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Climatic impact of explosive volcanic eruptions

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Summary

An analysis of sea surface temperatures for the northern hemisphere around the times of major volcanic eruptions in the past 100 years does not reveal any consistent tendency to significant post-eruption coolness. Air temperature anomaly maps suggest that volcanic eruptions do not predispose the atmospheric circulation to particular patterns. A report of overall coolness over land culminating a few months after northern hemisphere eruptions appears to be essentially correct, but such results may suffer from slight systematic bias induced by the Southern Oscillation.

1. Introduction

Kelly and Sear (1984) reported a marked air temperature decrease over land in the northern hemisphere in the 2 months following major northern hemispheric eruptions, and a lesser decrease in the 18 months following major southern hemispheric eruptions. The present paper extends the analysis of Kelly and Sear, using marine temperatures together with a land air-temperature data set based on Russian analyses and documented by Robock (1982).

The volcanic eruptions selected were the same as those used in the superposed epoch analysis of Kelly and Sear — see Table I. In this table the Volcanic Explosivity Index (VEI) is as defined by Simkin *et al.* (1981) and by Newhall and Self (1982); and the Dust Veil Index (DVI) (not weighted by the extent of the veil) is as defined by Lamb (1970). Following Kelly and Sear, the October 1902 eruption of Santa Maria (14.8°N, 91.6°W: VEI=6, DVI=600) was omitted from the superposed epoch analysis, because it followed Pelée and Soufrière by only 5 months. The effect of this choice is discussed later in the paper.

Monthly sea surface temperature anomalies (relative to 1951–60) from the Meteorological Office Historical Sea Surface Temperature data set (MOHSST3) were corrected for instrumental factors as in Folland *et al.* (1984), and then areally averaged over the northern hemisphere, before being combined into superposed epoch time series extending from 1 year before to 4 years after the eruption date. As done by Kelly and Sear, the northern and southern hemispheric eruptions were treated as separate sets. Individual eruptions were also considered separately. Fig. 1 shows the results of the superposed epoch analyses, and corresponds to Fig. 1 of Kelly and Sear. One difference from Kelly and Sear's procedure is that the sea surface temperature anomalies were not normalized, because the inter-annual standard deviation of monthly northern hemisphere sea surface temperatures has no discernible annual cycle,

Table I. *Volcanic events selected for superposed epoch analysis*

Date	Eruptions	Latitude	Longitude	VEI	DVI
		Northern hemisphere			
May 1902	Pelée	14.8°N	61.2°W	4 (twice)	100
	Soufrière	13.4°N	61.2°W	4	300
Mar. 1907	Ksudach	51.8°N	157.5°E	5	500
June 1912	Novarupta (Katmai)	58.3°N	155.2°W	6	500
Mar. 1956	Bezymyannaya	57.1°N	160.7° E	5	30
		Southern hemisphere			
Aug. 1883	Krakatau	6.1°S	105.4°E	6	1000
June 1886	Tarawera	38.2°S	176.5°E	5	800
Apr. 1932	Azul (Quizopu)	35.7°S	70.8°W	5	70
Mar. 1963	Agung	8.3°S	115.5°E	4	800

being (on the basis of data for 1951–80) between 0.13 °C and 0.17 °C for all months. Fig. 1 does follow Kelly and Sear, however, in referring the sea surface temperatures to the average level in the pre-eruption year.

Fields of air temperatures over land and sea were also subjected to limited superposed epoch analysis, in a search for systematic geographical, circulation-related changes.

Finally, the effects of altering the choice of eruptions have been assessed, and the uncertain effect of the 1982 eruption of El Chichon is noted.

2. Results

(a) *Superposed epoch analysis*

Fig. 1(a) is unlike the corresponding sequence obtained by Kelly and Sear, in that there is not a sharp minimum 2 months after the eruption, but a broad trough from 6 months to nearly 2 years after it. There is evidence, however, in both cases that cooling began before the eruption, suggesting that the shape of Fig. 1(a) may be a fortuitous result of the effects of fluctuations on 2–5 year time-scales, such as the Southern Oscillation. The dashed lines in Fig. 1 represent the 95% significance levels $\pm 2\sigma N^{-1/2}$ where σ is assumed to be 0.15 °C and $N = 4$ eruptions. The number of excursions beyond these lines does not exceed random expectation (5% of 60 months, i.e. 3 months). This statistical test is probably too lax because the data are serially correlated, and Kelly and Sear's Monte Carlo test is to be preferred: but the lack of significance found by the lax test emphasizes the nullity of the results. It can of course be expected that the ocean, owing to its thermal capacity, responds more slowly and to a lesser degree to short-term thermal forcing than does the land. However, Fig. 1 does not show that there is any clear-cut response whatsoever. Fig. 1(b) presents a particularly unsystematic picture.

The possible influence of the Southern Oscillation on Fig. 1(a) was investigated by combining into a superposed epoch time series the Southern Oscillation Index of Wright (1977) for the periods around the relevant four northern hemispheric eruptions (Fig. 2). Analysis of MOHSST3 data has revealed that, in general, maximum (minimum) northern hemisphere sea surface temperature lags behind minimum (maximum) Southern Oscillation Index by about 9 months. Although the trends in Fig. 2 are not

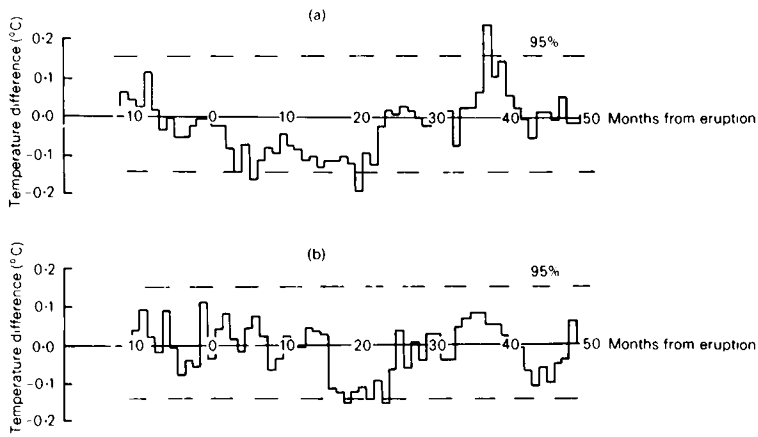

Figure 1. Sequences of northern hemisphere sea surface temperature difference around the time of major volcanic eruptions in (a) the northern hemisphere and (b) the southern hemisphere. The reference level is the mean of months −12 to −1, and the dashed lines represent the 95% significance levels.

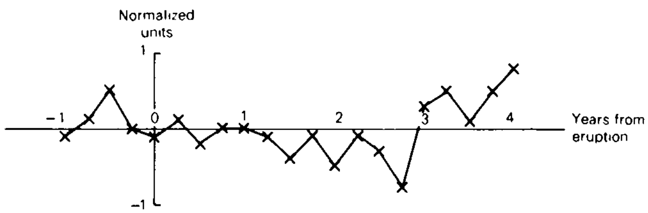

Figure 2. Sequences of Southern Oscillation Index around the time of major volcanic eruptions in the northern hemisphere.

marked, they would indicate a weak fortuitous minimum of sea surface temperature about one season (3 months) after the eruption. The maximum atmospheric (as opposed to oceanic) warmth occurs 6 months after minimum Southern Oscillation Index or maximum eastern tropical Pacific sea surface temperature (Pan and Oort 1983), but this includes the tropics where the lag is reduced: over the generally higher latitude northern hemisphere land area studied by Kelly and Sear the lag is likely to be nearer 9 months, as for the ocean, again giving minimum warmth about one season after the eruption. Thus sampling bias with respect to the Southern Oscillation may have slightly affected the results of Kelly and Sear.

The land air-temperature data from the Russian source, documented by Robock (1982), were used to repeat the computations made by Kelly and Sear including the normalization process. The results were very similar to those of Kelly and Sear, with peak coolness 2 months after eruptions, as expected in view of the high correlation (>0.9) between data sets (Jones *et al.* 1982).

(b) *Sequels to individual eruptions*

Fig. 3 (northern hemispheric eruptions) and Fig. 4 (southern hemispheric eruptions) demonstrate the diversity of the sequels to the eruptions. Soufrière and Pelée were followed by a brief warming of the northern hemisphere sea surface, and Ksudach by little change despite its DVI of 500 (Table I). The prolonged minimum in Fig. 1(a) appears to have resulted largely from one eruption, Katmai, with small or shorter contributions from the other three, weighing against the statistical significance of the composite. The shape of Fig. 1(b) derives to a considerable extent from the sequel to Agung (Fig. 4(d)).

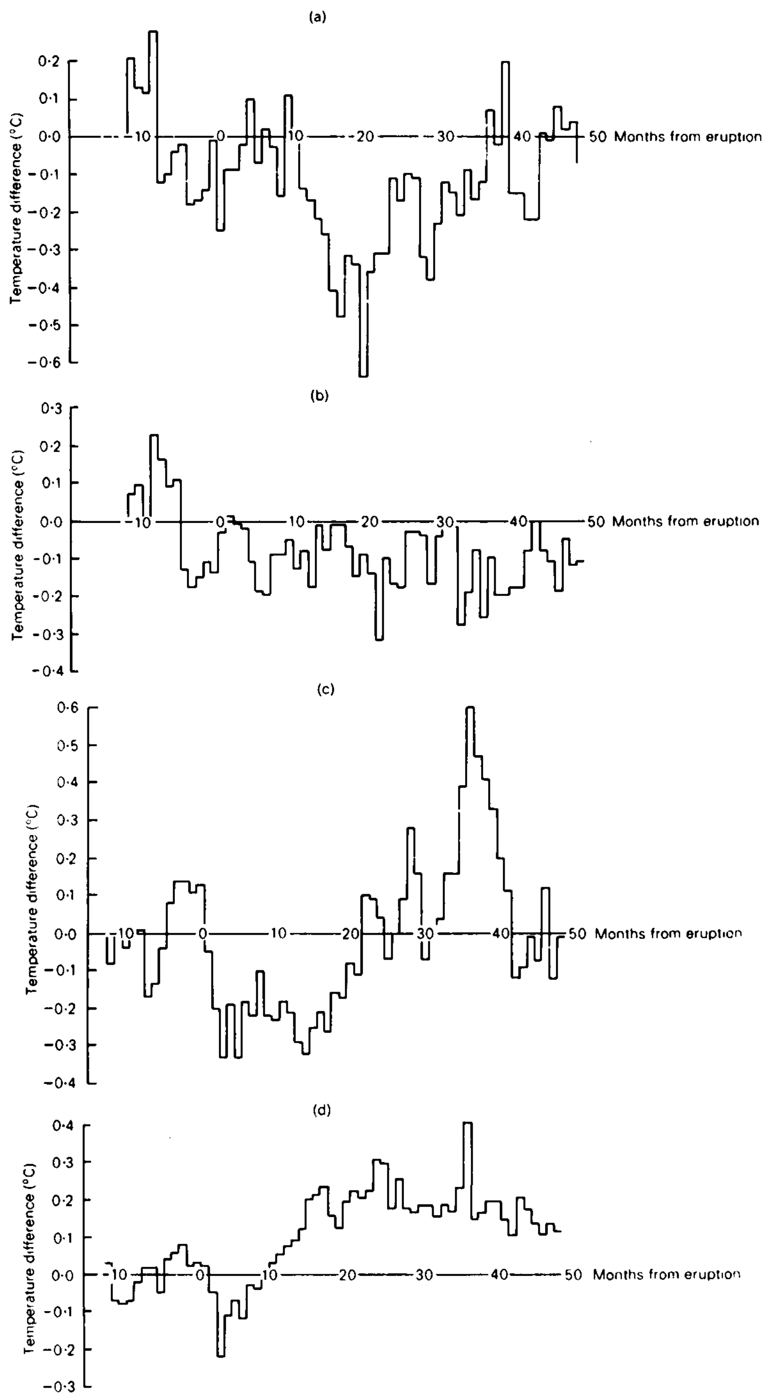

Figure 3. Sequences of northern hemisphere sea surface temperature difference around the time of major volcanic eruptions in the northern hemisphere, (a) Soufrière and Pelée (May 1902), (b) Ksudach (March 1907), (c) Novarupta (Katmai) (June 1912) and (d) Bezymyannaya (March 1956). The reference level is the mean of months -12 to -1.

