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SHIPBOARD PRESSURE MEASUREMENTS DURING JASIN 1972

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Summary. Shipboard pressure data obtained during the Joint Air–Sea Interaction Experiment (JASIN) in 1972 have been analysed in some detail. The results suggest that typical instrumental error for the Meteorological Office Precision Aneroid Barometer (PAB) is about 0·2 mb. Random errors due to ship-induced accelerations were about 0·1 mb. Sets of observations obtained for different ship headings relative to wind demonstrated variations of measured pressure with heading of several tenths of a millibar in winds of force 4 or 5 in spite of the barometers' being connected to well-exposed static heads. Intercomparisons of pressure readings obtained when ships were adjacent showed inconsistencies due either to short-term barometer drift or, more probably, to reading errors which varied between observers.

Introduction. The Joint Air–Sea Interaction Experiment (JASIN) is a meteorological and oceanographic investigation of mixing processes in the lower troposphere and upper ocean on time scales of up to a few weeks and horizontal scales of up to about 100 km. Preliminary experiments in the series took place in 1970 and 1972 near ocean weather station (OWS) 'J' (52½°N, 20°W), and the main experiment is planned for the summer of 1978 near OWS 'I' (59°N, 19°W). At least three ships are required for the meteorological programme, spaced far enough apart to allow the calculation of divergence with reasonable accuracy from their upper-wind measurements, but also sufficiently close to support the oceanographic programme effectively and to ensure that atmospheric mesoscale systems cross the array in a time short enough for their identity to be preserved—say a few hours. These requirements conflict to some extent and if only three ships are available then a compromise is necessary, with a ship-spacing of about 100 km.

The meteorological programme is concerned *inter alia* with the relationships between surface fluxes and large-scale parameters. One of the latter is the surface geostrophic wind

$$V_g = \frac{1}{\rho f} \nabla p \times \kappa,$$

where ρ is the air density, f the Coriolis parameter and κ the unit vertical vector. There have always been doubts whether the size of the area enclosed by the JASIN ships would be large enough to allow the measurement of the pressure gradient with sufficient accuracy to provide useful estimates for V_g, and in both the 1970 and 1972 exercises there were special experiments to investigate this point. An error in pressure measurements of 0·1 mb over a distance of 100 km would produce a wind-speed error of 0·8 m/s, or for a typical geostrophic speed of 10 m/s a direction error of 5°. It is believed that errors even as small as these are barely acceptable for JASIN.

In 1970 the pressure experiment was carried out with sensors mounted on meteorological buoys: the results[1] demonstrated the inadequacy of the sensors for measurements of the required very high accuracy. The 1972 experiment made use of buoys with different pressure-measuring systems supplied and maintained by the University of Miami, and also investigated the possibility of obtaining satisfactory data from instruments on board ship. The present note discusses these ship observations.

The difficulties of making atmospheric-pressure measurements of very high accuracy are greater when the observations are made aboard ships rather than on land. The main errors likely to arise are briefly as follows:

(a) Changes may occur in the sensor calibration and these are detectable usually only on recalibration: since recalibration is not feasible on board ship the nature of the shift (for instance sudden change or slow drift) is not known and there is uncertainty about which calibration figure to use.

(b) Ship's motions (heave, pitch and roll) produce fluctuations in pressure caused by changes in height of the sensors and by the acceleration forces on the transducer and its mounting. The first type of fluctuation can be reduced to negligible amounts either by inserting a suitable constriction in the pipe connecting static head and sensor or alternatively by averaging over several cycles of the ship's motion. Acceleration forces can also be averaged out provided that the mean orientation of the sensor was that in which it was calibrated, but if the instrument is tilted, for example by incorrect levelling when mounted or by the ship's listing in a strong beam wind, then errors may result.

(c) With sensors such as the Meteorological Office Precision Aneroid Barometer (PAB) where manual setting is required, leading to some imprecision, different observers may arrive at a different setting for the same ambient pressure, especially when the ship's motion is vigorous.

(d) The ship will disturb the airflow from its free-stream pattern and then in spite of the use of static heads the measured pressure will differ from that in undisturbed flow. If it is assumed that Bernoulli's equation holds for this case then departures of $\pm$ 5 m/s from a free-stream velocity of 10 m/s produce pressure changes of $-0·75$ and $+0·45$ mb: even changes in velocity of ± 1 m/s cause significant variations ($\approx \pm$ 0·1 mb) at this mean speed.

(e) In a rolling ship with the static head above the pressure sensor there will be a net upward force on the air in the pipe connecting them (Pollard, personal communication, 1971). The mean error is about $-0·02$ mb for a roll angle of $\pm$ 10 degrees with a period of 6 seconds and with the static head 15 metres above the barometer.

Experimental design and instrumentation. The three ships involved in JASIN 72 were O.W.S. *Weather Adviser* (on Station 'J'), R.R.S. *Discovery* and m.v. *Researcher*, spaced 100 kilometres apart at the corners of an equilateral triangle. The pressure sensor used on all ships was the Meteorological Office Precision Aneroid Barometer (PAB).[2,3] This incorporates a capsule stack whose deflexion is measured by a micrometer calibrated in millibars and tenths: contact between micrometer and capsule is indicated by an electrical make-and-break circuit. The display can be read with a precision exceeding 0·05 mb but there is a dead zone in the micrometer system of about 0·05 mb and a reading resolution better than this is not justified. The instruments were calibrated before and after the experiment in the Meteorological Office test room against a precision Bourdon gauge, readings being given to 0·1 mb. Three PABs were used on each ship—it was hoped that the multiple pressure observation would allow an improvement in the accuracy of the mean of the measurements on each ship as well as providing data for assessing the performance of the aneroids by intercomparison of the readings. On all ships the PABs were connected to a standard Meteorological Office static head mounted in a reasonably well-exposed position; these positions and those of the PABs appear in Table I.

TABLE I—BAROMETERS AND STATIC HEADS

Ship	Barometer type, position and approximate mean height above mean sea level	Static head type, position and mean height above sea level
Weather Adviser	3 PABs, Meteorological Office, 3 m.	1. Meteorological Office pattern, port side of platform on mainmast, 18 m. 2. Meteorological Office pattern, starboard side of platform on mainmast, 18 m. 3. Meteorological Office pattern, on mast above shelter, 15 m.
Researcher	3 PABs, Laboratory, 3 m.	Meteorological Office pattern, starboard side of mast above wheelhouse, 9 m.
Discovery	3 PABs, gravity room, 3 m.	1. Meteorological Office pattern, starboard side of platform on mainmast, 18 m.
	1 PAB, bridge, 12 m. Kollsman, either (a) bridge, 11 m, or (b) gravity room, 2 m.	2. Meteorological Office pattern, port side of lookout area of monkey island, 13 m. 3. Miami (Snyder) pattern, starboard side of monkey island, 13 m.

The pressure distribution over any object obstructing the airflow differs from that in the free stream (page 158) so that apart from any errors introduced by the transducers the pressure observations from ships will always be in error except in very light winds. To obtain some information on these errors additional static heads were mounted on *Weather Adviser* and *Discovery* (Table I). On *Adviser* an extra head was mounted on the mainmast, at the same level as, but on the opposite side to, the existing head, and another was placed on a mast about 4 m above the top of the balloon shelter (aft of the mainmast). Valves were used to connect the selected head to the PABs. On *Discovery* the extra head was placed on the bridge. *Discovery* also carried two additional barometers, a PAB mounted above the bridge deck and connected to the Meteorological Office head on the bridge, and a Kollsman sensor mounted either in the gravity room or on the bridge deck, and capable of connection to either of the two Meteorological Office heads or to a University of Miami head on the bridge.

The fluctuations produced by the change in height of the PABs above sea level due to ship's motion were reduced to less than $\pm$ 0·1 mb by fitting 'damping caps' (constrictions) to the inlet pipes of the barometers.

The observations. The main series of measurements were made at 1-hourly intervals on all ships. The PABs were read twice in the sequence 1–2–3, 1–2–3, using the mainmast static head on *Adviser* and the foremast head on *Discovery*. There were additional measurements made on each ship (Table II) the principal object of which was the determination of the effect on the observed pressure of changes in relative wind direction. *Researcher* carried out two series of this type in winds of force 3 and 5, the PABs being read in the same sequence as for routine observations. *Adviser* also carried out two series in similar winds, but here observations were made with all three static heads at each heading, each thus producing 18 pressure readings. Two similar series were carried out aboard *Discovery*, with 12 readings of each PAB at the various headings. Five intercomparisons of PABs on different ships were made, in all but one case with only two adjacent ships (Table II).

TABLE II—SPECIAL PRESSURE OBSERVATIONS DURING SEPTEMBER 1972

Series number	Ship	Period Date/Time (GMT)	Barometer and static heads	Notes
1	*Researcher*	06/1022–06/1110	3 PABs, mast head	Measuring pressure at 16 different headings relative to wind: each PAB read twice on each heading.
2	*Researcher*	10/1055–10/2055	3 PABs, mast head	Various different relative headings: PABs read twice on each heading.
3	*Adviser*	10/1410–10/1535	3 PABS, all static heads	16 different relative headings: PABs read twice for each static head on each heading.
4	*Adviser*	20/0800–20/0848	3 PABs, all static heads	16 different relative headings: PABs read twice for each static head on each heading.
5	*Discovery*	09/0000–23/0700	Kollsman (bridge), Miami head	100-second averages every 5 minutes.
6	*Discovery*	23/1150–23/1950	Kollsman (gravity room), mast head	100-second averages every 5 minutes.
7	*Discovery*	23/2005–24/0315	Kollsman (gravity room), mast head	100-second averages every 5 minutes.
8	*Discovery*	24/0320–24/0548	Kollsman (gravity room), 3 PABs, mast head	16 different relative headings: PABs read 12 times for each heading. 120 Kollsman 1-second averages at 1·5-second intervals on each heading: also single 100-second averages before ship changed heading.
9	*Discovery*	24/0550–25/1515	Kollsman (gravity room), mast head	100-second averages every 5 minutes.
10	*Discovery*	25/1520–26/1615	Kollsman (bridge), Miami head	100-second averages every 5 minutes.
11	*Discovery*	26/1620–26/2305	Kollsman (bridge), bridge Met. Office head	100-second averages every 5 minutes.

TABLE II—*continued*

Series number	Ship	Period Date/Time (GMT)	Barometer and static heads	Notes
12	*Discovery*	26/2318–27/0132	3 PABs, mast head, bridge PAB, bridge Met. Office head, Kollsman (bridge), all three static heads	8 different relative headings: gravity room PABs read 12 times for each heading, followed by 18 readings of bridge PAB. 100-second averages from Kollsman using mast head and bridge, Met. Office head (both simultaneous with PAB readings), and Miami head on each heading.
13	*Discovery*	27/0140–28/0850	Kollsman (bridge), Met. Office bridge and mast head	100-second average every 5 minutes.
14	*Discovery*	28/0855–28/1340	Kollsman (bridge), alternate heads (Met. Office and Miami)	100-second average every 5 minutes.
15	*Discovery*	28/1340–29/1150	Kollsman (bridge) Miami head	100-second–averages every 5 minutes.
16	*Discovery* *Adviser*	04/1410–04/1420	3 PABs, mast head 3 PABs, all heads	Intercomparison. Each PAB read twice on *Discovery*, 3 times for each head on *Adviser*.
17	*Discovery* *Researcher*	05/1910–05/1940 05/1855–05/1955	3 PABs, mast head 3 PABs, mast head	Intercomparison. Each PAB read twice at 15-minute intervals on both ships.
18	*Discovery* *Researcher*	13/1010–13/1155 13/0955–13/1255	3 PABs, mast head 3 PABs, mast head	Intercomparison in very light winds. PABs read twice at 15-minute intervals.
19	*Adviser* *Discovery* *Researcher*	18/0800–18/0900 18/0740–18/0855 18/0755–18/0855	3 PABs, port mast head 3 PABs, mast head 3 PABs, mast head	Intercomparison. PABs read twice at hourly intervals on *Adviser*. Read twice at 15-minute intervals on *Discovery* and *Researcher*.
20	*Adviser* *Discovery*	27/1810–27/2010 27/1825–27/2010	3 PABs, all heads 3 PABs (gravity room), mast head. Bridge PAB, bridge head.	Intercomparison. PABs read twice for each head on *Adviser* at 15-minute intervals. Gravity room PABs read twice at 15-minute intervals, bridge PAB single reading every 15 minutes on *Discovery*.

