completely clouded
L3	29	43 05	32 35	17.00	28–29	28–29	5	18.4	1	1	2	×		bright
L4	1–7–'65	43 05	23 15	16.00	31–33	24–25	5		4	2	4		×	semi-transp. layer of clouds
L5	3	43 00	17 15	10.00	29–30	27–28	5		5	3	5	×		semi-transp. layer of clouds
M1	9–8–'65	46 00	06 05	12.00	26–27	25–26	5–10		4	1	1	×		bright
M2	12	46 10	19 00	12.00	31–33	30–32	5–10		3	1	6	×		bright, partly clouded
M3	15	46 30	32 00	12.30	29–31	24–25	5		4	1	2	×		bright, clouded
M4	17	46 45	44 00	10.00	27–28	23–25	10	19.2	4	2	5			completely clouded
N2	6–9–'6	49 00	34 00	12.00	25–26	23–24	5–10		1		3			completely clouded
N3	8	49 00	24 30	12.00	17–19	14–15	15–20		4	3	6		×	bright, rough sea
N4	9	49 00	17 00	14.00	19–20	17–19	10–15		4	2	4	×		bright, partly clouded, rough sea

H_w = wave height 0 : $\frac{1}{4}$ m
1 : $\frac{1}{2}$ m
2 : 1 m
3 : $1\frac{1}{2}$ m, etc.