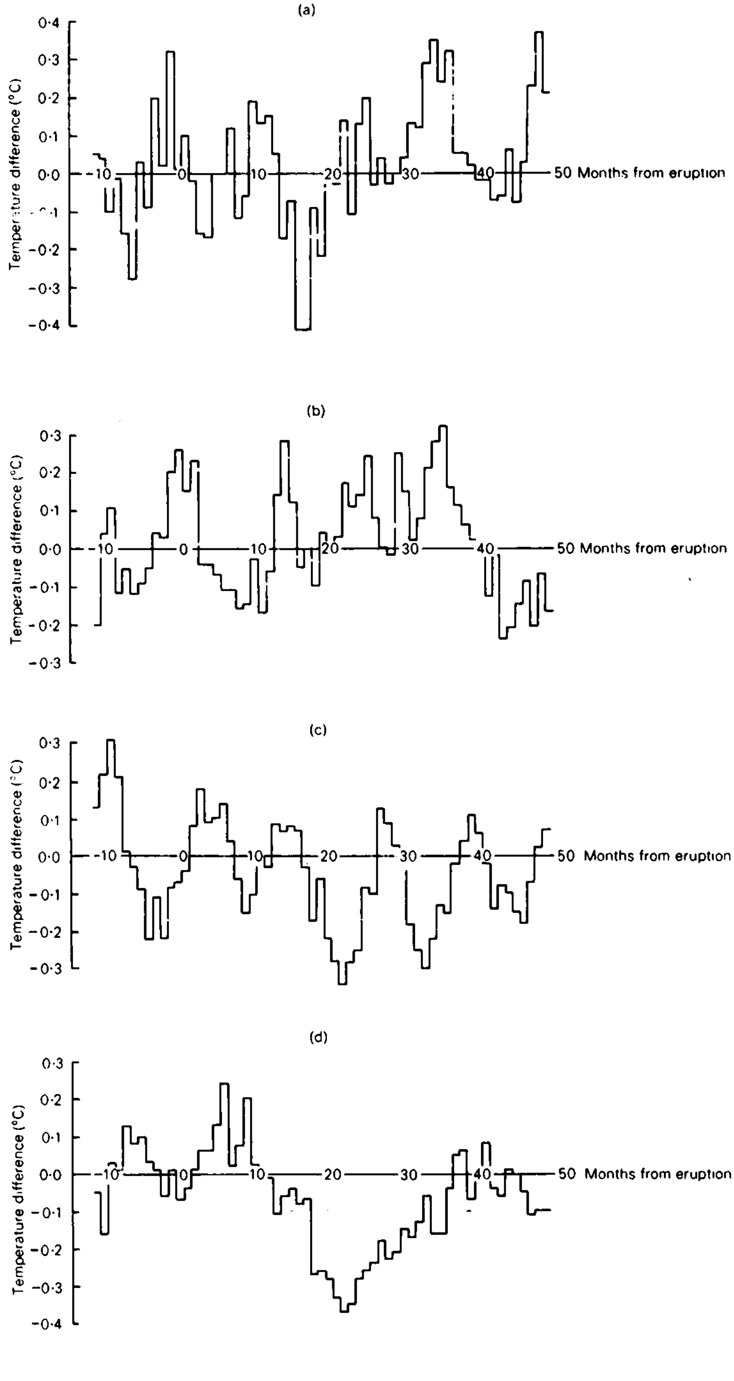

Figure 4. Sequences of northern hemisphere sea surface temperature difference around the time of major volcanic eruptions in the southern hemisphere, (a) Krakatau (August 1883), (b) Tarawera (June 1886), (c) Azul (April 1932) and (d) Agung (March 1963). The reference level is the mean of months -12 to -1.

Note an apparent annual cycle in some of the sequences in Figs 3 and 4. This is likely to be partly the result of a need to apply seasonally varying corrections to sea surface temperatures as measured from uninsulated buckets; but the sequel to Azul (Fig. 4(c)) also appears to reflect a real enhancement of the annual cycle in the 1930s in the Gulf Stream region, affecting marine air temperatures also and probably resulting from enhanced summer anticyclonicity and enhanced winter north-westerly flow in the atmosphere.

Fig. 3 of Kelly and Sear shows rather diverse sequels to southern hemispheric eruptions, but their Fig. 2 consistently indicates relatively cold conditions about 2 months after each northern hemispheric eruption. The present paper therefore now examines fields of air temperatures world-wide 2 months after the northern hemispheric eruptions, in order to discover geographical patterns of, and possible reasons for, the consistent results obtained by Kelly and Sear. Fig. 5(a) shows a composite field which refers to 2 months later than each of the four eruptions. The land air temperatures are from the Russian source documented by Robock (1982), and the marine air temperatures are from the Meteorological Office Historical Marine Air Temperature (MOHMAT2) night-time data set. These times of observation were used to avoid spurious heating on deck. The data are not normalized: this would have been necessary over land if the months combined had ranged throughout the calendar, but in fact they only ranged from May to August. The data are anomalies with respect to 1951–80. There are no land data for the southern hemisphere. It is immediately clear that the composite cooling of Kelly and Sear derived from a marked effect over Canada, changes elsewhere being weak, though detailed interpretation of Fig. 5(a) is inappropriate because the reference is 1951–80 and not the pre-eruption years. Fig. 5(b) presents the same anomalies relative to those prevailing in the eruption months: the coldness over North America is again evident, but is greater in the southern USA and in northern Siberia than in Fig. 5(a), because the eruption months happened, on average, to be warm in these regions. The reverse applies to south-eastern Europe. Figs 6 to 9 display air temperatures (relative to 1951–80) 2 months after the individual eruptions, and show that the Canadian coldness resulted from the sequels to Ksudach and Bezymyannaya (Figs 7 and 9) and not the other two eruptions, which, however,

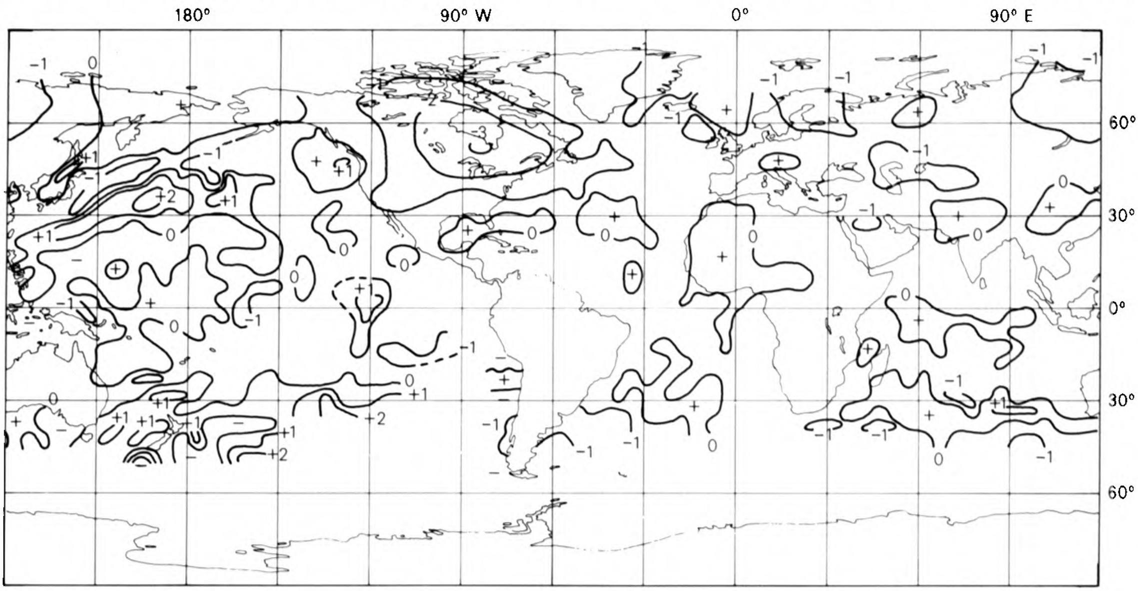

Figure 5(a). Land air temperature and night-time marine air temperature anomalies (°C), with respect to 1951–80, composited from data for July 1902, May 1907, August 1912 and May 1956 (2 months after each northern hemispheric eruption).

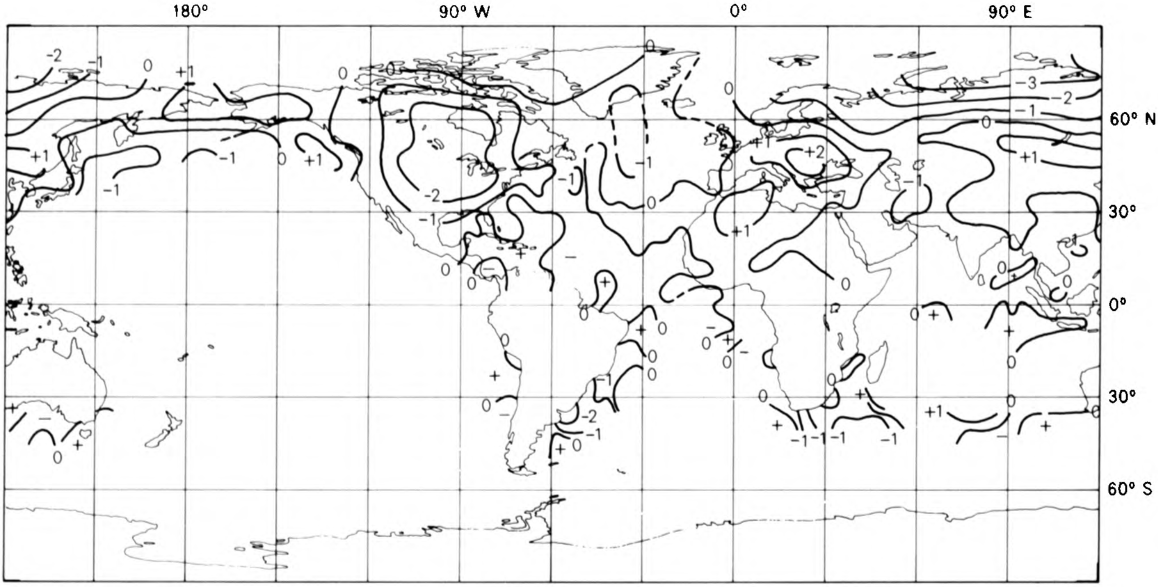

Figure 5(b). Land air temperature and night-time marine air temperature composited anomalies (°C) for July 1902, May 1907, August 1912 and May 1956 with respect to composited anomalies for May 1902, March 1907, June 1912 and March 1956.

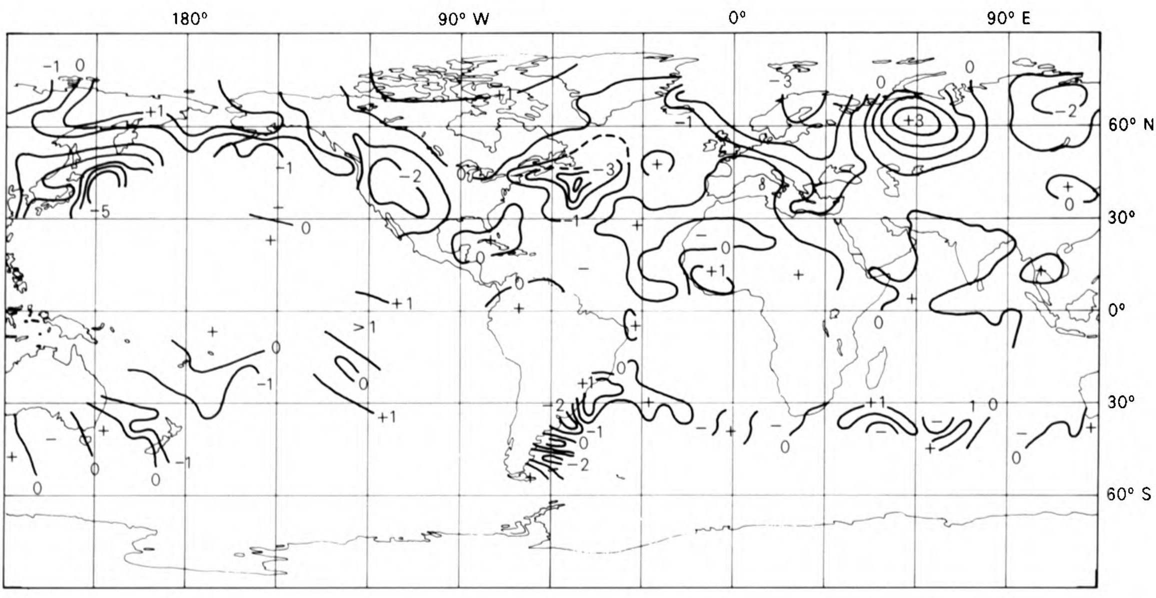

Figure 6. Land air temperature and night-time marine air temperature anomalies (°C), with respect to 1951–80, for July 1902 (2 months after Soufrière and Pelée).