On board *Discovery* the Kollsman sensor was used in association with different static heads to obtain extensive data, occasionally simultaneously with PAB observations and sometimes sharing static heads with them. Details of these trials are also given in Table II.

Results and discussion

(a) *PAB readings.*

(i) *General results.* Before detailed discussion of the results it is appropriate to consider the magnitude of two of the pressure errors described in the Introduction. One important cause of uncertainty is the change of calibration revealed after recalibration of the sensors (page 158). The PAB corrections found before and after JASIN 72 are shown in Table III. Changes were very small for all three PABs on *Discovery* (0·1 mb or less) and usually less than 0·2 mb for *Adviser* but (presumably coincidentally) only one of *Researcher's* instruments showed a drift of less than 0·2 mb. Because of lack of information on the causes of the changes it had to be assumed that they were due to linear drifts with time.

TABLE III—BAROMETER CORRECTIONS

Ship	PAB	980 mb	Correction to be added 1000 mb	1020 mb	1050 mb	Calibration date
			millibars			
	1	+0·1	0·0	+0·1	+0·1	15 June 1972
		+0·2	+0·2	+0·1	+0·3	19 October 1972
Adviser	2	+0·1	0·0	0·0	+0·1	2 August 1972
		0·0	+0·1	+0·1	+0·1	19 October 1972
	3	−0·1	−0·1	−0·1	−0·1	2 August 1972
		0·0	0·0	0·0	+0·1	19 October 1972
	1	+0·1	+0·1	+0·1	+0·2	15 June 1972
		+0·3	+0·3	+0·3	+0·5	19 October 1972
Researcher	2	0·0	−0·1	−0·1	+0·1	2 August 1972
		+0·3	+0·3	+0·3	+0·4	19 October 1972
	3	0·0	0·0	0·0	+0·1	2 August 1972
		0·0	−0·1	+0·1	+0·3	19 October 1972
	1	−0·1	0·0	0·0	+0·1	15 June 1972
		0·0	+0·1	+0·1	+0·2	19 October 1972
Discovery	2	−0·1	−0·1	−0·1	−0·1	7 August 1972
		−0·1	−0·1	−0·1	−0·1	19 October 1972
	3	0·0	0·0	0·0	+0·1	7 August 1972
		+0·1	0·0	+0·1	+0·2	19 October 1972

Errors are also introduced by the difficulties of averaging out the effects of ship-induced acceleration (page 158). They can be reduced by mounting the PABs on fore-and-aft bulkheads because the sensitivity to rotation about an axis (A) along this direction is substantially less than for rotation about a horizontal axis at right angles to this (B). This is demonstrated by Table IV where typical changes in pressure readings for rotation about both axes are given. Because of the difficulty of finding suitable mounting points for the PABs on the ships it was only possible to use fore-and-aft bulkheads on *Researcher*: the other aneroids were mounted athwartships. Observers were instructed to average out as far as possible the fluctuations due to ship's motion (heave, pitch and roll) though this was difficult to do in the heavier seas. Systematic errors to be expected from the barometer's sensitivity to tilt would occur as a result of the ship's taking up a mean angle of roll due to wind on either beam (page 158). For *Adviser* and *Discovery* the magnitude of the error would be about 0·025 mb per degree of roll, with the sign of the error positive or negative for roll towards port or starboard respectively. The error for *Researcher* was about 0·005 mb per degree of roll.

TABLE IV—SENSITIVITY OF PRECISION ANEROID BAROMETERS TO PITCH AND ROLL (OBTAINED FROM STATIC TILT TESTS)

Angle of pitch (about axis B) *degrees*	Angle of roll (about axis A) *degrees*	Change in reading *millibars*
0	0	—
+10	0	0·2
+20	0	0·5
+30	0	0·75
−10	0	−0·3
−20	0	−0·55
−30	0	−0·75
0	+10	0·05
0	+20	0·1
0	+30	0·2
0	−10	−0·05
0	−20	−0·1
0	−30	−0·15

All pressure data recorded during JASIN 72 were 'as read' and corrections for calibration changes and for height above sea level were applied when the data were processed on an ICL 1905 computer. Allowances were made where necessary for variations in ship's draught during the voyage (changes of calibration with temperature were ignored: typical changes are about 0·1 mb for a 10-degC variation of temperature).

The resulting 10 000 or so routine pressure values are summarized in Table V in the form of mean daily pressure for each PAB. It is clear that there are persistent systematic differences between corrected data from different aneroids. Disagreements as large as 0·3 mb occurred between the readings of barometers which showed the largest calibration changes with time (for example the PABs on *Researcher*) and in these circumstances an accuracy in measurement of the pressure at the static head of ± 0·1 mb clearly cannot be claimed even when an average is taken of the readings from three PABs. On the other hand changes in differences between PABs are usually small, and, with the exception of one sensor on *Researcher*, within the range ± 0·1 mb.

The corrected PAB readings (x_{ijk}, $i=1,2$; $j=1, \ldots 3$; $k=1, \ldots\ldots 24$ (i=reading number, j=barometer number, k=hour number)) showed considerably more scatter than their daily means

$$\frac{1}{48}\sum_{i,k} x_{ijk}.$$

If it is assumed that differences between these daily means also apply to the hourly values it is then possible to correct the six observations obtained each hour on each ship to a common reference to give a new set of values x'_{ik} ($i=1, \ldots 6$). The daily averages of the resulting standard deviations

$$\frac{1}{24}\sum_{k}\left[\frac{1}{6}\sum_{i}\left(x'_{ik}-\frac{1}{6}\sum_{i}x'_{ik}\right)^2\right]^{\frac{1}{2}}$$

are given in Table VI. The least scatter was always shown by the readings on *Discovery*, a compliment to the observers, but probably the result also of the greater stability of this ship.

TABLE V—DAILY MEAN PRESSURES (LESS 1000 mb) AS MEASURED ABOARD THREE SHIPS IN SEPTEMBER 1972

PAB Date	*Adviser* (A) 1	2	3	*Discovery* (D) 1	2	3	*Researcher* (R) 1	2	3	Means A	D	R	State of sea*
2				34·60	34·60	34·74	34·59	34·71	34·68		34·65	34·66	M→S
3				36·88	36·88	37·03	36·90	37·08	36·99		36·93	36·99	S
4	32·70	32·86	32·89	32·78	32·85	32·99	33·37	33·52	33·55	32·81	32·87	33·48	M
5	24·93	25·12	25·12	25·07	25·13	25·24	25·25	25·43	25·53	25·06	25·15	25·40	M
6	16.30	16·46	16·46	16·01	16·08	16·16	16·14	16·24	16·27	16·41	16·08	16·22	S to M
7	14·79	15·02	15·05	15·16	15·24	15·32	15·31	15·50	15·46	14·95	15·24	15·42	M
8	16·07	16·24	16·27	16·96	17·02	17·10	16·96	17·17	17·17	16·19	17·03	17·10	M→R
9	19·29	19·53	19·50	19·29	19·32	19·43	20·04	20·31	20·35	19·44	19·35	20·23	R→M
10	24·10	24·28	24·31	23·86	23·85	23·95	24·37	24·61	24·68	24·23	23·89	24·55	M
11	27·30	27·46	27·50	27·29	27·31	27·39	27·56	27·83	27·90	27·42	27·33	27·76	M
12	29·27	29·47	29·53	29·27	29·29	29·41	29·25	29·51	29·57	29·42	29·33	29·44	M
13	29·34	29·50	29·57	29·47	29·50	29·62	29·36	29·57	29·65	29·47	29·53	29·53	M
14	27·42	27·56	27·61	27·73	27·76	27·86	27·12	27·37	27·43	27·53	27·78	27·31	M
15	25·78	25·95	25·99	25·85	25·87	25·94	23·98	24·23	24·34	25·91	25·89	24·18	S
16	26·49	26·68	26·73	26·24	26·27	26·35	25·72	25·93	26·01	26·63	26·29	25·88	S
17	31·11	31·24	31·33	30·82	30·91	31·04	30·70	30·96	30·93	31·23	30·92	30·86	S
18	30·53	30·72	30·78	30·50	30·57	30·71	30·61	30·87	30·87	30·68	30·59	30·78	M to R
19	24·41	24·60	24·67	23·83	23·90	23·94				24·56	23·89		M
20	19·45	19·67	19·71	19·56	19·64	19·70				19·61	19·63		M→R
21	18·29	18·50	18·56	16·55	16·60	16·68				18·45	16·61		R
22	16·35	16·59	16·65	13·86	13·98	14·08				16·53	13·97		VR
23	18·47	18·64	18·69	17·68	17·72	17·79				18·60	17·73		VR→R
24	19·02	19·32	19·34	18·04	18·12	18·19				19·23	18·12		M to R
25	14·64	14·87	14·95	13·56	13·66	13·69				14·82	13·63		R
26	18·49	18·69	18·72	18·33	18·41	18·46				18·63	18·40		R→M
27	21·85	22·09	22·09	21·54	21·60	21·63				22·01	21·59		M to R
28	14·54	14·80	14·81	14·42	14·51	14·56				14·72	14·50		M to R
29	03·49	03·65	03·70							03·61			R to VR
30	07·78	07·94	07·93							07·89			VR

* S Slight (wave height 0·6–1·25 m); M Moderate (wave height 1·25–2·5 m); R Rough (wave height 2·5–4·0 m); VR Very rough (wave height > 4·0 m).

TABLE VI—DAILY AVERAGE STANDARD DEVIATIONS OF HOURLY PAB READINGS

Date		Standard deviation	
	Adviser	*Discovery*	*Researcher*
September 1972		*millibars*	
2nd		0·029	0·062
3rd		0·029	0·047
4th	0·081	0·029	0·064
5th	0·063	0·026	0·058
6th	0·064	0·028	0·067
7th	0·076	0·038	0·059
8th	0·079	0·033	0·075
9th	0·093	0·046	0·061
10th	0·081	0·045	0·048
11th	0·069	0·042	0·053
12th	0·079	0·033	0·054
13th	0·066	0·034	0·055
14th	0·069	0·036	0·050
15th	0·050	0·037	0·066
16th	0·075	0·028	0·049
17th	0·069	0·032	0·046
18th	0·098	0·049	0·052
19th	0·077	0·035	
20th	0·072	0·039	
21st	0·083	0·059	
22nd	0·112	0·100	
23rd	0·096	0·055	
24th	0·083	0·042	
25th	0·090	0·029	
26th	0·081	0·045	
27th	0·069	0·045	
28th	0·100	0·049	
29th	0·086		
30th	0·075		

The aneroids were more favourably mounted in *Researcher* (fore and aft) and this is perhaps the reason for the standard deviations being smaller than those of *Adviser*. The standard deviation of the hourly observations corrected for systematic barometer differences was nearly always less than 0·1 mb and so a typical non-systematic error after averaging the six corrected readings would be less than $0{\cdot}1/\sqrt{6}$ mb. It appears then that the random effects of ship's motion and reading errors on the pressure observations were reduced to nearly negligible amounts after averaging. An attempt to assess systematic reading errors is discussed later.

Typical differences between the three pairs of PAB readings obtained hourly on each ship were about 0·2 mb, and this value may be used to give a rough idea of the accuracy with which the geostrophic wind may be calculated from the pressure data, provided that the errors due to disturbance of local airflow by the ship are ignored or else assumed to be of similar magnitude on each ship. These assumptions are not likely to be justified except in light winds.

A 10 per cent accuracy in geostrophic wind would require pressure differences between ships of about 2 mb. However, for most of JASIN the differences between ships were less than this. Clearly in these circumstances some improvement in the accuracy is required if geostrophic winds of acceptable accuracy are to be calculated. One possibility is by the use of intercalibration data obtained with the ships in close proximity.