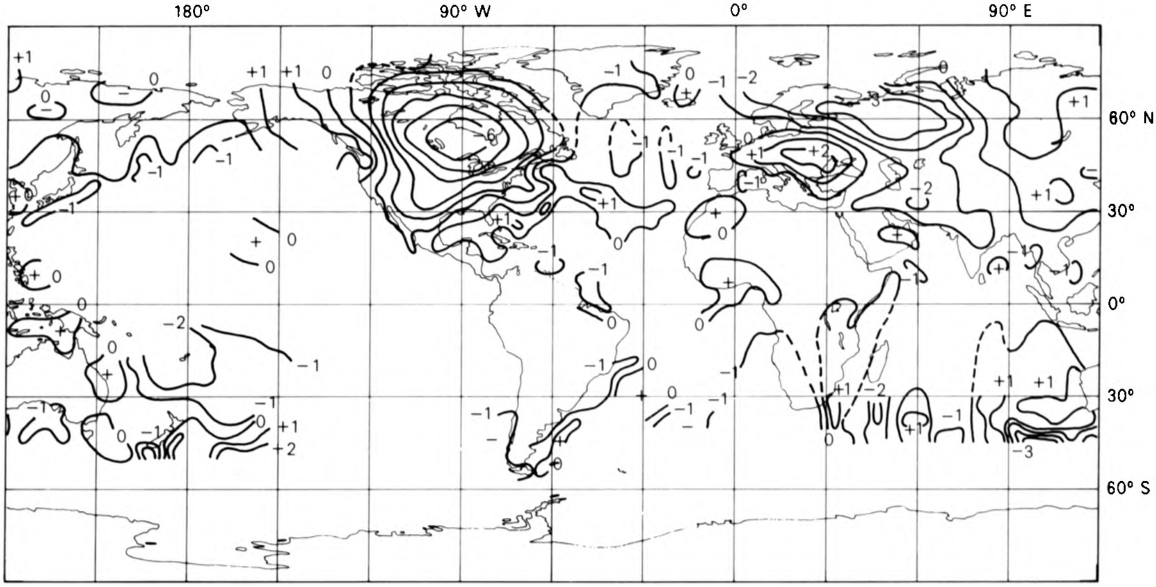

Figure 7. Land air temperature and night-time marine air temperature anomalies (°C), with respect to 1951–80, for May 1907 (2 months after Ksudach).

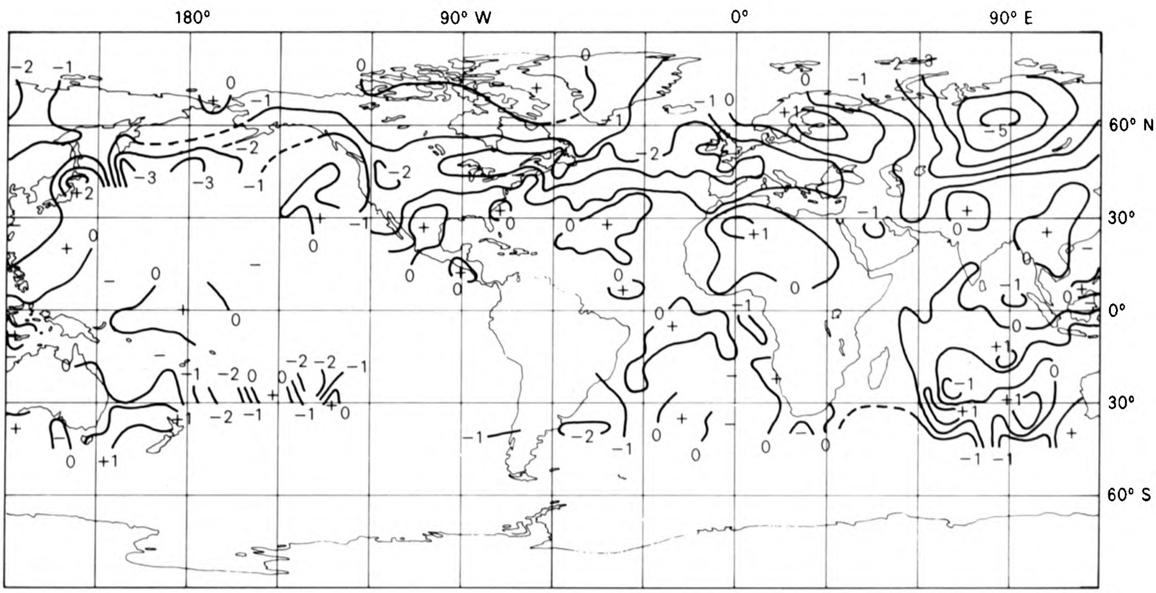

Figure 8. Land air temperature and night-time marine air temperature anomalies (°C), with respect to 1951–80, for August 1912 (2 months after Katmai).

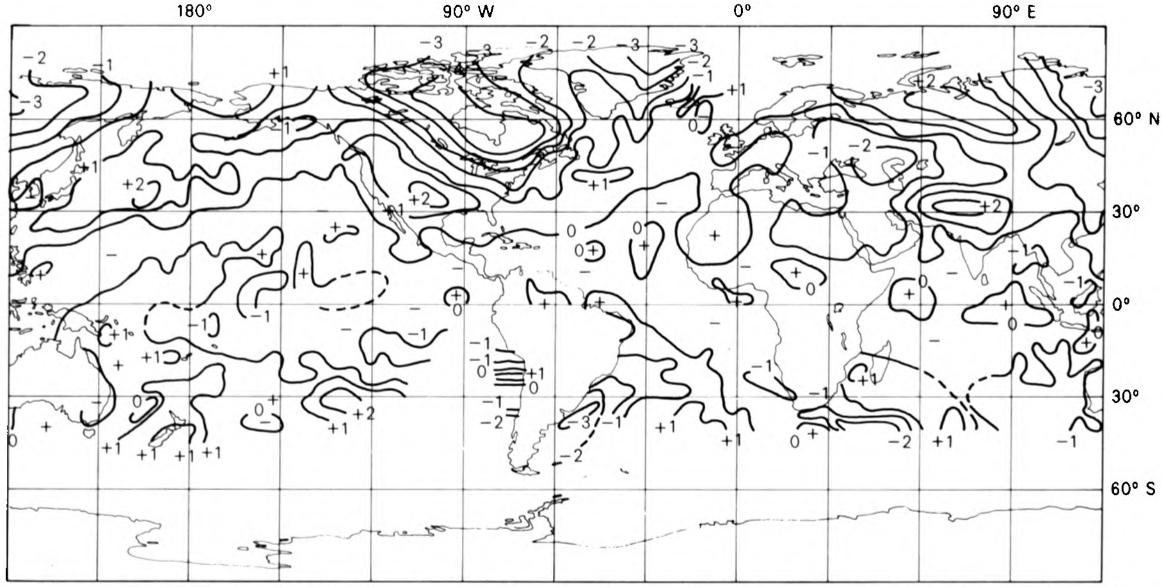

Figure 9. Land air temperature and night-time marine air temperature anomalies (°C), with respect to 1951–80, for May 1956 (2 months after Bezymyannaya).

happened to have predominantly cold sequels over the northern hemisphere land masses (Figs 6 and 8) in agreement with Fig. 2 of Kelly and Sear. The extreme cold of August 1912 (Fig. 8), 2 months after Katmai, stands out even against the average conditions for 1911–20 which were colder than the 1951–80 normal (Fig. 10: see also Folland *et al.* (1984)). The diversity of the results in Figs 6 to 9 weighs against the hypothesis, discussed by LaMarche and Hirschboeck (1984), that volcanic eruptions predispose the atmospheric circulation to particular anomalous patterns. Although the general coldness in Figs 6 to 9 supports Kelly and Sear, the caveat concerning sampling with respect to the Southern Oscillation still stands. A further problem, the small sample size, cannot yet be overcome because of the brevity of reliable observational records.

(c) *Santa Maria*

The eruption of Santa Maria was larger than that of Pelée or Soufrière (Table I), and there is therefore a strong case for using its date (October 1902) as the zero-time for the 1902 eruptions. Examination of Kelly and Sear's Fig. 2 shows that this will slightly weaken the immediate post-eruption cooling, as the standardized temperature remained constant for 2 months after Santa Maria, before a sharp temporary rise. Their essential result would, however, be unchanged. A similar amendment to the present work for sea surface temperature would move the bottom of the trough in Fig. 2(a) to 10–15 instead of 15–20 months, without drastically altering the general conclusions.

It is relevant to note that there was a sharp global marine cooling around 1903, introducing the coldest period of the 1856–1984 record (Folland *et al.* 1984). The spatial distribution of this cooling is shown for summer in Fig. 11 which also shows that the land did not, on average, cool significantly at this time. There was a major cooling of the mid-latitude North Atlantic. This cooling is consistent with changes of Ekman drift and evaporation caused by the distribution of mean-sea-level pressure change shown in Fig. 12: in other words, the 1903 cooling appears, on cursory examination, to be an ocean–atmosphere interactive phenomenon which may not have any connection with the volcanic eruptions of 1902. It has already been stressed that in the light of Figs 6 to 9, volcanic eruptions do not seem to encourage particular atmospheric circulation patterns.

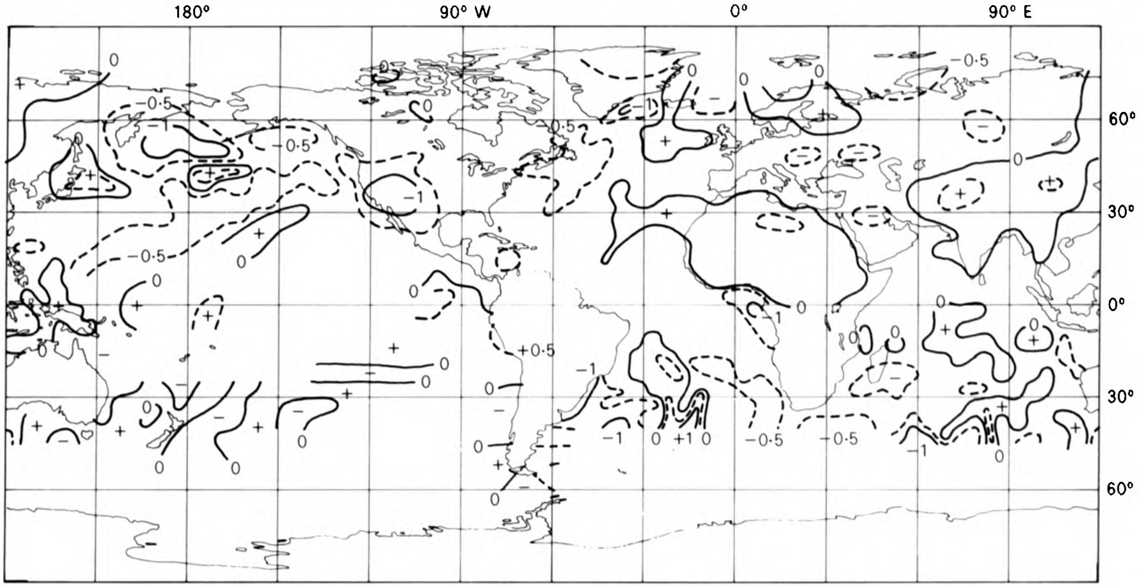

Figure 10. Average land and night marine air temperatures for July–September 1911–20 relative to 1951–80. Contours every °C (solid lines) and at ½°C (dashed lines).

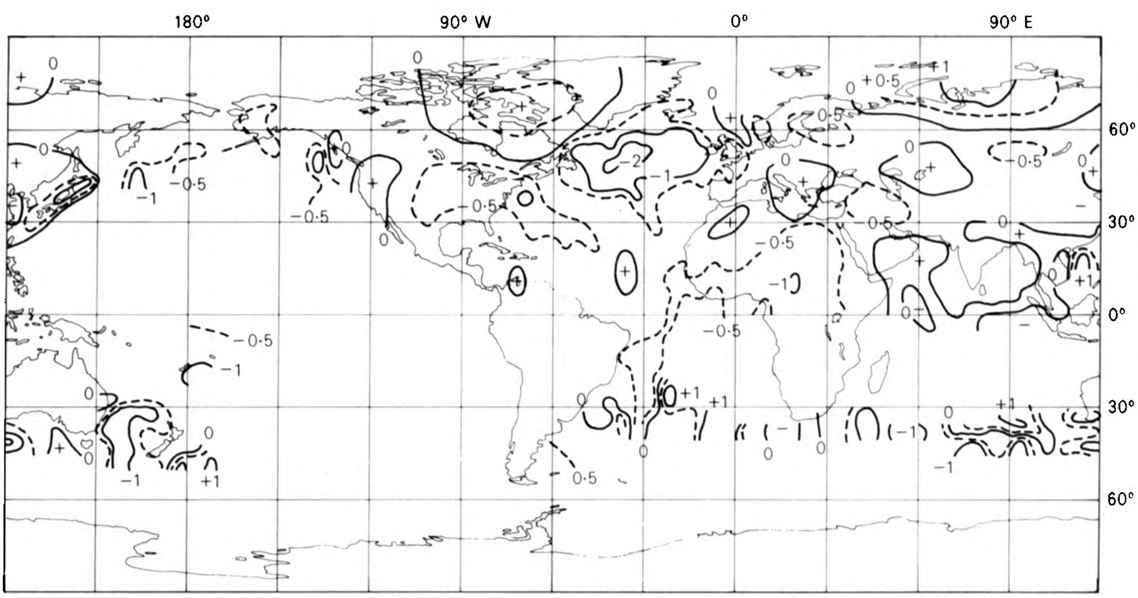

Figure 11. Average land and night marine air temperatures for July–September 1903–7 relative to those for 1898–1902. Contours every °C (solid lines) and at ½°C (dashed lines).

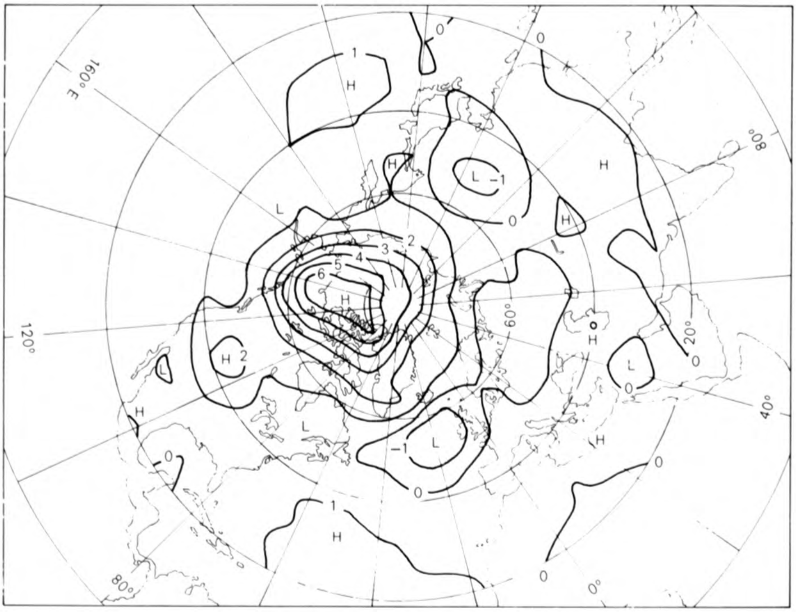

Figure 12. Mean-sea-level pressure for June–September 1903–7 relative to that for 1898–1902. Contours every mb.

(d) *Bezymyannaya (The Russian word means 'nameless')*

This eruption may have been feebler than the others in Table I, and its omission must therefore be considered. This would make the results obtained by Kelly and Sear more marked, because Bezymyannaya was followed by the weakest cooling (their Fig. 2). Omission of Bezymyannaya would also strengthen the present results (Fig. 3(d)).

(e) *El Chichon*

The temperature anomaly field in June 1982, 2 months after the major eruption of El Chichon (Mexico), is shown in Fig. 13 and adds further variety to the sequels already shown in Figs 6 to 9. Kelly and Sear point out that study of the effects of El Chichon is likely to be very difficult because of the exceptional warmth of 1981 and the onset of cooling before the eruption. The sea surface temperature sequence for the northern hemisphere (Fig. 14) appears to show a discontinuity between December 1981 and January 1982, when the operational data set succeeds the historical data set. The historical data set is probably unreliable for late 1981 because the data are sparse: the operational data are more plentiful but have been subjected to less stringent quality control. Thus, firm conclusions cannot be drawn, but there appears to be only gradual cooling during 1982–4, and the maximum coolness 5 months after the eruption is not marked in view of the 0.15 °C inter-annual standard deviation of northern hemisphere monthly sea surface temperature.

4. Conclusion

The present study does not reveal any consistent tendency to significantly low northern hemisphere sea surface temperatures after the eruptions. Air temperature anomaly maps suggest that volcanic eruptions do not predispose the atmospheric circulation to particular patterns.

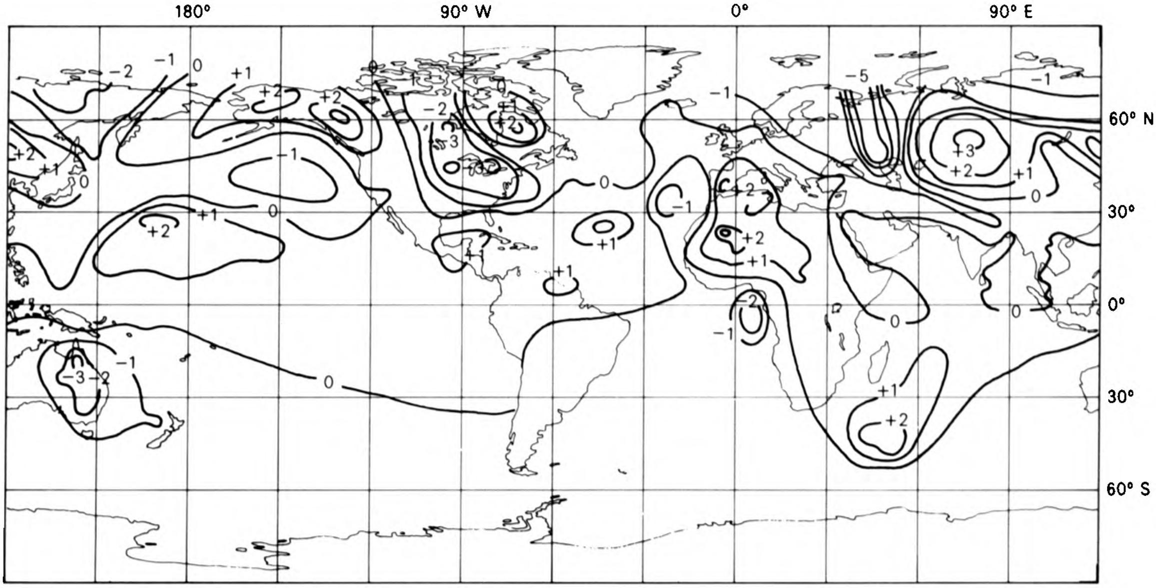

Figure 13. Land air and sea surface temperature anomalies (°C) for June 1982 (2 months after El Chichon). A variety of periods was used for 'normals'.

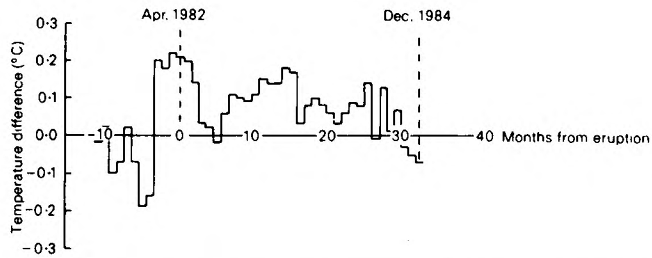

Figure 14. Sequence of northern hemisphere sea surface temperature difference around the time of the eruption of El Chichon. The reference level is the mean of months −12 to −1.

The result obtained by Kelly and Sear, of coolness over northern hemisphere land peaking 2 months after northern hemispheric volcanic eruptions, is as valid as can be obtained in the present situation, but the following factors weigh against the statistical significance of the results:

(a) slight systematic bias in the superposed epoch analyses, resulting from the Southern Oscillation and

(b) the unavoidably small sample size.

The selection of volcanic events used by Kelly and Sear is sound in view of the known volcanic record (e.g. Lamb 1970). The results are not sensitive to slight changes in the selection criteria.

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The HERMES system

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Summary

A description is given of the mini-computer-based system which has recently been installed in the Satellite Meteorology Branch of the Meteorological Office to aid research into the uses of high-resolution satellite data. Examples of images processed on the system are illustrated, as well as results from the Local Area Sounding System.

1. Introduction

The HERMES (High-resolution Evaluation of Radiances from MEteorological Satellites) system is a minicomputer-based data-processing facility which was installed in the Satellite Meteorology Branch of the Meteorological Office during 1983. The aim is to assist research and development into the applications of high-resolution digital satellite data which are broadcast by the polar-orbiting and geostationary satellites. So far, this work has mainly concentrated on two specific topics: firstly the development of a Local Area Sounding System (LASS) which can routinely generate temperature and humidity profiles for the North Atlantic and western European area from the raw sounding-instrument data broadcast by the USA's TIROS-N series satellites; secondly, the investigation of ways that the full-resolution, multi-spectral, digital-imagery data can best be exploited to provide forecasters with useful satellite products.

This paper has been prepared to give an account of the development of the system and a status report on both these projects, but with particular emphasis on the LASS development work since soundings generated by the system are now being used operationally within the Meteorological Office.

2. Hardware

The HERMES system is based on a Digital Equipment Corporation (DEC) VAX 11/750 mini-computer with 2 megabytes of memory and three Winchester hard discs capable of storing over 500 megabytes of data. Fig. 1 shows the major hardware components of the VAX computer and the system console. Access to the system is via eight visual display units (VDUs) in the Satellite Meteorology Branch, and development work can take place in parallel with the semi-operational tasks connected with LASS operations.

Figure 1. The DEC VAX 11/750 computer of the HERMES system.

A Sigmex Electronics Advanced Raster Graphics System (ARGS) 7000 (shown in Fig. 2) is available for the display of satellite imagery or graphical output from LASS in a number of forms including fields of data, tephigrams and cross-sections. The ARGS contains its own 16-bit microprocessor along with 3 megabytes of image memory which can be configured in a number of ways depending on the application. The monitor has a resolution of 1024 by 1024 picture elements (pixels) with a palette of 16 million colours available for use in image displays!

There are currently three main external communications links from the HERMES system:

(a) A Remote Job Entry link to the Meteorological Office's COSMOS computing facility, running at 9.6 kilobits per second.

(b) A link, operating at 9.6 kilobits per second, to the satellite receiving station at Lasham in Hampshire, along which the sounding data from the polar-orbiting satellites are transmitted.

(c) A DECnet link to 'HOMER', the twin computer system of HERMES, at the Meteorological Office Unit at Oxford University where part of the Satellite Meteorology Branch is now located. This operates at 48 kilobits per second over a British Telecom KILOSTREAM link.
A schematic diagram of the HERMES system is shown in Fig. 3.

Figure 2. The Sigmex ARGS 7000 used on the HERMES system.

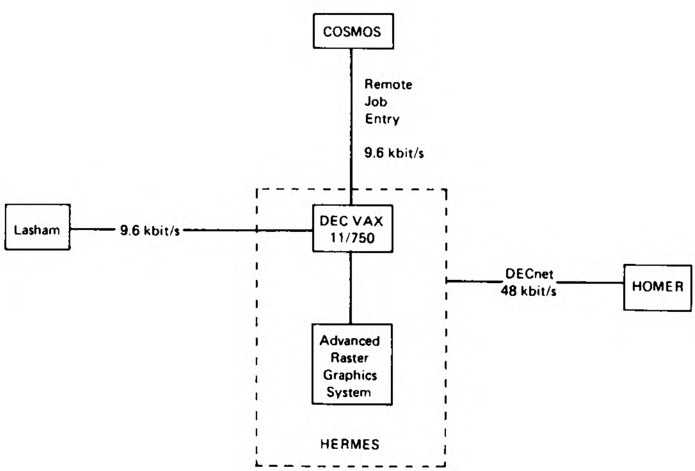

Figure 3. The HERMES system and its data links.

3. Image processing

The computing facilities of the HERMES system offer great scope for investigations into the uses of satellite imagery, both for specific research tasks and also for developing new products for future operational dissemination.

The operational satellite imagery dissemination system currently used within the Office (AUTOSAT and SATFAX) is largely based on data broadcast by the satellites in analogue format. These data are primarily intended for output on facsimile recorders and provide data with a coarser horizontal resolution, a lower number of grey levels, and with fewer spectral channels than can be obtained if the full digital data stream from the satellite is used.

Research is therefore under way into applications of the full-resolution data which will shortly be available at Bracknell in near-real time via the METSATNET link from Lasham. METSATNET will use a British Telecom MEGASTREAM link operating at 2 megabits per second to send Meteosat PDUS (Primary Data Users' Station) and TIROS-N series AVHRR (Advanced Very High Resolution Radiometer) data from Lasham to the Meteorological Office Headquarters.

Until METSATNET is operational, selected images in digital format are obtained on computer compatible tapes (CCTs) for use in research projects on the HERMES system. Five-channel AVHRR images, at the full horizontal resolution of 1 kilometre, are obtained from the University of Dundee, who store all AVHRR data for passes over the United Kingdom, or from the Royal Aircraft Establishment at Farnborough who maintain a 1-week rolling archive of the data received at Lasham. Occasional CCTs of Meteosat PDUS images are also obtained from Lasham.