(ii) *Effect of ship's heading on results.* Before discussing the JASIN intercalibration in detail some consideration must be given to the disturbance in the pressure field caused by the ships obstructing the airflow in their vicinity since these effects will be present when an intercomparison takes place. Calculations and measurements of flow round obstacles[4] show that velocity deficits usually occur both upwind and downwind of obstacles, but that excesses appear round the side and above the obstruction. Thus, depending on the positioning of the static head, pressures either above or below the free-stream value may be measured. Variations of 1 m/s in a free-stream velocity of 10 m/s produce a pressure change of about 0·1 mb.

Ships taking part in any operation such as JASIN 72 have a variety of hull shapes and will thus influence the airflow in different ways; it is therefore not possible for a single static head position to be found for each ship which would at least assure pressure errors of similar magnitude for each ship and hence negligible error differences between ships. The magnitude of the errors will be much reduced if the static head is mounted a considerable distance from the main superstructure (the results of Kondo and Naito[4] for flow across a triangular-shaped bank showed velocity perturbations of less than 10 per cent at approximately three times the bank height, and these results might be considered a rough guide for a ship lying-to (across wind), with the relevant vertical dimension now the average height of the superstructure). It had been the intention to mount the principal static heads very high on each ship in a well-exposed position but this was not found possible. Nevertheless it was hoped that the heads had been placed in positions with fair exposures where actual winds would not depart excessively from those in the undisturbed flow. Secondary heads in *Adviser* and *Discovery* were deliberately positioned in poorly exposed locations in order to obtain some idea of pressure variations over the hulls. Changes in the pressure field caused by the ships are roughly proportional to the square of the wind speed and so investigations of these changes are best carried out in at least moderate winds.

Variations of a few tenths of a millibar might be expected in winds of around 10 m/s (see above) but since the typical semi-diurnal pressure oscillation is about 0·5 mb in stationary synoptic situations it is important that any experiment should be carried out within a reasonably short space of time so that, for example, pressure changes due to variations of relative wind direction may be isolated from any diurnal or synoptic changes. In some cases it was not possible to achieve either of these criteria.

The first experiment of this nature was carried out aboard *Researcher* in winds of around 10 m/s (Table II, series 1) and occupied less than one hour. Observations were taken on 16 different relative wind directions and the initial and final pressures, obtained on the same relative bearing, were identical, suggesting only small synoptic changes. The standard deviation (S.D.) of the observations for each heading was calculated after corrections for mean differences between PABs had been made by using averages of all the observations in the series. Thus six pressure values were used to calculate the S.D.s on each heading. On average the value was about 0·05 mb and the standard deviation of the means was therefore about $0{\cdot}05/\sqrt{6} \approx 0{\cdot}02$ mb. The plotted mean values (Figure 1) demonstrate clearly that there are highly significant pressure changes up to 0·25 mb with changes of relative wind direction; also a small direction change may produce a relatively large pressure variation. The pressure distribution is

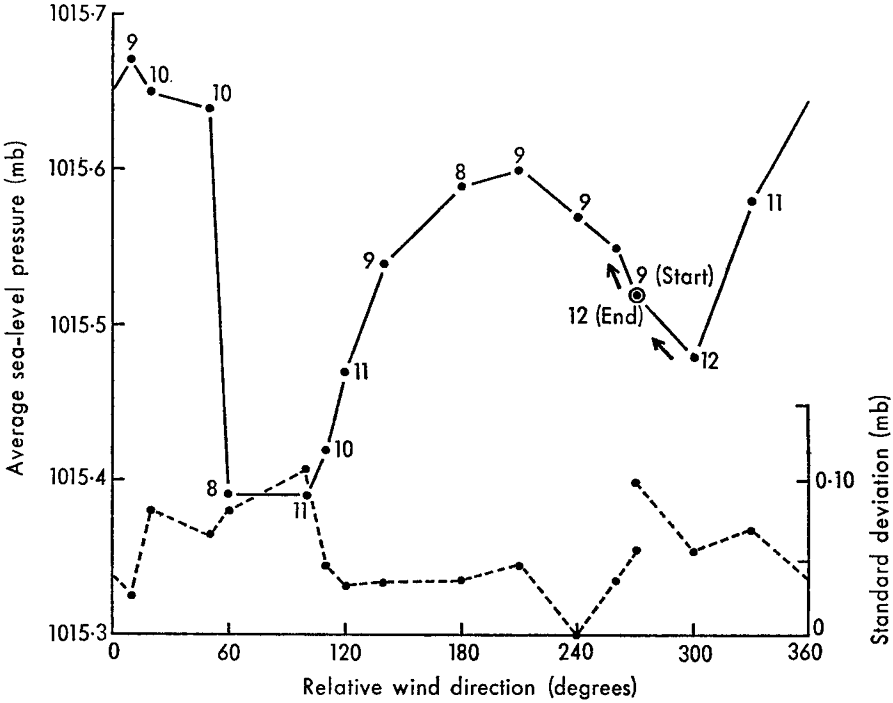

FIGURE 1—VARIATION OF MEASURED PRESSURE WITH RELATIVE WIND DIRECTION, FROM 1022 TO 1110 GMT ON 6 SEPTEMBER 1972 ('RESEARCHER')

The plotted points joined by continuous lines represent the means of 6 observations (2 from each precision aneroid barometer (PAB)). The standard deviations plotted in the lower part of the diagram are calculated from these observations after correction for systematic differences between PABs. Figures adjacent to plotted points denote wind speeds in metres per second.

consistent with stronger winds at the static head when the ship is lying-to rather than aligned alongwind. The pressure trough is more pronounced with the wind on the starboard beam and this is presumably because of the better exposure of the head for this wind direction than when on the port beam. There is also an indication of slight asymmetry in the pattern, with the highest pressure for wind along the approximate line 020–200 degrees, and this is probably due to the asymmetric position of the head. Which of the relative directions provides the 'correct' pressure is not of course revealed by the figure and must remain unknown in the absence of further data.

The second experiment aboard *Researcher* (Table II, series 2) occupied 10 hours, in winds of only 4 m/s, so although a considerable number of observations were obtained for a variety of relative ship headings it was not possible to separate variations of pressure with heading from those due to real changes in the pressure field even after applying a linear-trend correction to the observations.

The results from the two series of observations for different relative wind directions carried out aboard *Adviser* are plotted in Figures 2 and 3: a linear-trend correction has been applied to reduce the contribution from changes in the pressure field. On 10 September the mean wind speed was about 5 m/s and here the mean readings from port and starboard static heads on the mainmast agreed

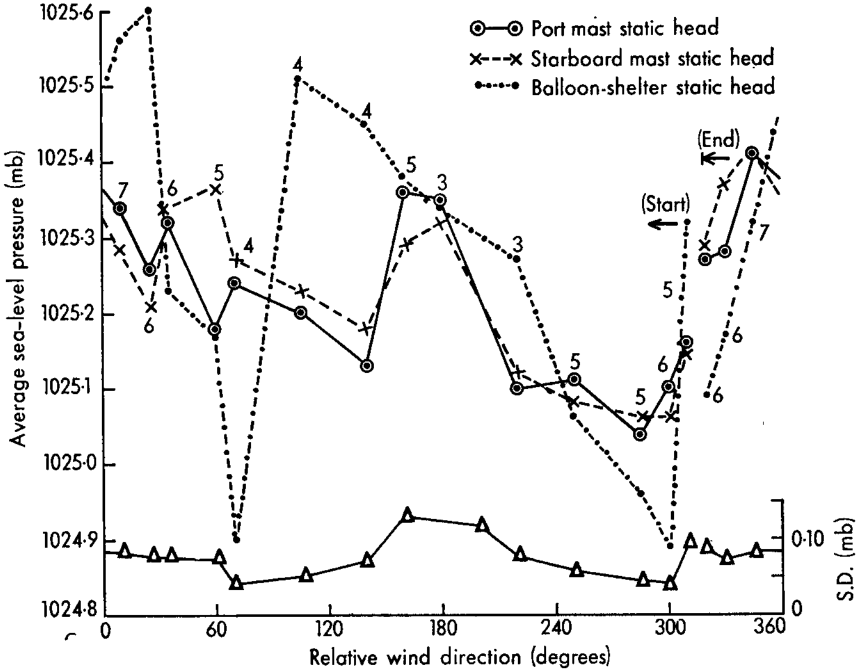

FIGURE 2—VARIATION OF MEASURED PRESSURE WITH RELATIVE WIND DIRECTION, FROM 1410 TO 1535 GMT ON 10 SEPTEMBER 1972 ('WEATHER ADVISER')

The plotted pressures represent the means of 6 observations (2 from each PAB). Figures adjacent to plotted points denote wind speeds in metres per second. The standard deviations are calculated as for Figure 1: plotted values are means of the standard deviation for each static head.

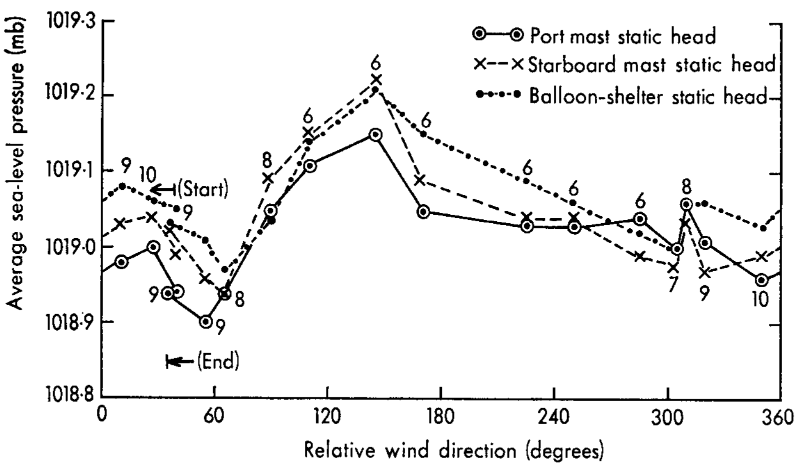

FIGURE 3—VARIATION OF MEASURED PRESSURE WITH RELATIVE WIND DIRECTION, FROM 0800 TO 0848 GMT ON 20 SEPTEMBER 1972 ('WEATHER ADVISER')

The plotted pressures represent the means of 6 observations (2 from each PAB). Figures adjacent to plotted points denote wind speeds in metres per second.

to within less than 0·1 mb on 16 out of 17 occasions, the maximum difference being 0·19 mb from a direction of 060°. The standard deviation of the 6 observations (reduced as before to a common mean pressure) for each static head was about 0·07 mb and the probable error of the mean was therefore about 0·03 mb. Differences between heads of 0·1 mb are thus highly significant. The experiment lasted nearly 90 minutes and some interference from synoptic changes of pressure must be expected but it appears that the mast-head values are higher with the ship alongwind and lower when it is acrosswind, in broad agreement with the results from *Researcher*, though the range of about 0·4 mb was higher than that found for *Researcher* in winds twice as strong. Pressures measured using the balloon-shelter static head showed very large departures from the others but showed slight similarities to the corresponding observations on 20 September (Figure 3) with peaks and troughs occurring for broadly similar relative wind directions. The wind was somewhat stronger in this latter case (about 8 m/s) but even so the port- and starboard-head values agreed to 0·08 mb or better. In contrast to 10 September the mast and balloon-shelter heads produced similar variations of pressure with wind direction. The pattern of variation for the mast heads is markedly different from that shown in Figure 3 and makes an interpretation of the results very uncertain. There is perhaps an implication that the airflow was relatively stronger when the ship was lying-to or headed into wind than when the wind was astern but the correlations appear rather weak. The probable random error of the mean was about 0·02 mb and the total variations of pressure with heading were about 0·3 mb.

The first experiment aboard *Discovery* where pressures were measured for different ship headings (Table II, series 8) was carried out in winds of about 8 m/s with both Kollsman and PAB sensors connected to the mast static head (the Kollsman readings are discussed below). The probable random error in the mean of the PAB values was about 0·02 mb for most of the experiment, rising to 0·04 mb near the end owing to increasing swell. The general shape of the PAB distribution (Figure 4) shows no obvious similarities to those obtained from *Weather Adviser* and *Researcher* for different headings and is therefore probably the result of changes in the pressure field (the experiment lasted about 150 minutes, and observation from *Adviser* showed a similar variation of amplitude at around this period: it is unlikely therefore that the broad shape of the distribution is the result of a variation of ship heading). (The results from the second experiment are included in the general discussion on the Kollsman observations on page 174.)