Fig. 4 is a typical example of a full-resolution, single-channel AVHRR image displayed on the ARGS, and shows the channel 2 (0.9 μm) image from NOAA-6 at 1819 GMT on 5 June 1980. At this time there

Figure 4. A NOAA-6 AVHRR channel 2 image at 1819 GMT on 5 June 1980.

was intense convective activity in the Midlands, and the deep vertical extent of the cumulonimbus clouds can be seen from the shadows cast by the early evening sunlight. Fig. 5 shows a section from a Meteosat visible image for 1000 GMT on 15 October 1984. At the latitude of the United Kingdom the horizontal resolution is approximately 3 km in the east–west and 5 km in the north–south direction.

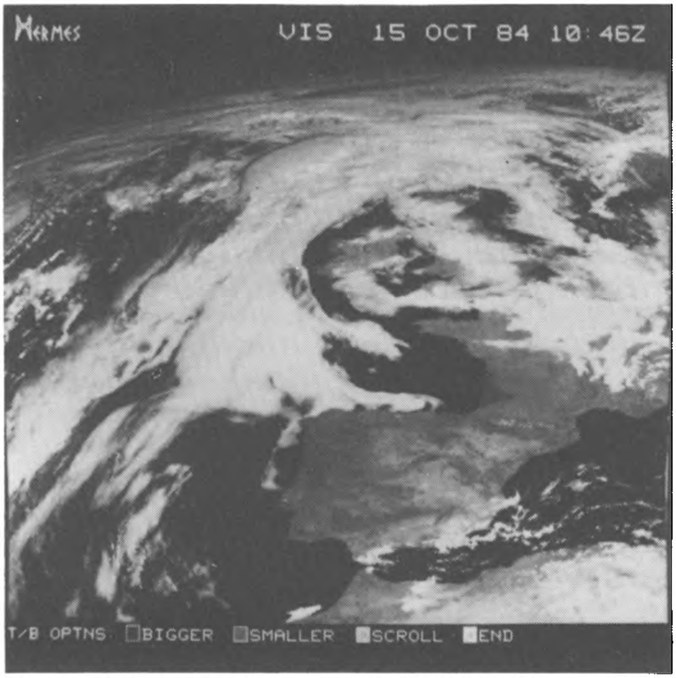

Figure 5. A Meteosat visible image at 1000 GMT on 15 October 1984.

One of the earliest studies with these data has been in the detection of fog or low stratus at night using data from the 3.7 and 11 μm channels of AVHRR. This technique is now being evaluated for possible operational use in the future and has been described by Eyre *et al.* (1984).

Currently, imagery research is taking place on a number of specific topics, with one of the most important being the derivation of surface temperatures from the 'split-window' 11 and 12 μm channels of the AVHRR/2 on NOAA-7 and NOAA-9. The basic technique used has been described by Llewellyn-Jones *et al.* (1984) and the possible applications of these data for use by forecasters and as input to the mesoscale model are under investigation. See Golding (1984) for the current status of the mesoscale model.

These high-resolution digital data offer tremendous possibilities for assisting operational forecasters in many areas of their work, and imagery research on the HERMES system is being directed towards preparing for its operational utilization in the future.

4. The Local Area Sounding System (LASS)

4.1 *Why a local area sounding system?*

Until recently the only atmospheric sounding data available routinely within the Office were the SATEM messages derived in the USA and received over the Global Telecommunication System (GTS), in the form of thicknesses between standard levels. These are produced by the National Environmental Satellite Data and Information Service of the National Oceanic and Atmospheric Administration (NOAA/NESDIS) in Washington from the global raw satellite-instrument data which are recorded on the satellites and replayed to one of three reception stations. The problem with these data is that the time between the satellite making an observation and the resulting sounding being received at Bracknell is at least 3 hours and can be much longer. Consequently many of the observations fail to arrive early enough to be included in the main numerical analyses which are produced at T+2 hours and T+(3 hours 20 minutes) for the fine-mesh, limited-area and coarse-mesh, global analyses respectively. This delay results in the forecasts being run when only about 25% of the potentially available SATEMs have been received.

The other disadvantage of the SATEMs is that the data are horizontally averaged to a resolution of around 400 km and, while this may be adequate to describe the broad-scale thermal structure, it is not possible to resolve sub-synoptic-scale features.

The LASS was therefore established with the aim of exploiting the full potential of the sounding data, by deriving atmospheric profiles with a much higher horizontal resolution (currently 80 km) and delivering the data to the operational users within a very short period of the satellite overpass. (See Table I.)

Table I. *Comparison of SATEM data and LASS soundings*

	SATEMs	LASS
Coverage	Global	3000 km radius of Lasham
Horizontal resolution	400 km	80 km
Time lag (reaching COSMOS)	At least 3 hours	40 minutes
Data available	Thickness values and precipitable water content for standard layers	Standard-level temperatures, dew-points, plus derived thermal winds, thicknesses and precipitable water content

4.2 *The satellite instruments*

The TIROS-N series of polar-orbiting satellites contain a number of instruments for monitoring the atmosphere and the underlying surface. The best known are the imaging radiometers which produce high-resolution images for use in synoptic analysis, and also allow the computation of surface and cloud-top temperatures. These instruments measure radiation at wavelengths in the visible and infra-red regions of the spectrum where the atmospheric absorption is low, and consequently depict the surface or cloud tops with only minimal atmospheric attenuation.

However, the TIROS-N satellites also carry radiometers which detect radiation at wavelengths where most of the radiation has been emitted by the atmosphere itself, and from which information on the temperature and humidity structure of the atmosphere can be derived. This group of sounding instruments is collectively known as the TIROS Operational Vertical Sounder (TOVS) and is made up of the three following components:

(a) The High-resolution Infra-Red Sounder (HIRS/2), which has 19 infra-red channels (and 1 visible) for sounding in the troposphere and the lower stratosphere.

(b) The Microwave Sounder Unit (MSU) which has four channels at frequencies at around 55 GHz, also for sounding in the tropopause.

(c) The Stratospheric Sounder Unit (SSU) which has three channels in the infra-red at around 15 μm and uses a pressure modulation technique to detect radiation from the middle and upper stratosphere.

Further information on the design and operation of the TOVS can be obtained from Schwalb (1978), while the SSU (which is provided by the Meteorological Office) has been described in detail by Miller *et al.* (1980).

Each of the instruments scans the earth from left to right, covering a swath below the satellite track which is over 2000 km wide for the HIRS and MSU, and 1500 km for the SSU.

At wavelengths for which atmospheric absorption is high, most of the radiation measured at the satellite has been emitted by the atmosphere itself. It is possible to isolate radiation emitted by particular layers of the atmosphere by careful selection of the wavelengths sensed by the instrument. (See Eyre and Jerrett (1982) for a fuller discussion of the selection of wavelengths.) The 20 channels of the HIRS have been chosen so that information is available for a number of different sounding tasks. The temperature sounding data are available from seven channels in the 15 μm carbon dioxide band and five channels in the 4.3 μm carbon dioxide/nitrous oxide band, while water vapour sounding can be performed using the three channels in the 6–8 μm water vapour band.

The four MSU channels are all located around 55 GHz with three channels in a region of strong oxygen absorption to provide temperature sounding data which are little affected by cloud contamination.

The SSU is designed to produce data from which stratospheric (25–50 km) temperature profiles can be determined. In conjunction with HIRS and MSU data it is therefore possible to generate temperature profiles from the surface to 50 km. At the moment SSU data are not processed on HERMES, although the system could be modified to do so.

4.3 *The LASS processing system*

As described earlier the global TOVS data are recorded on the spacecraft and transmitted to the ground stations for the generation of the SATEMs. However, the full TOVS data for the area currently viewed by the satellite are also broadcast in real time, and can be acquired by any receiving station in the satellite's direct line of sight. Since September 1983 the HERMES system has been receiving the TOVS data in real time from the ground station at Lasham, which can receive data from the TIROS-N series spacecraft when they are within about 3000 km.

The processing of the raw TOVS data into temperature and humidity mixing ratio profiles takes place automatically on the HERMES system which, when there are two satellites operating, can process up to 16 passes per day.

The suite of programs which generate the meteorologically useful products was originally obtained from the NOAA/NESDIS Development Laboratory at Madison, Wisconsin, and modified to allow it to be run on the hardware configuration of the HERMES system. The technique used to perform the 'retrieval' (i.e. to obtain temperature and humidity profiles from the radiances received at the satellite) is very similar to that used to derive the SATEMs and has been described by Smith *et al.* (1979). The scheme is based on the use of multiple linear regression to obtain the standard-level temperatures and humidity mixing ratios from the HIRS and MSU radiances, with the regression coefficients currently being received every week from the USA. The coefficients are derived from collocations of satellite soundings and radiosondes over the previous 2 weeks, and separate coefficients are provided for each 30° latitude band. Interpolation is used to prevent steps at zone boundaries.

The actual processing of the satellite data involves many stages. However, the major components of the system are illustrated in Fig. 6 and can be summarized as follows:

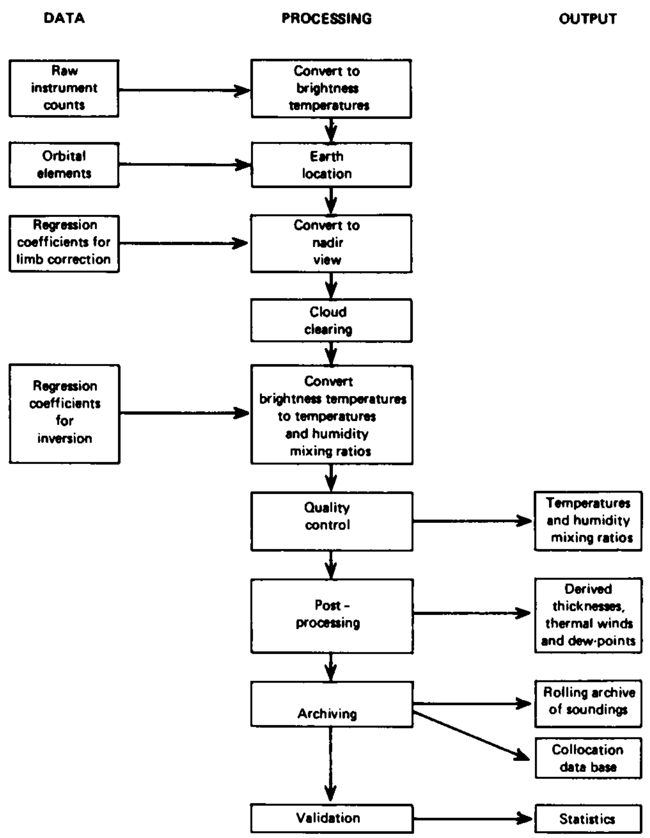

Figure 6. The LASS processing system.

(a) Unpacking the raw satellite data and converting the instrument counts into radiances by using the calibration information in the data stream and then deriving an equivalent black-body temperature (brightness temperature).

(b) Computing the latitude and longitude of each sounding using orbital information received over the GTS.

(c) Converting the measured brightness temperatures to those which would have been obtained if the instruments had been looking vertically at the same atmospheric profile. (This is necessary since the instruments are looking at an angle of over 50° from the sub-satellite track at the edges of the swath.)

(d) Detecting cloud-free soundings, and attempting to remove the effects of the cloud from other soundings so that the 'cloud-free' radiances can be obtained. In very cloudy conditions the cloud-clearing process may not work, in which case the MSU-only retrieval can be supplied.

(e) Using multiple linear regression to obtain standard-level temperatures and humidity mixing ratios from the calculated brightness temperatures.

(f) Quality control of the resulting soundings by comparing the HIRS+MSU soundings with MSU-only soundings.

(g) Derivation of additional products such as the dew-points from the humidity mixing ratios, thicknesses from the standard-level temperatures and thermal winds from the local thickness gradients.

(h) Sending the LASS products to the main COSMOS computing system where the data are used in the numerical analyses and charts of 1000–500 mb thickness are produced for use in the Central Forecasting Office (CFO).

(i) Archiving all LASS products on CCTs and inclusion of the last 16 passes of data in a rolling archive of results which can be displayed on the ARGS.

(j) Collocating the LASS soundings with radiosonde ascents for validation of the retrievals.

Further details of the LASS can be found in Eyre and Jerrett (1982) and Jerrett *et al.* (1982), while the whole question of satellite remote sounding is dealt with by Houghton *et al.* (1984).

4.4 *An example of the LASS products*

The LASS products used most frequently in CFO are the charts of 1000–500 mb thicknesses and derived thermal winds, and a typical example is shown in Fig. 7 for 12 November 1984. On this occasion it was possible to receive four consecutive passes beginning at 0220 GMT over eastern Europe and finishing south of Cape Farewell at 0720 GMT. Fig. 8 shows the CFO 1000–500 mb thickness analysis for 0000 GMT on the 12th and it can be seen that the analysis of the LASS soundings gives very much the same pattern, although the absolute values differ in places. There is, however, much more detail

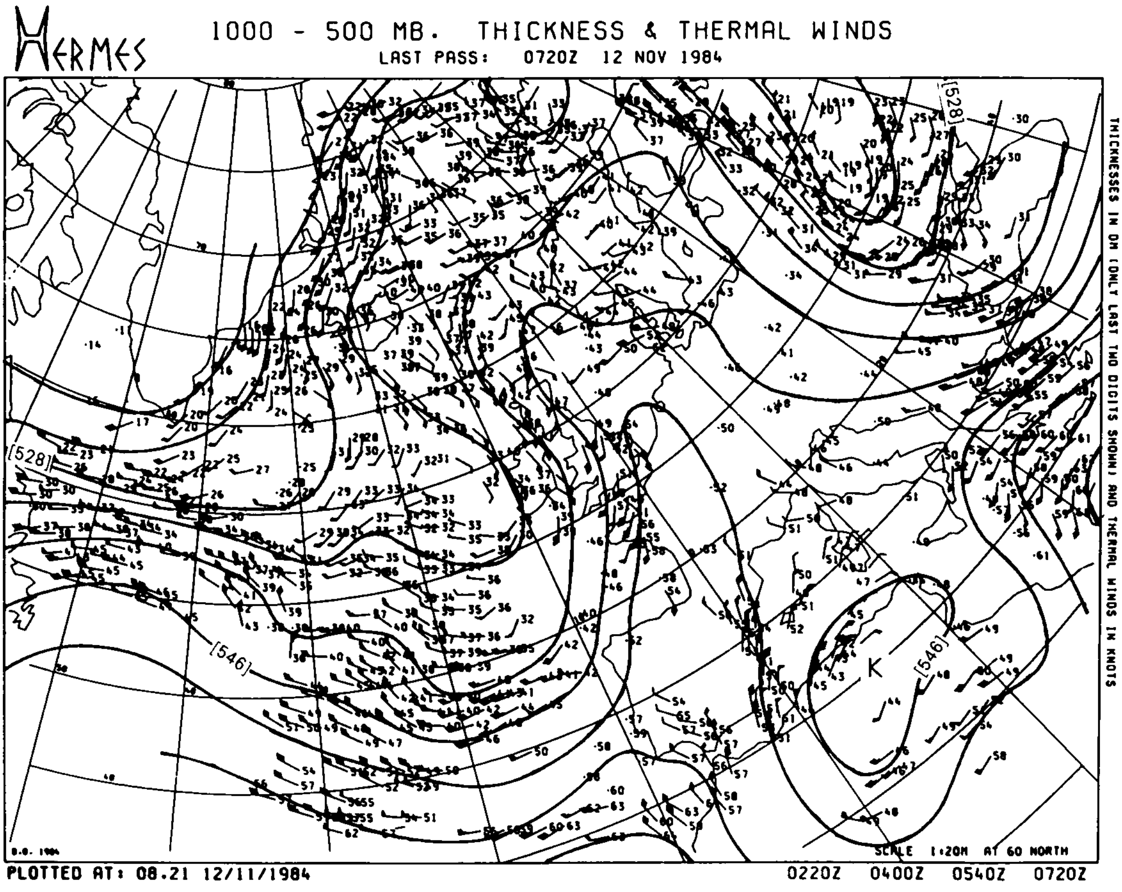

Figure 7. LASS thicknesses and thermal winds together with analysis for 12 November 1984.

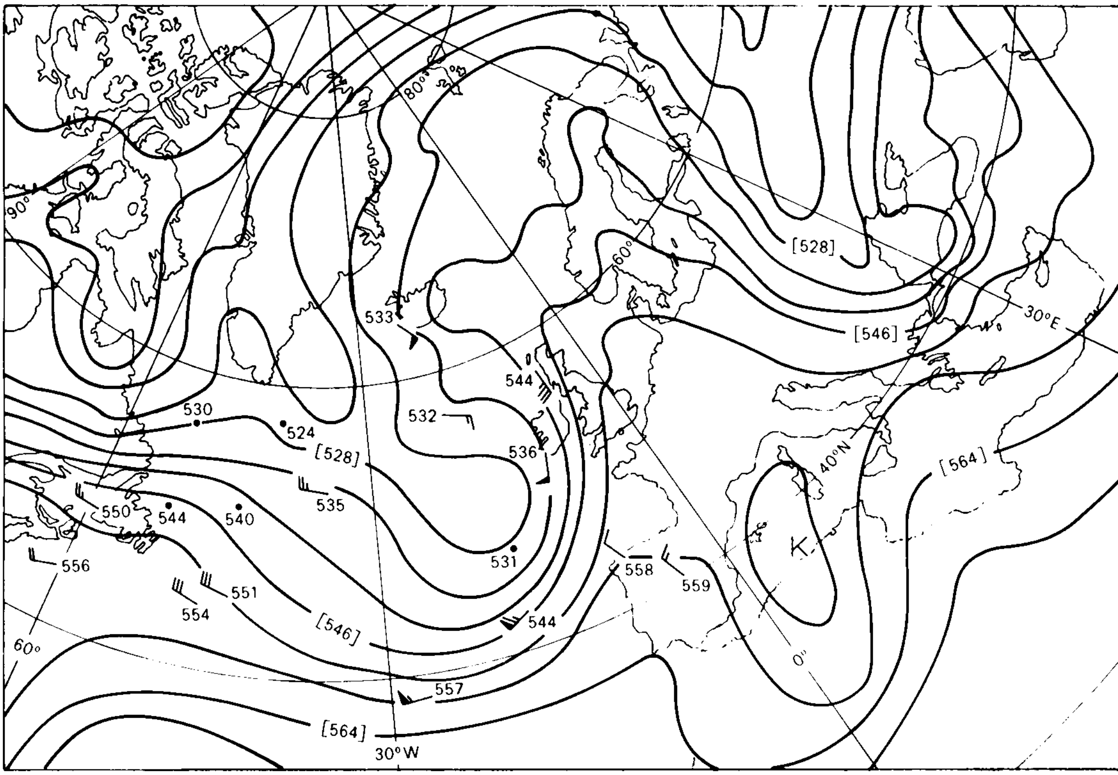

Figure 8. CFO 1000–500 mb thickness analysis for 0000 GMT on 12 November 1984.

apparent with the LASS data, especially over the Atlantic where there are few conventional soundings. In particular the LASS soundings were able to provide useful guidance in the area of the push of cold air south-eastwards around 50°N, 20°W and where, with hindsight, it is possible to suggest that the thicknesses within the elongated trough were greater than those of the CFO analysis, which had little data in this area.

4.5 *How accurate are the LASS soundings?*

As part of the routine validation of the LASS products, all soundings which are found to collocate with radiosonde ascents are stored with the corresponding radiosonde profile to allow a comparison to be made of the soundings from these two very different observing systems.

The statistics generated from the collocation data base consist of mean bias differences and standard deviations (SDs) for temperatures and dew-points at standard levels, and thicknesses of various atmospheric layers. These statistics are calculated each day as means for all collocations within the LASS area, and monthly mean figures are also computed.

Fig. 9 shows the monthly mean bias and SD collocation figures for October 1984 and illustrates some of the problems associated with satellite-derived temperature soundings. The features of most interest in Fig. 9 are:

(a) The larger SDs at low levels and around the tropopause.
(b) The cold bias at 1000 mb.
(c) The warm bias at the tropopause.

The problems at low levels are thought to be mainly due to the inability of the present LASS processing scheme always to detect and correct for the effects of cloud. Because of the broad weighting functions of the instruments the LASS soundings will always tend to be slightly bland and lacking in definition in the vertical. Fig. 10 gives an example of a collocated radiosonde and LASS retrieval and illustrates many of the strengths and weaknesses of satellite-derived temperature soundings. In particular the soundings are able to describe the mean features well, but do not show the fine structure obtainable with a balloon-borne sensor. It is also clear that the satellite sounding is unable to resolve fully the sharpness of the tropopause and for this reason the monthly mean statistics at the level of the tropopause invariably have a larger SD than at other levels.

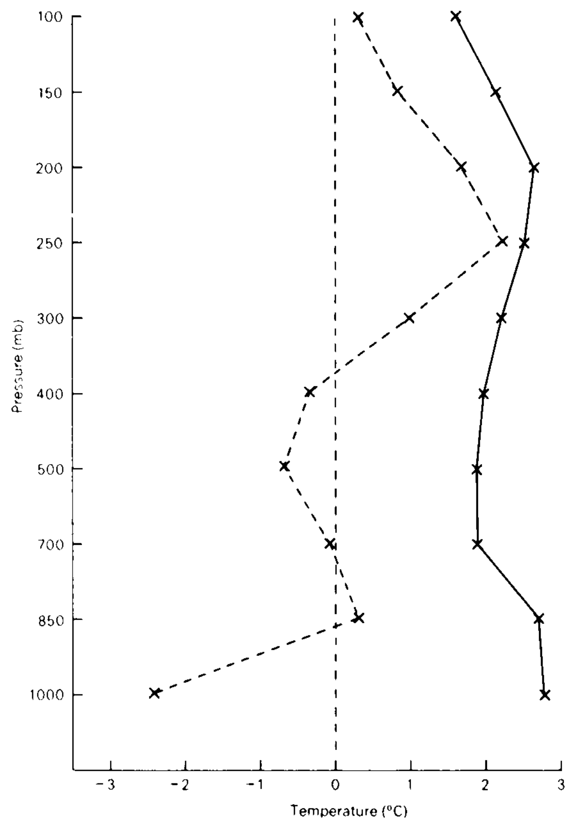

Figure 9. Monthly mean bias (pecked lines) and standard deviation (solid lines), for October 1984, for collocated LASS and radiosonde data.

However, the LASS soundings are able to provide useful information on the overall horizontal structure of the atmosphere which is especially valuable in data-sparse areas such as the Atlantic Ocean. The lack of vertical resolution is also less of a problem when the data are included in the numerical analysis system, as the model used in the operational assimilation cycle has relatively coarse vertical resolution. Thus the LASS soundings should be able to add information to the analyses in the data-sparse areas provided that any biases in the soundings can be handled.

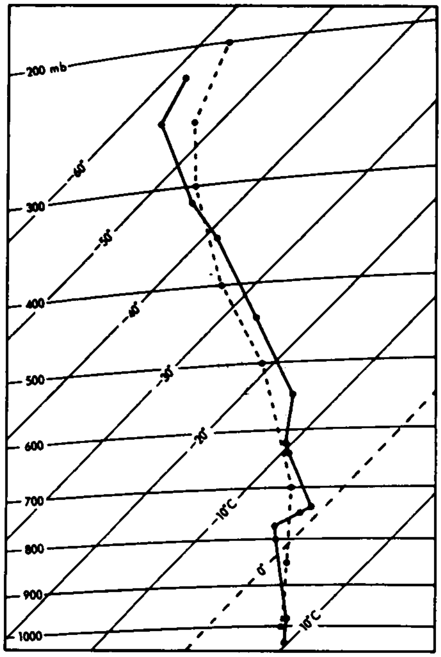

Figure 10. Radiosonde profile for Lerwick (solid lines) at 1200 GMT on 14 May 1984 with collocated LASS retrieval profile (pecked lines) at 0907 GMT on the same day.

4.6 *Future developments*

During the last 2 years the LASS system has been developed to a point where data from all the passes of TIROS-N series satellites over the United Kingdom are processed automatically and temperature and dew-point profiles supplied to the forecaster in CFO and to the fine- and coarse-mesh numerical analyses. During this period it has been established that the quality and characteristics of the LASS soundings are almost identical to those of the SATEMs.

Work is now taking place to assess fully the accuracy of the soundings, both by comparing the retrievals against radiosondes, and by examining the data in conjunction with the numerical analyses and CFO subjective analyses. Several significant problems have been identified and a number of these have been outlined above. At the moment the major areas of development are:

(a) The generation of our own regression coefficients from a carefully compiled set of historical radiosonde profiles and corresponding calculated brightness temperatures for the North Atlantic/European area. For a number of reasons these coefficients are expected to give better local results than the global NESDIS coefficients.

(b) The development of improved cloud detection and cloud-clearing techniques.

(c) Reassessing the limb corrections applied at the edges of the swaths where larger errors are found.

(d) Examining the possibility of using retrieval techniques which make more use of the radiative transfer equations and which use model forecast information as a background field.