(iii) *Inter-ship calibrations.* Ideally the intercomparisons were required over a wide range of relative headings and wind speeds so that the routine PAB observations taken in any circumstances on the different ships could be corrected to a common standard. Because of the ship programmes and meteorological variability it was clearly impossible to do this, and the comparisons which were carried out provided rather limited information. Probably the most consistent series of observations was made on board *Adviser* and *Discovery* on 27 September (Table II, series 20, and Figure 5). Winds were between 6 and 9 m/s and the relative wind direction remained within the range 240 to 270 degrees and 360 to 020 degrees respectively for the whole series. After allowing for time differences between the observations the mean pressure difference was $-0{\cdot}10 \pm 0{\cdot}05$ mb. In another comparison between these ships on 4 September (winds of 8 m/s, Table II, series 16) *Adviser*'s heading relative to wind was 360 degrees and

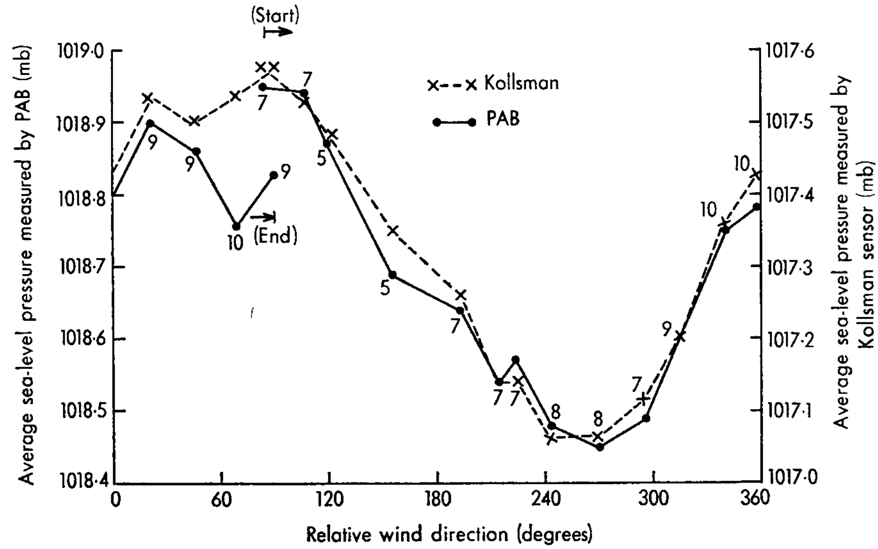

FIGURE 4—VARIATION OF MEASURED PRESSURE WITH RELATIVE WIND DIRECTION, FROM 0320 TO 0548 GMT ON 24 SEPTEMBER 1972 ('DISCOVERY')

Each plotted PAB value is the mean of 36 observations (12 from each PAB). Kollsman values are means of 100 one-second long observations made at 1·5-second intervals. Figures adjacent to plotted points denote wind speeds in metres per second.

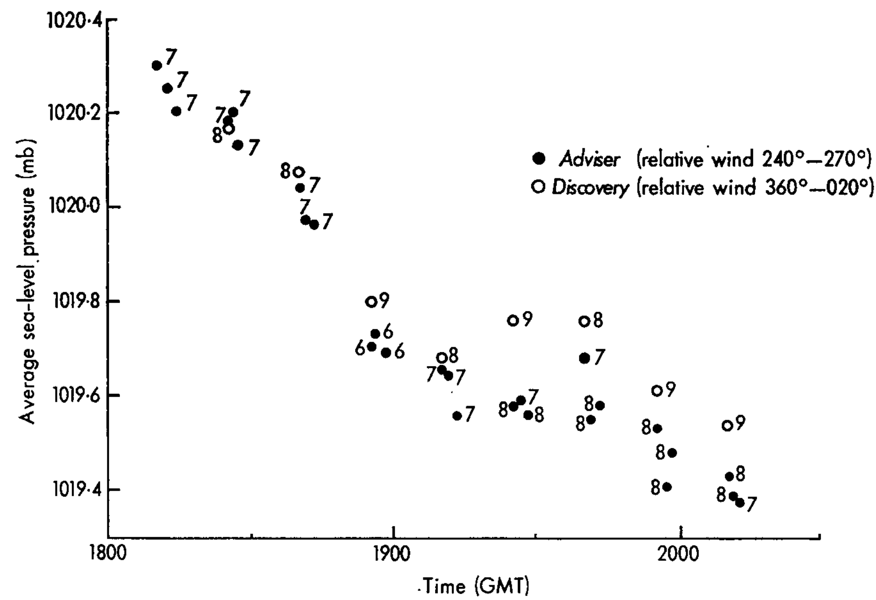

FIGURE 5—INTERCOMPARISONS BETWEEN 'WEATHER ADVISER' AND 'DISCOVERY' PRECISION ANEROID BAROMETER OBSERVATIONS ON 27 SEPTEMBER 1972

The plotted pressures represent the means of 6 observations (2 from each PAB). Figures adjacent to plotted points denote wind speeds in metres per second.

Discovery's 030 degrees. Each PAB was read nine times aboard *Adviser*, and twice aboard *Discovery*, with standard deviation of random errors 0·08 and 0·03 mb respectively: the mean difference was + 0·13 mb. The change of sign of the difference when compared to the other occasion is consistent with a change of airflow from abeam to along *Adviser*. On a third occasion on 18 September (Table II, series 19) winds were less than 3 m/s but a significant swell was present and the barometer readings showed considerable scatter especially on *Adviser*. The difference was −0·08 mb but this cannot be considered significant in view of a standard deviation for the *Adviser* observations (six readings only) of 0·16 mb.

The results of comparisons of readings made on *Discovery* and *Researcher* are given in Figures 6–8. In the first of these, carried out in winds of 5–6 m/s (Table II, series 17) three sets of simultaneous observations were taken while *Researcher* was lying-to but for *Discovery* the relative headings were 270, 360 and 030 degrees. All the *Researcher* values were lower, the average difference being 0·08 mb. Figure 1 suggests that on the basis of a square-law dependence on wind speed of the ship's influence on pressure there would be a difference of about −0·06 mb between *Researcher* observations for relative directions of 090 degrees and 360 degrees at 5 m/s. The results on 5 September suggest therefore that if the ships had both been headed directly into wind the measured pressures on each would have agreed very closely. Similar observations made on 18 September (Table II, series 19) in generally lighter winds but again with considerable variations in relative heading for *Discovery* gave a mean difference

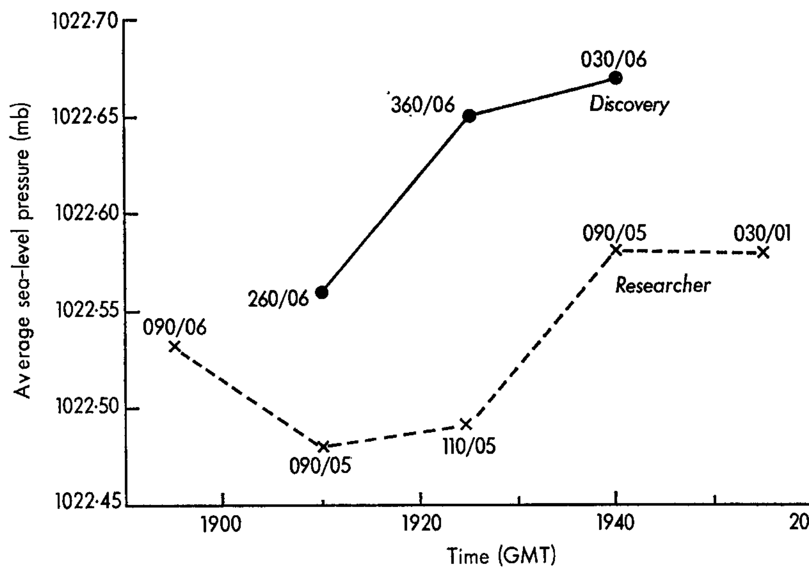

FIGURE 6—INTERCOMPARISON BETWEEN 'DISCOVERY' AND 'RESEARCHER' PRECISION ANEROID BAROMETER OBSERVATIONS ON 5 SEPTEMBER 1972

The plotted pressures represent the means of 6 observations (2 from each PAB). Relative wind direction and speed are shown in the form ddd/ff, where ddd is the relative wind direction in degrees and ff the wind speed in metres per second.

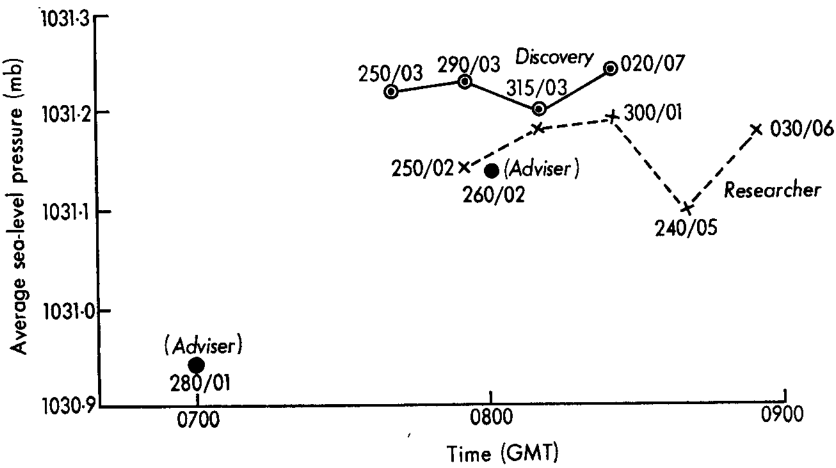

FIGURE 7—INTERCOMPARISON BETWEEN PRECISION ANEROID BAROMETER OBSERVATIONS FROM THREE SHIPS ON 18 SEPTEMBER 1972

The plotted pressures represent the mean of 6 observations (2 from each PAB). Wind speed and direction are indicated as in Figure 6.

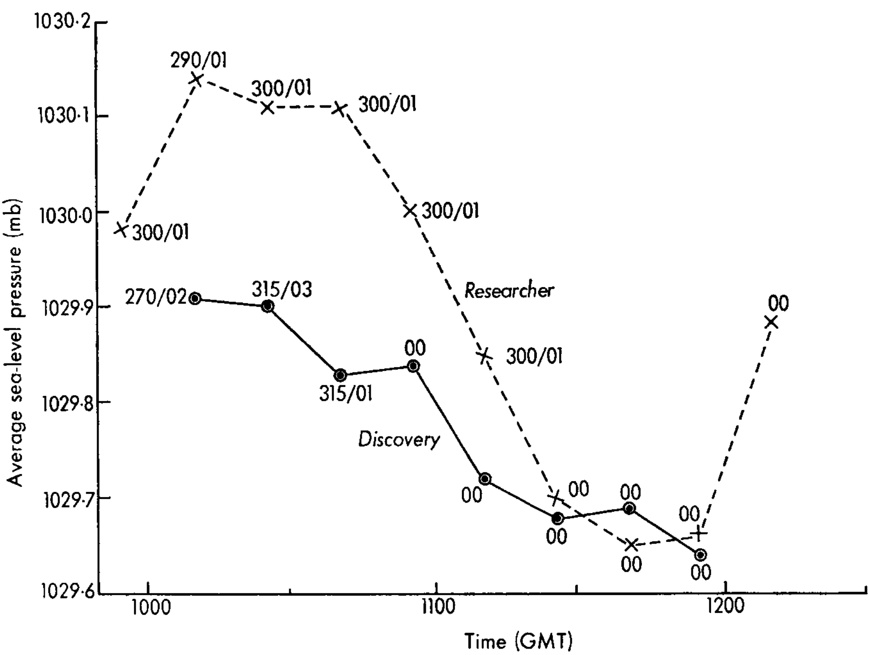

FIGURE 8—INTERCOMPARISON BETWEEN PRECISION ANEROID BAROMETER OBSERVATIONS MADE ABOARD 'DISCOVERY' AND 'RESEARCHER' ON 13 SEPTEMBER 1972

The plotted pressures represent the mean of 6 observations (2 from each PAB). Wind speed and direction are indicated as in Figure 6 (00 = calm).

of 0·05 mb, *Researcher's* figures again being the lower. An observation from *Adviser* during this period while adjacent was about 0·08 mb lower than *Discovery's*. However, the idea that the observations made aboard *Discovery* and *Researcher* are closely comparable, with significant differences partly explicable in terms of different relative headings, is apparently destroyed by an inspection of Figure 8 which shows results from 13 September (Table II, series 18). Here the relative wind speeds were very low so that the disturbing effects of ships on the pressure field should have been negligible. However, whereas the standard deviations of *Discovery's* observations were less than 0·05 mb (each PAB was read twice at each observation time and the S.D. was calculated as before for each set of six readings after correcting to a common standard by using the observed daily mean differences between the PABs) those from *Researcher* showed much more scatter, typical S.D.s being about 0·15 mb. On the other hand reference to Figure 9 suggests that most of the contribution to the S.D.s of the *Researcher* observations was non-random, since the spread of the two individual observations made with each PAB at each time was usually small (the spread is shown by the vertical bars). There is perhaps an indication here of systematic calibration changes over a short period of time. Table V supports the view that there can occur significant changes in the daily means of readings of PABs, and Table VII, (routine PAB observations aboard *Researcher* on 13 September) suggests that changes may occur on a much shorter time scale.

TABLE VII—OBSERVATIONS MADE ABOARD 'RESEARCHER' ON 13 SEPTEMBER 1972

Time GMT	PAB 1	PAB 2	PAB 3	2−1	3−1	3−2
		1029 mb +			*millibars*	
00	0·72	0·91	1·13	0·19	0·41	0·22
01	0·55	0·83	0·75	0·28	0·20	−0·08
02	0·34	0·55	0·59	0·21	0·25	0·04
03	0·11	0·23	0·35	0·12	0·24	0·12
04	0·09	0·29	0·42	0·20	0·33	0·13
05	0·11	0·28	0·45	0·17	0·34	0·17
06	0·01	0·28	0·35	0·27	0·34	0·07
07	0·13	0·35	0·52	0·22	0·39	0·17
08	0·42	0·71	0·72	0·29	0·30	0·01
09	0·65	1·01	1·11	0·36	0·46	0·10
10	0·85	0·88	1·15	0·03	0·30	0·27
11	0·75	1·21	1·05	0·46	0·30	−0·16
12	0·53	0·75	0·67	0·22	0·14	−0·08
13	0·85	0·98	1·08	0·13	0·23	0·10
14	0·79	0·93	0·92	0·14	0·13	−0·01
15	0·55	0·73	0·82	0·18	0·27	0·09
16	0·29	0·45	0·55	0·16	0·26	0·10
17	0·09	0·21	0·22	0·12	0·13	0·01
18	0·09	0·23	0·32	0·14	0·23	0·09
19	0·09	0·18	0·35	0·09	0·26	0·17
20	−0·01	0·15	0·25	0·16	0·26	0·10
21	0·19	0·31	0·47	0·12	0·28	0·16
22	0·31	0·65	0·65	0·34	0·34	0·00
23	0·26	0·53	0·59	0·27	0·33	0·06

The extreme differences between readings from PABs 1 and 2 on this day occurred at 1000 and 1100 and were observations actually included in the intercomparison with *Discovery*. Three observers took pressure observations during the intercomparison and it is feasible therefore that the systematic changes in differences between PABs are due to different ways adopted by individual observers of smoothing out fluctuations induced by ship motion. It is interesting

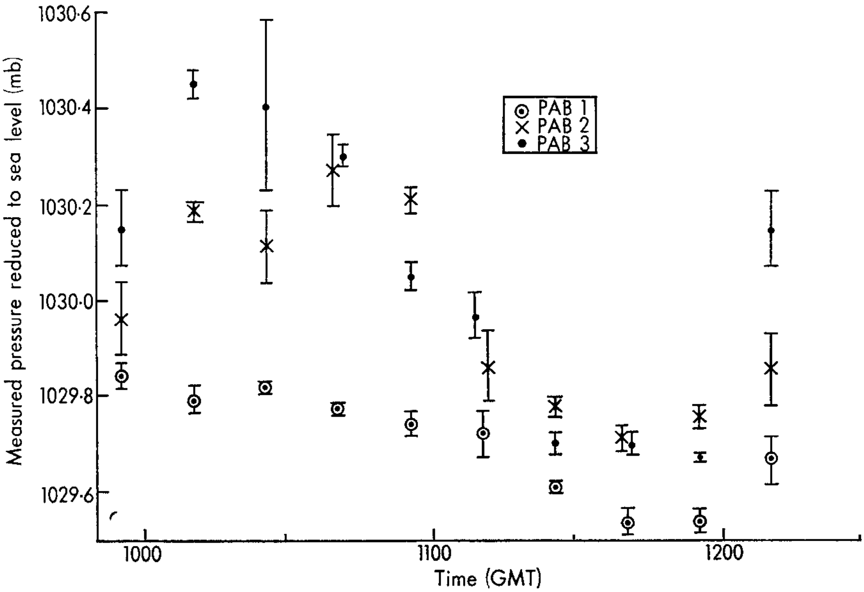

FIGURE 9—PRECISION ANEROID BAROMETER DATA FROM 'RESEARCHER' DURING INTERCOMPARISONS ON 13 SEPTEMBER 1972

The span of the individual observations and also their mean are shown for each PAB.

that the observations from *Researcher* most in apparent discord with those from *Discovery* (1010–1110, and perhaps 1210) were all made by the same observer whereas those in closest agreement (1125–1155) were made by two others. The extensive series of observations obtained with the Kollsman sensor aboard *Discovery* allow this possibility of observer bias to be explored in more detail below.

(b) *Kollsman readings.* The Kollsman device has the advantage of automatic averaging and print-out of observations. The shortest averaging time used was 1 second, and this gave an opportunity of investigating the effects of ship's motion on the output. During each of a number of 3-minute periods on 24 September (Table II, series 8) about 120 1-second averages were obtained, and the typical range of measured pressure was found to be 1·0 mb. Swell was only moderate at the time (less than 3 m) and it therefore appears that the Kollsman output is significantly affected by acceleration forces on the transducer. However, all the Kollsman data which will be discussed here were either 100-second averages or alternatively averages of observations of duration 1 second taken at 1·5-second intervals over periods of about 3 minutes and so the effects of acceleration or height displacements would have been reduced to insignificant amounts by this smoothing.

Figure 4 shows a comparison of Kollsman and PAB observations obtained by use of the same static head during the first of *Discovery's* series of special pressure measurements involving different ship headings relative to wind. The broad details of the shape of the PAB plot have been discussed already and the point of interest here is the disparity between this plot and that for the Kollsman data. Most obvious is the difference of about 1·4 mb between observations from the two types of sensors, a difference confirmed (at least approximately) by data obtained on other occasions. Clearly the Kollsman sensor had not been properly calibrated (the Meteorological Office standard against which the PABs were checked is accurate to about 0·1 mb and is checked against a National Physical Laboratory working standard every three months). It must be hoped that the Kollsman's error was systematic and did not reflect uncertainty either in short-term stability or in the slope of its calibration curve. After elimination of the systematic difference between the sets of recordings the residual maximum differences between averaged PAB and Kollsman observations were ± 0·04 mb except for the last two pairs. Here the difference increased to about −0·15 mb, because, it is believed, of increased difficulties in reading the PABs due to an increase in swell. The trend corrections used in the plots in Figure 4 were therefore derived from the Kollsman data.

Figure 10 shows the results of Kollsman measurements using all three static heads in turn in a wind of about 4 m/s. The observations were taken over a period of about two hours when significant changes in the pressure field were occurring and the linear-trend correction which was applied almost certainly failed to eliminate these entirely from the results. The basic shape of the distributions was probably not a consequence therefore of the variable heading of the ship. The second Meteorological Office head was mounted on the port

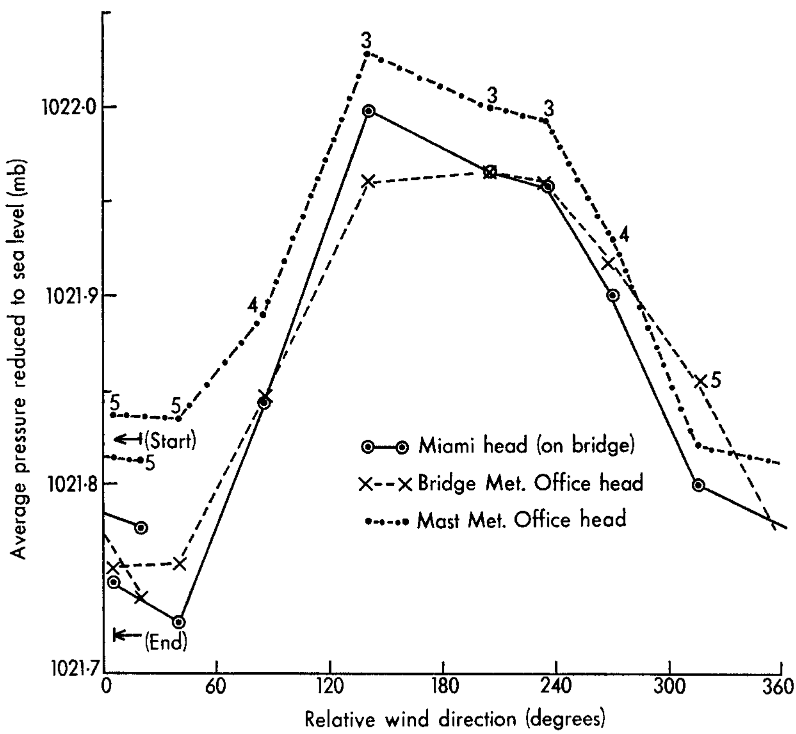

FIGURE 10—KOLLSMAN PRESSURE DATA FROM 'DISCOVERY' FOR THE PERIOD FROM 2320 GMT ON 26 SEPTEMBER TO 0132 GMT ON 27 SEPTEMBER 1972

The plotted points are 100-second averages. Wind speeds are expressed in metres per second.

guard rail of the lookout area on the monkey island, and the Miami head was positioned on the after rail of the island. Differences between pressures measured using these heads were usually less than 0·05 mb. For all observations but one the mast static head produced higher pressures, which is consistent with the stronger flow being in the region closer to the superstructure of the ship. Typical differences between mast-head and bridge-head readings were less than 0·05 mb.

Table VIII gives the differences between Kollsman and mean PAB readings for different headings on the same occasion, with both types of sensors connected to the mast static head, and also differences when the Kollsman and the single PAB on *Discovery*'s bridge were connected to the bridge (Meteorological Office pattern) head. The likely random error in the first case for the PAB mean was less than 0·02 mb. There were 36 readings at each heading, with a standard deviation of about 0·09 mb after correcting for systematic differences between PABs, and this is consistent with the observed small variations in the pressure differences between the two types of sensor. A similar scatter was found for observations with the single (bridge) PAB but the differences between the meaned values and the Kollsman showed substantially more variation than in the first case (Table VIII). The reason for this is not clear.

TABLE VIII—COMPARISONS BETWEEN BAROMETERS ON SAME STATIC HEAD ABOARD 'DISCOVERY', 26–27 SEPTEMBER 1972

	(Mast Head)		(Bridge Head)	
Relative wind (approximate)	Kollsman minus average of PABs	Difference from mean	Kollsman minus bridge PAB	Difference from mean
degrees	*millibars*		*millibars*	
360	−1·211	0·002	−1·155	0·040
315	−1·210	0·003	−1·277	−0·082
270	−1·177	0·036	−1·173	0·022
225	−1·226	−0·013	−1·249	−0·054
180	−1·194	0·019	−1·106	0·089
135	−1·209	0·004	−1·187	0·008
090	−1·225	−0·012	−1·168	0·027
045	−1·240	−0·027	−1·149	0·046
000	−1·221	−0·008	−1·287	−0·092

Data obtained on the 28th (Table II, series 14) provided a further opportunity to study the effects of different positions of static heads on measured pressure. Here all three heads were used in turn, usually at 5-minute intervals. The relative wind speed changed markedly during the period, from about 15 m/s during the first part to 6 m/s towards the end. Mean pressures for the two wind speeds are given in Table IX.