5. Conclusion

This paper has outlined the main components and functions of the HERMES system. Using this system with the full range of digital data broadcast by the satellites, it is possible to explore a large range of imagery and sounding products which have useful research and operational applications. The sounding data are now used operationally in the numerical analyses and will play an increasing role as retrieval techniques improve. It is also hoped that the high-resolution imagery data will, over the next few years, come into operational use both at the Meteorological Office Headquarters and at outstations and have a significant impact on the Office's operations. The computing facilities available within the HERMES system will make it possible to take full advantage of these potentially very valuable data.

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Smoke-screens — the early years

By R. J. Ogden

Summary

A reminiscent account is given of work carried out in the United Kingdom during the Second World War on the meteorological conditions necessary for the successful laying of smoke-screens as a protection against enemy air raids.

During the War years, urgent posting notices for Meteorological Office staff were sometimes issued on the meteorological broadcast channel during the hourly break for collection of observations. Not surprisingly, with the teleprinter in local circuit, local jokers could all too easily prepare a spurious message posting a colleague to some outlandish location. In July 1940, when stationed at Croydon

Airport, I was presented one day with a teleprinter signal ordering me to report as soon as possible to 71 Ewell Road, Surbiton. My first reaction was to ignore this as a typical bogus message; but checks revealed that the instruction was quite genuine, although no-one at Headquarters was prepared to say what I was supposed to do at such an off-beat location.

On arrival next day at the given address, I became even more suspicious about a possible hoax, because 71 Ewell Road proved to be a large three-storeyed house on a busy main road, with a notice board in the front garden informing the public that this was the local Food Control Office, where one could obtain ration books. Enquiries inside at first drew a complete blank and I was on the point of returning on my bicycle to Croydon when someone suggested that perhaps I was connected with 'that odd man in the attic'. So I climbed the stairs and found that I had indeed come to the right place. The man in the attic was a forecaster who had arrived a few days previously and was struggling to create, out of virtually nothing, a completely new kind of meteorological advisory unit in support of a smoke-screen.

The concept of industrial smoke-screens

Many years later I discovered that, on 29 May 1940, the Prime Minister had directed that a committee should be set up to review the possibility of using smoke-screens to hide factories from aerial attack at night (see Air Ministry (Air Historical Branch) 1954). In those days, shortly after Dunkirk, and under threat of German bombing and indeed invasion, decisions could be acted upon remarkably quickly. Admittedly there had been some earlier studies at Porton about the use of smoke-screens, but even so it is astonishing that within a month from the date of Churchill's minute, the committee had considered the matter and reported favourably, the Ministry of Home Security had set up an appropriate organization, and a full operational trial had been mounted at Stewartby, near Bedford. This was made under full-moon conditions on 20 June 1940, and although aircraft observations of the effectiveness of the screen were inconclusive, there was enough positive evidence to encourage a Cabinet decision to go ahead, as quickly as possible. The following month, in July 1940, smoke-screens were set up to protect ten key factories, including the one at Tolworth with which I was then concerned, Incidentally, the small meteorological unit at Ministry of Home Security Headquarters set up to oversee the scheme was headed by P. A. Sheppard, later Professor of Meteorology at Imperial College. Also working in Sheppard's team was A. W. Brewer, later to become Reader in Meteorology at Oxford University and then Professor of Meteorology at Toronto University.

It was initially assumed that pin-point visual identification of a target from the air at night would be possible only in bright moonlight; this implied that screens were needed only during a period of about a fortnight each month when the moon — at least half full — was above the horizon for some part of the night. Within this potential risk period, a screen had to be laid whenever there was expected to be less than full cover of cloud (or thick fog) below 5000 feet, unless the wind exceeded about 20 knots in which case it was recognized that any screen would be ineffective. The required meteorological input was therefore firstly for a general forecast of the occurrence or otherwise of the limiting cloud and strong-wind conditions, and secondly, on operating nights, for a detailed local wind forecast so that generators could be positioned to give the necessary smoke cover over the target.

The smoke generators used during the early years were mostly of the orchard heater type. Each consisted of a cylindrical 'pot' containing 20 gallons or so of diesel oil, and surmounted by a tall chimney so that the whole assembly was about 4 feet high. Pots were positioned about 10 yards apart, ideally in a semi-circle about 2000–3000 yards upwind of the target. An alternative array for use in flat calm or very light and variable winds was that of a cross centred near the target and extending outwards to the circuit used when the wind was determinate. In practice, however, for obvious logistic reasons, the ideal layout could rarely be achieved because generators had to be located on roads, or at least on tracks which could be used by lorries. The generators burnt about 2 gallons of diesel oil per hour and produced thick, black, oily smoke.

The July 1940 operation

The first (and only) operational period of the Tolworth screen can only be described as a total shambles. Not surprisingly, in view of the extremely short period between the decision to go ahead with industrial smoke-screens and this first operation, generators were in very short supply and there were barely enough for a modest arc upwind of the target. Thus, not only had they to be positioned afresh each night according to the predicted wind directions and then be returned to the depot after close down, but also if the wind direction changed during the night, generators had to be extinguished, moved, and re-lit in new positions. With 10 gallons of diesel inside the pot it must have weighed the best part of a hundredweight, so all this moving about was no easy task.

The Ministry of Home Security District Officer at each screen was responsible for obtaining locally both transport and the necessary staff. Finding suitable lorries was difficult enough, but recruiting a labour force was a nightmare. His first approach was naturally to the local Labour Exchange, but most of the registered unemployed proved to be quite useless for heavy work of this kind; far from being able to hump fuel oil in bulk, some of the men who turned up had themselves to be lifted up onto the lorries. In the 1980s it may sound hard to believe, but the temporary solution was to obtain volunteers from the staff of a large department store in Kingston, who agreed to turn out at night after a day's work to help us out.

Meteorologists also had their share of problems. The direction of a wind of 1 knot is of no consequence at an airfield, but for an effective smoke-screen it is absolutely vital to understand, and to be able to predict the almost imperceptible but sometimes quite steady drifts of air that occur on a good radiation night. Similar problems, logistic and meteorological, were found at all other screens during this first moonlight period of operations, and it was wisely decided to have a breathing space before the next operation.

Meteorological field-work

In August 1940, all the meteorological staff working on smoke-screens were brought together in two groups; those from screens in hilly areas went to Rogerstone, near Newport (Gwent) and the remaining dozen of us went to Slough (Bucks). We were given 4 weeks in which to discover as much as possible about airflow at night across mixed urban–suburban–rural areas, especially under clear sky, light gradient conditions. This was indeed a fascinating challenge, and despite the obvious difficulties of working out of doors nearly every night for a month in the black-out and sometimes during air raids, we learnt many lessons that were subsequently put to very good use in helping to achieve more effective screens.

It was clear that for reference purposes, a good observer would have to make full and more or less continuous observations at a representative and well-exposed site in the area. Remaining members of the team were then positioned to give detailed coverage of the study area for the night, for example in and around a wood, a housing estate, farm land, the town centre and so on. We investigated the extent to which streets of houses, trees, large buildings and hedges affected the local airflow in stable inversion conditions and up to roughly what height. We were also very much concerned to discover the detailed effects of local orography on katabatic drainage. It emerged from this latter study that when one is interested in the extremely light drifts that will move smoke, quite modest areas of higher ground can initiate katabatic flow. At Slough we expected a katabatic wind from the Chilterns to the north (indeed under ideal conditions it can reach 5 knots), but we were surprised to find also a perceptible southerly drift across the Thames into the outskirts of the town from Windsor Great Park, the highest parts of which are only some 150 feet above the valley floor.

I can recall solitary nights during this field-work period spent sitting on a kerbstone in a housing estate with a smoke generator for company, in a field of cows (who seemed to make noises of one sort or another throughout the night), on a sewage farm, wandering along hedged country lanes north of the town, and in the middle of a field of cabbages. It was in this last location, having just released a pilot balloon with lantern, that I was shot at by a Home Guard who fortunately missed. I must confess that the call of self-preservation was then louder than the call of duty, and abandoning the rest of my observing program for the night I crawled out of the field and returned to base. Working as we were in an area which by virtue of the target was extremely sensitive from a security point of view, we naturally maintained very close liaison with the RAF, Army, Police and Home Guard, so that everyone concerned should have known in advance exactly what we were doing, where, and at what times. In addition to the normal RAF passes we all carried special Ministry of Home Security identity cards authorizing us to enter and work in security areas, and for the most part these kept us out of serious trouble. But none of these measures gave complete protection from Home Guards who were, very properly, highly suspicious of odd behaviour. Their internal dissemination of information was at times virtually non-existent, and individuals on patrol seemed often to be genuinely unaware of our activities, despite thorough briefing of Home Guard Duty Officers at the local Headquarters. One of my colleagues, then based at a screen in the Midlands, was arrested by the Home Guard and kept in solitary confinement for 48 hours before he was allowed to see an officer who ordered his release after checking his credentials.

There is no doubt at all that our activities and indeed our appearance were somewhat bizarre. On setting forth for a night's work, for obvious reasons in old clothes, one was equipped with: a sensitive cup anemometer, a ribbon on a pole for wind direction plus a tin of swansdown for very light winds, a whirling psychrometer, three or four filled balloons on strings (these had to be filled in the yard behind the office), lanterns and candles, stop-watch, clipboard and data sheet, torch, matches, gas mask, tin hat, sandwiches and perhaps a flask of coffee. The observer at the reference site also had a theodolite, tripod and pilot balloon slide-rule. Balloons released at other locations were only partially filled to give either no lift (a not very successful method of tracking light surface airflows) or ascent at a gentle rate; these were observed, qualitatively, by eye alone. With hindsight it is surprising that we did not land in deeper trouble. One can hardly blame an ill-briefed Home Guard for suspecting the worst when he encounters, at 3.00 a.m., a rather scruffy figure standing on a bridge over the main railway lines to the West Country holding a cup anemometer at arm's length, or wandering along a quiet country lane in pursuit of a balloon at the end of a long thread, not to mention sending up a candle-lit lantern during the black-out from a cabbage field adjacent to a vital factory.

Subsequent operations

At the end of the month of field-work, it was decided not to continue with the Tolworth screen, and I remained at Slough where our first task was to reorganize the generator layout in the light of our findings. By this time, there were sufficient pots to permit a permanent array approximating to the ideal circle and cross; this was divided into 30 or more numbered sections, and on any particular night only those sections needed to provide an effective screen were lit. The idea of using local labour was abandoned; responsibility for fuelling, lighting, looking after and extinguishing the generators was taken over by a company of the Army Pioneer Corps, and this arrangement worked quite smoothly.

During each moonlight period, our daily cycle of work started with a visit in late afternoon or early evening to Headquarters 11 Group at Uxbridge to look at the charts in the meteorological office there and to discuss the situation with the local staff on duty. If a screen seemed likely to be needed, on return to Slough we advised which sections of the array should be lit. We then spent most of the night driving round the area in the smoke monitoring the effectiveness of the screen. If the wind was not exactly as predicted and the smoke was going in the wrong direction, some sections might have to be closed down and others lit. After close down, and in a filthy condition after some hours spent in the smoke, we went back to our digs for some sleep; but no matter how late one got to bed, attendance at a morning conference at 10.00 a.m. was obligatory. At this there was a general discussion about the previous night's operation with Ministry of Home Security and Army staff, and a daily meteorological report had to be written and sent to Headquarters.

By mid-autumn when the operation had settled down, although we worked very long hours, mostly at night, during the moonlight periods, we had time to spare during the rest of the month; I was then normally detached to an RAF station for a short spell of normal meteorological duties on day shift. But in December 1940 it was decided that in suitable weather two of the screens should be run on non-moonlight nights also, and early in 1941 I had a busman's holiday as leave relief on the Nottingham screen whilst the Slough screen was not working. Later, after I had been posted back to mainstream duties at RAF stations, this practice was extended to other screens. Shortly before I left Slough, I spent one non-moonlight period surveying the ground and advising on the circuit for a new screen being planned at Langley, some miles east of the Slough screen. From the total of 9 screens in operation during late 1940, numbers grew steadily to reach a peak of over 30 in 1942; thereafter a few were closed each year and the final operations took place in September 1944.

One of the minor irritations of the job was the fact that our offices were not equipped with secure telephones. Conversations on the public network with Uxbridge had to be conducted in a form of verbal code in which names of animals were substituted for each of the necessary words in a forecast. Of the hundreds of words in the code-book I recall that octopus, ocelot, barracuda and basking-shark cropped up regularly in place of the familiar phrases like surface wind, gradient wind, visibility, locally, and so on. We also had to invent a similar code of our own to use when informing the Army, police, etc. about each night's operation. With what I felt to be a misguided sense of humour, the forecaster at Slough in July 1940 had elected to use the name of a drink for each of the different sections of the circuit. There was no problem with words like tea, coffee, beer or milk, but dictating phrases like 'Chateau d'Yquem' to a corporal in an Army orderly room did present problems.