TABLE IX—KOLLSMAN OBSERVATIONS USING THREE STATIC HEADS ON 28 SEPTEMBER 1972 (SERIES 14)

		Mean pressures measured by		
Mean wind speed	Relative direction	Bridge (Meteorological Office pattern) head	Bridge (Miami pattern) head	Mast Static head
m/s	*degrees*		*millibars*	
15	010	1012·18	1012·10	1012·72
6	010	1013·05	1013·04	1013·14

The results confirm others discussed earlier, that is to say there were relatively small differences between bridge-mounted heads but significantly higher pressure at the mast static head particularly in the period with strong wind. As might be expected the difference between mast and bridge static-head values is roughly proportional to the square of the wind speed, and its magnitude suggests that (if Bernoulli's equation can be applied) the wind over the bridge static head is about 20 per cent higher than that at the mast static head.

During the period from 9 to 23 September (Table II, series 5) Kollsman readings were taken at 5-minute intervals using the Miami head, and therefore although the data cannot be directly compared with the routine PAB observations in order to assess, for example, the relative stability of the two types of transducer, they do provide an opportunity to investigate the effects of observer bias on the PAB data. Thus in spite of differences between the two sets of data varying with time, owing, for example, to the variation of the ship's heading, or relative wind speed, the number of hourly observations is large enough (approximately 350) for these variations to be distributed reasonably uniformly between the three observers involved in the PAB observations. The results are given in Table X in the form of means and standard deviations of differences between Kollsman and PAB readings for each of the three observers involved in the PAB observations. Observer 2 made observations with the smallest standard deviation and was presumably the most effective in averaging out the effects of ship's motion on PAB readings. Data obtained by Observer 3 had the largest scatter but otherwise they were closely comparable in the mean with those from Observer 2. In contrast, Observer 1 produced data which showed systematically higher values for each of the PABs, suggesting that he was using a reading technique somewhat different from that adopted by the other two observers.

TABLE X—OBSERVER BIAS IN PAB RESULTS (9–23 SEPTEMBER)

Differences between PAB and Kollsman readings

PAB	Observer 1 Mean	Observer 1 Standard deviation	Observer 2 Mean	Observer 2 Standard deviation	Observer 3 Mean	Observer 3 Standard deviation
	millibars					
1	1·349	0·236	1·309	0·216	1·288	0·252
2	1·394	0·249	1·345	0·227	1·347	0·278
3	1·491	0·236	1·439	0·219	1·437	0·264
Means	1·411	0·240	1·364	0·221	1·357	0·265

During the period 23–25 September (Table II, series 6, 7 and 9) the Kollsman and PABs were connected to the mast static head and the resulting observations allowed a further investigation of observer bias. The results appear in Table XI. Again the scatter was smallest for Observer 2 and largest for Observer 3 but in contrast to the results given above the highest average values were obtained by the latter. However, because of the relatively small number of data the largest difference between the means is significant to no better than about the 30 per cent level.

TABLE XI—OBSERVER BIAS IN PAB RESULTS (23–25 SEPTEMBER)

Difference between mean PAB and Kollsman readings

Observer 1 Mean	Observer 1 Standard deviation	Observer 2 Mean	Observer 2 Standard deviation	Observer 3 Mean	Observer 3 Standard deviation
millibars					
1·324	0·061	1·321	0·056	1·342	0·067

(On page 169 it was pointed out that one of the intercomparisons involving *Researcher* and *Discovery* produced some fairly strong evidence for substantial barometer errors apparently caused by the way in which one of the observers smoothed out the effects of ship's motion while he noted the PAB readings. In Table XII the mean values of the routine observations obtained by each observer aboard *Researcher* during JASIN 72 are listed. Each mean was calculated from about 120 observations, spread more or less evenly throughout the day (6-hour shifts were worked) so that the differences between means are expected to be affected to only an insignificant extent by normal diurnal pressure variations. Observer 2 appears to have made readings about 0·2 mb higher than the other two: he also made the anomalous observations in the intercomparison between *Discovery* and *Researcher*, which therefore appears to be subject to observer bias rather than short-term sensor drift.)

TABLE XII—MEAN VALUES OF OBSERVATIONS MADE ABOARD 'RESEARCHER' FOR EACH OBSERVER

Observer	1	2	3
Mean (mb)	1026·38	1026·60	1026·46

Conclusions. Wind speeds were generally low during JASIN 72 and it was therefore not possible to carry out all the shipboard pressure experiments in conditions ideal for revealing the ship's disturbance of the local pressure field, but a number of useful results have emerged. In particular the Meteorological Office PAB appears not to be reliable to better than about $\pm$ 0·2 mb. However, the relative accuracy, found by comparing the daily mean values for each PAB on each ship separately, was with the exception of one sensor on *Researcher* within the range $\pm$ 0·1 mb.

Intercalibrations with ships in close proximity are clearly useful in giving data which may be used to reduce relative pressure errors *between* ships but necessarily demand that the ships involved take up orientations with respect to wind which are used in the routine observations since the ship-induced perturbation of the pressure field has been demonstrated to vary significantly with relative heading. However, the perturbation depends also on wind speed, and a range of wind speed would usually be achieved during an intercalibration only by ships heading into wind at various speeds, thus limiting the chosen relative direction to 360 degrees. On the other hand the present results support the idea that the perturbation is roughly proportional to the square of the wind speed and so, provided that the intercalibrations are carried out so as to include observations in *zero* relative wind, the corrections for the different headings can be deduced for speeds other than those occurring at the time of intercalibration. Clearly the intercalibration needs to be carried out in the shortest possible time (to avoid complications due to changes in the pressure field) and in strong winds (where perturbations are large).

The results have demonstrated fairly conclusively that observers differ in the way in which they smooth out the effect of ship motion on the PAB values, at best producing different amounts of scatter and at worst systematic differences in the mean. The solutions here (in the absence of modifications to provide automatic averaging and print-out) are to establish a uniformity of reading standard by training, to have all observers participating in intercalibrations, and to mount PABs with fore-and-aft orientations in order to decrease effects of ship's motion. The results from *Discovery* demonstrated that in a larger ship, even with athwartship orientation of PABs the observer differences may be as small on average as 0·05 mb.

The Kollsman sensor on *Discovery* appeared to function satisfactorily: however, it was surprising to find a calibration error greater than 1 mb. There was no evidence of any drift; for example the mean difference between PABs and Kollsman for series 5, and for series 6, 7 and 8 were respectively 1·38 and 1·33 mb: the small disparity in these values is explicable in terms of the two different positions of static head used in series 5. The 100-second averaging capability of the device was invaluable though it should be pointed out that the multiple-recording technique used for the PABs can also be very successful in reducing fluctuations of pressure due to ship acceleration.

As expected the experiments have not given much useful information on the most advantageous placing of the static heads. It is believed that the effects of ship's influence cannot be satisfactorily reduced by any particular, uniquely specifiable placing of the static head and so the best chance of making accurate pressure measurements may come from applying corrections to observations using the air velocity at the static head and an estimated 'free-stream' velocity at the same height in Bernoulli's equation. The first velocity might be measured fairly easily with a small cup anemometer and the second could be obtained with sufficient accuracy from an upward extrapolation of speed measured on an adjacent *meteorological* buoy. The type of buoy is stressed here because such an anemometer would have to be well exposed in order to measure speeds to within the required accuracy of a few per cent, and thus the buoy would have to be relatively uncluttered.

Acknowledgements. Installation of the PABs and static heads was carried out by D. Winters and D. R. Davies. Thanks are due to the Masters and crews of R.R.S. *Discovery*, m.v. *Researcher* and O.W.S. *Weather Adviser* for their co-operation and to the observers for their diligence in obtaining the PAB data.

Professor E. B. Kraus of the School of Marine and Atmospheric Science, University of Miami, provided the Kollsman sensors and made available data obtained by them.

The Institute of Oceanographic Sciences supplied on magnetic tape all the routine meteorological data from JASIN (including PAB observations).

Miss S. A. Matthews carried out most of the data processing.

Particular note should be made of the efforts of Dr R. T. Pollard, including the co-ordination of the Kollsman and PAB measurements on *Discovery*, and arranging the supply of Kollsman data and the re-formatting of data on magnetic tape.

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NOCTILUCENT CLOUDS OVER WESTERN EUROPE AND THE ATLANTIC DURING 1974

By D. H. McINTOSH and MARY HALLISSEY
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Positive observations of noctilucent clouds (NLC) between 26 May and 8 August 1974, made by the network of observers associated with the Data Centre at Edinburgh, appear in Table I. This network, which is associated with the Aurora Survey, consists of professional meteorological staff (on land and at sea) in Great Britain and Ireland, voluntary amateur observers, most of whom are members of the British Astronomical Association, voluntary observers in Denmark and Norway and aircrew personnel of British and Dutch aircraft. The Survey is financed by a grant from the Royal Society, with additional finance from the Meteorological Office. The data after analysis are sent to the other World Data Centres at Tartu and Toronto; reprints of this report are sent to scientists at home and abroad who are interested in the study of the phenomenon, and information is readily available, along with series of photographs, to workers in the field.

The dates in Table I cover the period of optimum viewing of the clouds between geographic latitudes 50° and 60°N. The period of time during which the clouds were observed appears in the second column, and should not necessarily be taken as the full extent of the display; this is stated where possible, but it is obviously difficult, particularly for voluntary observers, to record a display to the point of disappearance. Brief notes on the displays appear in the third column. In the remaining columns details of the relevant station co-ordinates are listed to the nearest half degree, and where known the maximum elevation and limiting azimuths of the observed cloud.

TABLE I—DISPLAYS OF NOCTILUCENT CLOUDS OVER WESTERN EUROPE AND THE ATLANTIC DURING 1974

Date—night of	Times	Notes	Station position*	Time	Max. elev.	Limiting azimuths
	UT			UT	degrees	degrees
26/27 May	2120–2150	Bands, billows and whirls with veil background extending almost to zenith in NNW.	51N 01E	2120	80	290–040
29/30	2125,2150 0150	Veil to 12° and outlining bank of tropospheric cloud, with two separate bright patches of NLC at higher elevation. At 0150 possible sighting from southern Ireland.	53N 0·5E	2150 0150	60 40	330 360–045
			52N 10·5W	0150		
			51N 01E	2125	20	320–010
3/4 June	2325	NLC suspected visible south-west Scotland.	55N 04·5W			
7/8	0045–0120	Bright banded area of NLC seen north-east Scotland and from OWS *Weather Adviser*	58N 14·5W	0100	20	360–020
			57N 02W	0045	14	360–020
8/9	0016–0350	NLC suspected visible 2300 south-west Scotland. Identified from North Wales after midnight as medium bright band low above N horizon. Two bands visible 0030 and 0045. Visible central England 0150, ill-defined and faint.	55N 04·5W			
			53·5N 03W	0016 0030,0045	3 4	 345–360
			53N 01·5W	0150 0310	15 20	360
9/10	2130	Bands and whirls in complex formation against veil background centred on Vega; bright banded area also against veil background to 20° in NNW. Southern edge of veil beyond observer's zenith.	51N 01E	2130	130	315–090

* To nearest 0·5 degree.

TABLE I—*continued*

Date—night of	Times	Notes	Station position	Time	Max. elev.	Limiting azimuths
	UT			UT	*degrees*	
12/13 June	2115–0400	NLC first seen south-west Scotland.	56·5N 07W	0145	30	045
		Bands seen central Scotland	56N 04·5W	2250	16	340–010
		2250–2325, only slight eastward	55·5N 07·5W	0050		325–040
		movement with sun until obscured	55·5N 04·5W			
		2325. From OWS *Weather*	55N 04·5W			
		Monitor NLC described as ill-	54N 10W			
		defined but with clear eastern edge,	54N 01·5W			
		fading S-N from white to sepia at	53·5N 09W			
		horizon.				
		From eastbound KLM aircraft	53N 51W	0200	1	045
		report of NLC 0200–0400; veil,	54·5N 36·5W	0300	5	
		bands and billows; simultaneous	55N 25W	0345	30	
		auroral appearance 0200 over				
		W Atlantic.				
13/14	2345	Faint, diffuse bands of NLC; little	55N 04·5W			
	0030–0100	movement. Upper band	54N 0·5W	0030	13	345–025
		brightening but later obscured by		0055	15	
		moonlight.				
15/16	2135	Bright veil to approx. 15° elev. with	51N 01E	2135	20	315–045
		detached bright patch in NNW				
		showing band structure.				
19/20	2247	Queried reports of NLC possibly to	57N 02W			
		high elevation in NE from north-	53·5N 03W			
		east Scotland and north-west England.				
20/21	2110–0130	Extensive though not brilliant dis-	57N 02W	2315	3	315
		play. Widely reported over Great	56·5N 03W	2354	38	
		Britain and Ireland, most clearly		0005	44	
		from central Scotland and northern		0046	44	
		Ireland. At 2300 large area of	56N 04·5W	2140	20	290–310
		parallel bands and transverse		2230	30	290–310
		billows detected. After midnight		2300	45	280–350
		these appeared from northern	55·5N 07·5W	2300	14	330–010
		Ireland and central Scotland as	55·5N 05·5W	2345	10	310–330
		two wide and bright bands, and at	55·5N 04·5W	2355	15	290–330
		2330 from southern Ireland as two	55·5N 03W	2400	20	
		intersecting bands.	55N 04·5W			
		A photograph of the clouds from	55N 03W			
		central Scotland at 0040 shows	54·5N 08W	0001	10	320–350
		faint band and billow formation and	54·5N 06W	0005	9	320–350
		clearly indicates their extension	53N 08W	0010	12	
		almost to the zenith.	52·5N 09W	2330	5	
21/22	2330	Possible NLC; no detail.	55N 04·5W			
22/23	2145–2350	Possibly faint NLC.	55N 04·5W			
24/25	2140–2155	Early sighting partly obscured by	58·5N 03W	2140	10	360–020
	2345–0200	low tropospheric cloud. After mid-		2155	2	
		night southward extension with veil,	56·5N 07W	0045	20	360
		bands and billows identified.	56·5N 03W	0005	32	
			55·5N 07·5W	0050	12	315–010
				0150	42	340–050
			55·5N 04·5W	0105	15	330–360
25/26	0247–0420	From eastbound British Airways air-	48N 50W	0247	1	340–030
		craft report of simultaneous	50N 40W	0333	2	340–035
		appearance of aurora and NLC, the				
		latter at very low elevation.				
		Horizontal bands of varying bright-				
		ness and fibrous 'mares' tails'				
		structure identified.				
29/30	2345,0145	NLC seen as bright band from	56·5N 07W	2345	9	015–030
		northern England. No other details.	55·5N 01·5W	0145	15	360–030
			54N 04·5W	0145	10	360, 020
3/4 July	2350–0200	Clear sightings from central and	57·5N 07·5W	0100		340–070
		north-west Scotland identify bands	56·5N 07W	0050	11	350–035
		and whirl formation; whirl patches		0150	16	
		very bright 0115. Possible sighting	56·5N 03W	0100	5	330–090
		from central England hampered by	53N 01·5W	2350	15	360
		tropospheric cloud.				
5/6	0700–0800	From aircraft over western North	50N 97W	0700	1	335–045
		America report of simultaneous	51N 94W	0725	7	045
		aurora and bands of NLC; aurora	52·5N 90W	0740	14	310–100
		associated with large-scale solar				
		activity and reaching low latitudes.				
		Both phenomena faded with daylight				
		0800.				
6/7	0030–0210	After clearance of heavy cloud at	57·5N 03·5W	0100	22	310–050
		2400 NLC patches of varying				
		intensity visible north-east Scotland;				
		faded by 0210.				
8/9	0130–0230	Early sighting of faint bands to high	57·5N 03·5W	0130	28	045
		altitude seen from northern	55N 10·5W	0215	35	350–022
		England. Later sightings from	54N 01W	0145	19	345–030
		OWS *Weather Surveyor*, north-east	53·5N 03W	2200	20	330–360
		Scotland and northern England;				
		described from northern England as				
		'brilliant veil' above low band of				
		tropospheric cloud.				

TABLE I—*continued*

Date—hight of	Times	Notes	Station position	Time	Max. elev.	Limiting azimuths
	UT			UT	*degrees*	
9/10 July	2150–0250	First sighting of display in NW	57N 02W	2215	70	290–360
		quadrant from central Scotland;		0200	75	290–350
		brightest to W with fibrous struct-	56·5N 03W	2215	40	315–360
		ure stretching to N up to 50°. At		2250	25	320–040
		2215 in area to W zenith of station	56·5N 02·5W	2230		
		in north-east Scotland structure	56N 04·5W	2240	40	310–060
		described as thickened southern	56N 03W	2150	50	315–360
		edge with series of billows	54N 01W	2210	25	340–010
		stretching towards north. Clouds	53·5N 03W	2220	16	325–020
		now seen from northern England.	53N 01·5W			
		At 2230 from central Scotland bands seen to appear in north-east as well as higher patch in north-west. After midnight formation of further bands in NNE, and structure clearly billowed at 0037 up to 15° as seen from north-east Scotland; at 0130 herring-bone formation visible. At 0200 patches of featureless cloud visible north-east Scotland up to 75°. Cloud suspected visible central England 0250.				
10/11	2115–0300	Clouds observed through binoculars	57N 02W	2340	10	300
		2115 in Denmark as faint bands		0025	15	335–045
		NNE–NE and by 2205 through		0105	70	320–085
		gaps in tropospheric clouds. From	56·5N 03W	0100		360–045
		north-west England at 2230 seen as	55·5N 03W	2250	16	340–360
		delicate bands and billows. In	55N 14·5E			
		north-east Scotland at 0105 parallel	54·5N 06W	2330	5	330–340
		bands clearly distinguished almost to	54N 04·5W	2240	10	350–020
		zenith NW–NNE.		0135	20	345–035
			54N 01W	0150	5	350–360
			53·5N 03W	2230	7	350–015
11/12	2150–0300+	Presence of NLC suspected south-	57·5N 07·5W	0150	19	030–060
		west Scotland 2150. Seen northern	57N 02W	0015	60	290–020
		England 2230 as bright bands.		0152	50	
		Photographs and sketches show		0215	90	
		bands, billows, whirls with wisps to	56·5N 07W	2330	10	340–020
		high elevation. Development noted		0030	15	350–030
		0100–0140 of longitudinal position		0100	25	350–060
		of bright band in NW. At 0145		0240	90	360–070
		whole display reported from north-	56·5N 03W	2336	8	350–020
		east Scotland to be moving south-		0009	20	020
		wards so that northern edge of		0100	17	010–020
		cloud appeared to be 5° clear of	55·5N 01·5W	0020	4	340–020
		N horizon. NLC visible in northern		0145	8	
		Ireland and north-east Scotland to	55N 04·5W			
		0300 when it was also reported	54·5N 06W	0010	7	330–020
		visible from aircraft over eastern	54N 01W			
		Atlantic.	53N 15W			
12/13	2310,2315	Faint NLC seen from south-west	56·5N 03W	2315	19	345
		Scotland; two patches of the cloud	55N 04·5W			
		also reported from central Scotland.				
13/14	2140–2215,	Unspectacular appearance of NLC	55N 04·5W	2140	15	360–045
	2250	seen from south-west Scotland and	54N 09W	2250	15	345
		western Ireland. No forms discernible.				
14/15	0050–0125	Very bright patch of NLC seen	57N 02W	0100	25	320–035
		from north-east Scotland with billow formation central to banded areas. Diffuse and weak band of NLC suspected to be in zenith of this station.				
15/16	2205–0035	Extensive and comparatively bright	56N 04·5W	2300	90	
	0230–0400	NLC seen from central Scotland to	53·5N 58W	0230	10	
		elevation 70+°, few strands of the	54·5N 30W	0400	10	
		cloud up to 90°. Bands, billows with single layer veil formation overhead. Pilot of KLM aircraft observed brilliant blue NLC during Atlantic crossing 0230–0400 with unchanging elevation 5° to 10°. Simultaneous aurora recorded 0230–0400 from this aircraft.				
17/18	2340–0245	Widely reported and extended	60N 01W	0100	30	330–040
		display inspiring many sketches and	59N 03W	0015	18	320–055
		drawings. Most southerly reporting		0115	23	330–065
		station records 'beautiful display of	56·5N 07W	2340	10	350–010
		bright green closely packed and		0150	15	340–030
		intricate bands and billows.	56·5N 03W	0145	9	360
		Although of limited altitude the	55·5N 07·5W	2350	4	360–040
		display was very bright and the		0145	6	360–045
		most satisfying I have so far		0215	5	350–070
		observed'.	55·5N 05·5W	0100	5	345–045

TABLE I—*continued*

Date—night of	Times	Notes	Station position	Time	Max. elev.	Limiting azimuths
	UT			UT	*degrees*	
17/18 July *continued*			54·5N 06W	0120	4	355–050
				0150	4	020–060
			54·5N 01·5W	0105	5	350–005
				0154	6	357–020
			54N 04·5W	0145	15	350–050
			54N 01W	0050	3	360
			53·5N 03W	2350	3	350–005
				0200	6	350–050
19/20	2225–0030	Static display of S-shaped band of	56·5N 03W			
		NLC with faint transverse billows.	56·5N 02·5W			
			52·5N 07·5W	2245	5	360
21/22	2150–0315	Excellent photographs (a) from	57N 02W			
		Denmark show the early stages of	56N 10E	2110	30	270–360
		the display with veil, bands and		2245	15	–045
		billows: (b) from England show the	53·5N 03W	2315	20	350–030
		clouds after 0200 with very bright	53N 0·5E	2150	5	015
		cloud mass, banded structure and		0220	7	335–040
		billows to NNE, and indication of		0302	8	350
		faint cloud to higher elevation.				
		This higher-elevation NLC also				
		suspected from north-west England.				
22/23	2330–0210	Observers at many stations	60N 01W	2350	90	
		prevented at times by tropospheric		0050	25	345–060
		clouds from seeing obviously	59N 03W	0100	14	330–050
		extensive NLC. Fibrous veil and	58·5N 03W	0050		315–045
		well-defined bands, billows and	57N 02W	0100	5	060
		whirls identified. At 0100 cloud		0140	18	340–050
		field seemed to move eastwards;	56·5N 03W	0045		020–060
		sharply defined horizontal billows	55·5N 01·5W	0145	10	350–020
		changed to appear by 0114	55N 03W	0045	6	350–020
		transverse and diffuse.		0130	9	350–040
			54N 01W	0001	2½	360–030
			53·5N 01W	0220		
			53N 01·5W	0140	5	020–050
23/24	2350–0300	Less widely reported display, though	59N 19·5W			
		bands and billows clearly defined.	56·5N 07W	0050	8	350–030
		Simultaneous appearance of aurora		0200	14	360–050
		reported from OWS *Weather*	56·5N 03W	0145	11	350–070
		Reporter. Whirl forms observed		0245	15	020–040
		from central Scotland.	56N 04·5W	0200	12	340–030
			55·5N 04·5W	0200	20	040–080
			55·5N 01·5W	0140	3	350–040
				0200	5	
26/27	2355–0135	Small traces of NLC moved	60N 01W	0035	8	340–020
		sufficiently far south for bands to		0050	5	340–020
		be identified; brightest 0050.				
27/28	2400–0220	NLC seen mainly as fibrous	59N 03W	0150	15	360–020
		structure with more intense	58·5N 03W			
		patches. Bands and billows	57N 02W	0008	20	300–070
		discernible from north-east		0147	25	330–020
		Scotland with southwards	56·5N 07W			
		extension of cloud area in	56·5N 03W	0130	5	360
		approaching dawn.		0145	10	020–040
28/29	2325–0220	Faint display; little structure.	57N 02W	2350	3	020
		Faded into dawn 0220.		0050	5	045
			56N 03W	0200	5	
			56·5N 03W	2400	1½	360
				0130	3	360–015
29/30	0050–0235	Narrow bands distinct against veil	59N 03W	0050	15	020–030
		background of very-low-elevation	56·5N 03W			
		NLC.	55·5N 04·5W	0150	5	350–040
			55·5N 03W	0145	5	355–015
				0215	8	
			55N 03W	0140	6	340–040
				0220	8	350–040
			54N 01W	0145	1½	360–020
31 July/	2215	Possible sighting from south	59N 09E	2215	58	340–020
1 Aug.		Norway. Clouds bright near NNW				
		horizon and stretching almost				
		to zenith.				
1/2 Aug.	2300–2330	Possible sighting of NLC from	53·5N 03W	2300	1	360
	0030	North Wales; low bright band near				
		N horizon, sepia tinged.				
2/3	0300	Distant NLC seen as very-low-	58·5N 03W	0300	3	325
		elevation 'lenticular' patch.				
4/5	0050	NLC patch; no details.	59N 03W	0050	20	350–010
7/8	2100–2140	Bright and short-lived appearance	56N 10E	2100	7	340–045
		of banded NLC seen from Denmark.		2115	5	
		Westward movement with decreasing				
		brightness and elevation.				

The clouds were reported to the Laboratory on 41 nights between 26/27 May and 7/8 August, 22 being during July, with an almost unbroken series from 5–24 July. Although information for the 'blank' nights of this series has been carefully examined, it is not possible to conclude firmly whether or not clouds were present. A single observation of possible NLC on 7/8 July was regarded as doubtful because of reported clear conditions at stations in the area at that exact time; reports for 16/17 July show mixed cloudiness, but 18/19 and 20/21 July show almost 100 per cent cloud cover. Many observers identify the clouds at times of large amounts of tropospheric cloud, whereas unless perfectly clear conditions exist at several stations throughout the twilight period, visual evidence of their absence is incomplete—factors which form only a part of the complex problem of calculating probability of occurrence.

Numerically, the peak of the observing period in 1974 was again in the first half of July and not, as in 1973,[1] in the latter part of June. A 10-year chart, which it is hoped may be published at a later date, shows a more marked contrast between these two half-months in the years 1967 and 1974.

Simultaneous appearances of NLC and aurora were reported on five occasions, four reports came from aircraft personnel and one from a Weather Ship observer. On 12/13 June, the pilot of a KLM aircraft noticed the NLC when observing details of the aurora over the western Atlantic. The clouds were unfamiliar to him, but realizing their unusual nature and having roughly computed their great height, he sketched their structure during two hours of transatlantic flight.

We trespass on the territory of another Data Centre with the report of simultaneous aurora and NLC on 5/6 July, when the aircraft concerned was *en route* from Los Angeles. The extensive equatorwards spread of the aurora was part of the activity associated with the solar outburst of early July. The flying height of the aircraft was 33 000 ft, and when first noticed the NLC was seen on the pilot's horizon.

The number of nights when NLC was reported overhead in southern England, i.e. two, is the same as during 1973. The clouds were reported overhead in the mainland of Scotland on a further six nights.

Among photographs taken were series from Aberdeen for 9/10, 10/11, 11/12, 22/23 and 28/29 July; from Dundee for 11/12 July; from West Raynham for 21/22 July and from Alrø, Denmark, for 21/22 July.

The help of the many observers who have sent reports and sketches to the Data Collection Centre at the Balfour Stewart Laboratory, Department of Meteorology, University of Edinburgh, is gratefully acknowledged.

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REVIEWS

Automatic air quality monitoring systems (Proceedings of the Conference held at the National Institute of Public Health in Bilthoven, The Netherlands, 5–8 June, 1973) edited by T. Schneider. 250 mm × 170 mm, pp. xvi + 267, *illus.*, Elsevier Scientific Publishing Company, Jan van Galenstraat 335, Amsterdam, The Netherlands, 1973. Price: Dfl. 42.

In common with many conference proceedings, this publication contains papers of variable scientific content, degree of complexity and standard of presentation.

The purpose of the symposium was to exchange knowledge on existing and planned automated air-quality monitoring systems and the analysis of air pollution data. It contains 18 papers almost entirely concerned with the monitoring of urban pollution. They can be divided into the following categories:

One paper describes the measuring techniques applicable to automated networks; two give basically historical and organizational accounts of the United States and United Kingdom sampling networks; three describe planned or operating automated sampling systems and one describes the results obtained from such a network.

A further seven papers deal with data analysis and presentation and urban pollution modelling and one paper is concerned with the mesoscale and large-scale transport of sulphur dioxide and sulphate particles.

In addition to the papers, the conference discussions have been reproduced. These make interesting reading and help considerably in placing the papers in context. Unfortunately discussion does not always follow the papers in the appropriate place. This causes great difficulty in following the discussion in some cases.

Although many of the papers make reference to the importance of meteorological measurements and forecasting in air pollution monitoring, none discusses meteorological aspects in any detail. The claim is made several times that 'real time' information on pollution concentrations is required as well as meteorological information if forecasts of pollution levels are to be made. However, it seems that forecasts on time scales as short as fractions of an hour are contemplated. When forecasting longer-period average concentrations the requirement for 'real time' pollution data seems less important.

The papers and particularly the discussions in this volume highlight the varied approaches to pollution control adopted by different countries and the consequent need for a range of air monitoring systems. The requirements very all the way from a continuous flow of 'real time' pollution data through continuous measurement but delayed presentation to the measurement of daily, weekly or monthly averages of concentrations.

The discussion of these different philosophies of pollution control sets the technical problems and costs of the various monitoring systems in context.

To sum up, this volume contains interesting accounts of pollution measurement systems and some illuminating discussion of the varied control philosophies. It contains little of direct meteorological interest.

J. L. BROWNSCOMBE

Energy fluxes over polar surfaces. Proceedings of the IAMAP/IAPSO/SCAR/WMO Symposium, Moscow 3–5 *August* 1971. WMO *Technical Note* No. 129 (edited by S. Orvig). 270 mm × 210 mm, pp. vii + 299, *illus.*, Secretariat of the World Meteorological Organization, Geneva, Switzerland, 1973.

As indicated in the subtitle, this volume is a collection of papers presented at a symposium. The 14 papers available here encompass a wide variety of topics ranging from micro-meteorological field work to numerical atmospheric modelling on a global scale and are of varying quality and standard.

Almost inevitably in the first two sections concerning detailed energy fluxes over land-ice and sea-ice surfaces there is a certain amount of repetition as fundamental micro-meteorological principles are restated in successive papers. In two of these papers and in one dealing with spectral energy distribution in short-wave fluxes there are apologias either for instrumental troubles or for data deficiencies. These, together with some of the consequent stop-gap assumptions, detract from the value of the work. Nevertheless the values of fluxes that are given seem reasonable enough, and add to the limited data already available. The ordinariness of these two sections is relieved by an original and fascinating discussion of the energetics of the Antarctic surface wind (U. Radok), the dominant features of which are compared with those of the trade winds. The author concludes that the surface-wind system is an essential part of the whole Antarctic circulation, even though this poses problems of identifying the control and feedback mechanisms.

The section on regional large-scale energy fluxes is more satisfactory and contains useful matter-of-fact papers dealing with the albedo of pack-ice, the surface heat balance and climate of the dry valleys in Antarctica, and the synoptic energy budget of the Beaufort Sea. In this last paper Vowinckel and Orvig present computations of data relating energy fluxes to the percentage ice-cover, which should provide useful boundary conditions in some atmospheric–numerical models.

The next section considers global studies of large-scale energy fluxes, and continues the theme of the effect of ice-cover in a paper on the numerical simulation of the influence of Arctic sea-ice on climate. The authors (Fletcher, Mintz, Arakawa and Fox) use a two-level atmospheric general-circulation model with simplified boundary conditions to examine the effects of full ice-cover and no ice-cover at the end of 400-day integrations. The more dramatic changes occur in Eurasia but the authors acknowledge that the results should be treated with reserve. A Russian contribution (Borisenkov and Chernukhin) examines the hemispheric distribution of 'useful potential energy' north of 50°N, and notes in passing the similarity between the variation of annual means of useful potential energy and Wolf numbers (sunspot activity) for the period 1958–68. Another Russian contribution (without offering any evidence) reasons that stratospheric warmings both Arctic and Antarctic are the result of localized meridional processes originating in the troposphere.

In the final section on the interaction between the ocean and the atmosphere there are two papers, one on the ice movement in the Gulf of St Lawrence, and the other on the electromagnetic and optic characteristics of sea-ice, both of which are not really pertinent to the subject of the Symposium.

The question arises whether WMO *Technical Notes* are the correct vehicle for symposium proceedings. In the present volume many of the authors are authorities in their own chosen field, and are stressing particular narrow aspects or unorthodox points of view. Consequently one does not get an unbiased account, and I would have preferred such a subject to have been treated by a single author in the form of a review paper. Because of the lack of coherent style and the uneven standard of both text and diagrams I cannot recommend this publication as an introduction to a study of polar energy fluxes, but to those meteorologists who are prepared to be selective there are some items worthy of consideration.

D. W. S. LIMBERT

NOTES AND NEWS

Retirement of Mr T. H. Kirk

After graduating in mathematics at King's College, London in 1935 and then taking a Diploma of Education, Mr T. H. Kirk turned to meteorology in 1937, starting his career in the Meteorological Office at Kew. Early in the war he was gazetted Flight Lieutenant in the Royal Air Force Volunteer Reserve and was mentioned in dispatches for his service in France. Later in 1940 he went to Wick and in 1942 he opened an office in the Faeroes. Promotion to Squadron Leader followed and in 1943 he was attached to the Royal Air Force in North Africa and subsequently moved with his Unit to Malta and Italy.

On demobilization Mr Kirk was posted to Harrow where he served as a Senior Scientific Officer in the Marine Branch for three years. This was followed by eight years at London/Heathrow Airport where he was promoted to Principal Scientific Officer in 1949. In 1957 he returned to Malta, where he spent the next six years as officer in charge. His wide experience of Mediterranean forecasting was put to good use in 1961 when he was a principal lecturer at a WMO/ICAO seminar for Middle East forecasters.

Mr Kirk was awarded special merit promotion to Senior Principal Scientific Officer in September 1963, and from then until his retirement on 31 May 1975 he served in the Central Forecasting Office (CFO) at Bracknell as Chief Forecasting Adviser. He became an acknowledged expert on analysis techniques, writing papers on a variety of topics in this field. His extensive knowledge of the use of satellite information and the evaluation of forecasts has been of great value. His quiet presence will be missed in CFO, where he kept a watchful eye on the day-to-day problems and continually sought ways of improving forecasting techniques. In the international field he represented the Office on the WMO Working Group on the Global Data Processing System.

Hubert Kirk's colleagues and friends will wish him a long and happy retirement.

M.H. FREEMAN

The new Meteorological Office Dry Spell Service

Farmers and growers who need to plan their work to make good use of spells of dry weather may wish to take advantage of the new Meteorological Office Dry Spell Service. The service is consultative and puts the farmer in direct touch with a forecaster specializing in regional weather.

Whenever three consecutive days of dry weather are expected subscribers are notified by telephone, or by telex if they prefer. Subsequently they may ring back to discuss with the forecaster any queries which they may have. For example, the messages are concerned only with the likelihood of rain, but if as well as rain-less weather the farmer needs light winds, or drying winds, or sunshine for a particular job he is welcome to contact the forecaster about those conditions. On the other hand, when a dry spell looks like ending, the farmer may want to know more about the kind of weather to be expected. He may find for example that the forecaster expects thunderstorms to break out but is not sure which districts they will affect. The chance that the farmer then decides to take with his operations may depend on the state of his work and the backwardness or otherwise of the season, as well as upon the forecaster's assessment of the weather risks.

Full details of the service may be obtained from:

The Director-General
Meteorological Office, Met O 7(a)
London Road
Bracknell
Berkshire RG12 2SZ

OBITUARY

It is with regret that we record the death on 14 February 1975 of Mr R. E. Bywater, Higher Scientific Officer, Meteorological Office, Royal Air Force Lyneham.

CORRECTION

Meteorological Magazine, March 1975, p. 73, Table I. The entry in the column headed 'height of rim above surface' and opposite 'WMO flush' should be 0 cm.

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NOTICES

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