Needless to say, the operation of smoke-screens in residential areas was not welcomed with open arms by the local population. Those who understood roughly what it was all about reluctantly accepted the need for screens, but nobody wanted a generator belching smoke and half-burnt diesel oil outside his front door. Keeping curtains or anything else clean must have been well nigh impossible, and we received many vociferous protests. I recall one winter evening when we had to light the cross part of the array which ran along two major roads through the town. The smell penetrated into a large cinema where the manager misguidedly switched on his full ventilation system; within minutes, the screen was invisible from the balcony and the box office was beseiged by patrons demanding their money back. There was nothing we could offer the manager but sympathy. In general, no compensation whatsoever was paid to anyone for dirt and inconvenience, so I counted it as a minor triumph that after several months of argument I eventually succeeded in persuading the Ministry of Home Security to pay a few shillings for the cleaning of a raincoat that had inevitably become impregnated with soot and oil.

Perhaps the most difficult problem faced by meteorologists was the situation when radiation fog was expected to form during the burn period. Timing such events to the nearest 10 minutes was difficult if not impossible, despite almost continuous monitoring of visibility and humidity in the area. Usually, when fog was clearly imminent, we took a chance and gave orders for the pots to be extinguished, but if the fog beat us to it because we had allowed insufficient time for an officer to get round the circuit telling the Army 'minders' to stop making smoke, the results could be quite catastrophic. I can remember very vividly one occasion when the fog formed quite suddenly and became so thick that it was impossible to get round the circuit giving instructions to douse. Within an alarmingly short time, the mixture of fog and smoke reduced visibility in the town centre to literally no more than 2 yards; it took me about an hour to walk barely half a mile along a main road from where I had abandoned my car to our office in the High Street.

Reference

Air Ministry (Air Historical Branch) 1954 The Second World War 1939–1945: Meteorology, 215–219. (Unpublished, copy available in the National Meteorological Library, Bracknell.)

Notes and news

Retirement of Mr C. V. Smith

Mr C. V. Smith, B.Sc., MA, Assistant Director (Agriculture and Hydrometeorology) retired from the Meteorological Office on 29 March after a career of almost thirty-seven years. During the early years he saw service as a forecaster at home and overseas but latterly will be remembered for his pioneering, far-sighted and productive application of meteorology to the needs of agriculture in the United Kingdom.

Cliff Smith was born in 1925 and was educated at the Coopers' Company School, Bow. During the war he was evacuated to a farm in Kent, an event which was to excite an interest in agriculture which found fulfilment many years later. He went on to gain a B.Sc. in Physics and Mathematics at Birkbeck College, and an MA in Physics and Chemistry at Cambridge. He joined the Office as a Scientific Officer in September 1948. After the customary spell at the Training School he was posted to the 'deep end' of a busy London Airport. This began his association with the synoptic forecasting for aviation which characterized the first half of his career.

In 1951 he started a three-year posting to the long-range forecasting team in M.O.22 under the guidance first of Sutcliffe and then of Sawyer; there he published useful papers with Forsdyke and Sumner on the properties of the long waves and use of Rossby theory. In 1954 he carried this experience back to operational forecasting in M.O.2. at Dunstable and was promoted to Senior Scientific Officer in 1955, whereupon he became a Senior Forecaster on the upper-air bench. He demonstrated a flair for forecasting synoptic development and continued to write and have published papers on techniques for medium-range forecasting based on the 500 mb flow.

In 1958 he began an overseas tour at RAF Luqa, Malta, where he rapidly made an impression as an above-average forecaster who demonstrated originality and initiative.

January 1962 represented an important watershed; Cliff returned to the United Kingdom and took up a post in M.O.7 which required him to study and advise on the ventilation of animal houses and grain stores. Although nothing in his previous professional career had prepared him for such work he made an immediate and impressive impact. Despite this the posting system did not quite have the courage of its convictions — in September 1963 he was moved on promotion to the Central Forecasting Office! However, even as a Senior Forecaster he continued to write up and publish the results of his research work in agrometeorology and two years later he became the Senior Meteorological Officer at Cambridge alongside the other specialists in the Eastern and East Midland Regions of the then National Agricultural Advisory Service.

During the next twelve years he transformed agrometeorology in the United Kingdom and, as an active and forthright member of the Commission on Agrometeorology of the World Meteorological Organization, extended his influence and reputation even more widely. There was almost no aspect of modern agrometeorology which did not receive his attention during this period. His earlier work on ventilation was extended to the problems of grain and potato storage, to the conditions favouring the outbreak of cereal mildew and to the environmental factors which influence animal growth and well-being. He made significant contributions in advising on the design and siting of glasshouses and on the calculation and practical use of concepts of 'degree days', 'machinery work days' and 'soil moisture deficit'. Throughout he was guided by the need to provide practical solutions to problems. He was ahead of his time in extolling the role of meteorology as a management aid in the agricultural industry and of the business approach to meteorology. His pioneering work on the potential benefits of meteorology to agriculture continues to be worthy of study.

In the summer of 1975, Cliff was posted to Met O 1 at Bracknell to gain some experience of Headquarters before the promotion to Assistant Director which was then foreseen. He settled down quickly, making well-received proposals for reorganization of the North Sea observing networks and of radiation work in the Office, which he subsequently helped to implement.

He was promoted and took up his appointment as Assistant Director, Agriculture and Hydrometeorology, in the spring of 1977. Since then Cliff has continued to apply himself and his staff very effectively to the practical exploitation of meteorological data and knowledge for the benefit of hydrology and agriculture. It is his avowed intention to seek new opportunities for such application in retirement. We therefore expect to see a lot of him in future. We look forward to that, whilst wishing good health and happiness to him and his wife Sylvia during his retirement.

P. Ryder

50 years ago

The following extract, including the editorial note, is taken from the *Meteorological Magazine*, June 1935, **70**, 118.

Blue Snow and Inky Rain in the Shetlands

Rain which fell on the forenoon of March 16th was quite dark-coloured. My attention was called to the colour of the water in the pools and when I got home I at once examined the water in the rain-gauge and found it too was tinted; looked as if it had been slightly diluted with black ink. The sky looked thundery, but I did not hear any thunder, though a thunderstorm was reported from Lerwick about 40 miles distant.

T. EDMONSTON SAXBY

Halligarth, Baltasound, Shetland, April 2nd, 1935.

[According to the *Shetland Times* of March 23rd, following a spell of very fine bright weather, the sky was overcast after daylight on Saturday, March 16th, and there were showers of wet snow. Thunder was heard shortly after 9h. and by 10h. the morning was becoming darker, with an ominous looking sky and a peculiar greenish light. Heavy thunder and several bright flashes of lightning followed between 10h. and 11h. and about 10h. 30m. exceptional darkness was experienced. In some districts heavy rain fell and in Lerwick the thunderstorm was followed by a heavy shower of wet snow and later rain. By noon weather conditions were normal and afternoon and evening were fine. A peculiar feature in several districts during the thunderstorm was that the snow which fell was of a dirty bluish colour and rain water which was collected in tanks and barrels was something of the colour of ink. Dr. Harrison, of Lerwick Observatory, states that black rain was reported from Bressay, 'but we saw nothing of this or of blue snow here'. The pressure gradient on March 15th and 16th was such that air from industrial districts might have reached Shetland. — ED., *M.M.*]

A summer school on mesoscale meteorology

A week-long, residential summer school is being organized jointly by the Meteorological Office and Reading University, on the general topic of mesoscale meteorology. It will be held at the Meteorological Office College, Shinfield Park, near Reading from 8 to 12 July 1985.

The program will consist of a series of lectures covering different aspects of mesoscale meteorology, supplemented by case-studies of specific situations carried out in working groups. The case-studies have been chosen to illustrate mesoscale features of fronts and of convective phenomena. The coupling of the case-studies with the lectures is intended to ensure that participants acquire a good understanding of the theoretical concepts introduced by speakers as well as giving some practical knowledge of their application and relevance to atmospheric phenomena.

The speakers will be mainly from the Meteorological Office and Reading University. Contributions will also come from the European Centre for Medium Range Weather Forecasts, Imperial College and the mesoscale research group at the Centre National de la Recherche Météorologique, Toulouse, who are working with the Meteorological Office on a joint venture — the Mesoscale Frontal Dynamics Project.

The participants, about 50 in number, will be drawn from both the Research and Forecasting Branches of the Meteorological Office, together with representatives from the universities and two French research groups. The steering group for the summer school consists of Dr K. A. Browning, Professor B. J. Hoskins, Dr B. Golding and Dr C. J. Readings.

Review

Prophet — or professor? The life and work of Lewis Fry Richardson, by Oliver M. Ashford. 160 mm × 240 mm, pp. xiv + 304, *illus*. Adam Higler Ltd., Bristol and Bolton, 1984. Price £18.00.

The title of Oliver Ashford's biography of Lewis Fry Richardson (1885–1953), *Prophet — or professor?* implies that the author had it in mind to leave the reader with the responsibility for assessing L. F. Richardson's life and works on the evidence he presents. Was L. F. Richardson a prophet or a professor? There is much about his life which was enigmatic, even to his contemporaries. His preference for solitude and an apparently less than easy relationship with his various employers in his early professional career probably stemmed from his unwillingness to become part of any organization or bureaucracy which threatened to inhibit the free exercise of his intellectual curiosity or force him to compromise on the truth as he saw it. For L. F. Richardson truth lay in the mathematical expression of phenomena as diverse as the flow of drainage water in peat, numerical forecasting and the foreign policies of nations.

The author describes how L. F. Richardson's published contributions to meteorology began in 1915 with a paper on thunderstorm detection by clicks on telephone lines. His subsequent published meteorological output ranged widely over many subjects including the physics and dynamics of precipitation, the use of balloons for recording upper-air temperatures and his classic book *Weather prediction by numerical processes* which was published in 1922. His final paper in meteorology was on 'The reflectivity of woodland, fields and suburbs between London and St Albans', published in 1930, although he published a brief note in the *Quarterly Journal of the Royal Meteorological Society* in 1952 replying to criticism of his 1920 paper on atmospheric turbulence. It is a measure of his productivity as a mathematician that his biographer cites 57 references to his published work after 1930, when his scientific output was almost entirely concerned with his search for the quantification, and the possible predictability, of conflict between nations.

L. F. Richardson has become a legendary figure to subsequent generations of meteorologists, largely because of his 1922 book of numerical forecasting in which he worked his way through a series of separate statements about the dimensions of atmospheric disturbances, the required accuracy, a discussion of the use of mathematical equations in the numerical prediction of the behaviour of the atmosphere and the variables which needed to be considered such as soil moisture transfer rates, evaporation and turbulence. A whole chapter is devoted to radiation processes, parcel theory and the definition of sea temperature. He then dealt with vertical velocity, the stratosphere and the observed data available to initialize his fields. L. F. Richardson was always open in his work and made available, separately from his book and financed out of his own pocket, a set of 23 computing forms . . . 'to assist anyone who wishes to make partial experimental forecasts from such observational data as are now available'. The core of his book lay in a worked example of a numerical weather forecast starting with the observed state of the atmosphere at 0700 GMT on 20 May 1910. The results were a disaster. An anonymous 'meteorological correspondent' in the *Manchester Guardian*, probably Sir Napier Shaw, noted that L. F. Richardson's fantasy of an orchestrated computing operation involving 64 000 human computers in a room the size of the Albert Hall 'sounds like the rhapsodies of an irresponsible visionary but, actually, it is an attempt to picture a "forecast-factory" of the future in which the weather of the whole globe will be predicted on highly rational and scientific lines'. L. F. Richardson was fallible, as his biographer points out elsewhere. His figure of 64 000 human computers was based on an error in his calculation — it should have been 256 000 — and Hyde Park rather than the Albert Hall would have been a more appropriate venue!

It is a remarkable commentary on subsequent developments in numerical forecasting that its foundations were relaid by a later generation of meteorologists working in the Napier Shaw Research Laboratory at Dunstable 30 years on and that L. F. Richardson's 'forecast-factory' is now well established as an operational national global forecasting centre, with an international role as one of the two World Area Forecast Centres for civil aviation with the National Meteorological Centre in Washington, in the Richardson Wing of the Headquarters building of the Meteorological Office at Bracknell.

By the summer of 1920 L. F. Richardson had come to a personally distressing decision to leave the Meteorological Office. He had been Superintendent of Eskdalemuir Observatory from 1913 to 1916, working in geomagnetism, atmospheric electricity and seismology, until he resigned to serve with the Friends Ambulance Unit in France from 1916 to January 1919 when he returned to the Meteorological Office, joining W. H. Dines in developing methods of upper-air measurement at Benson Observatory. The move of the Office into the newly created Air Ministry meant that he would have had to compromise his strongly felt Quaker beliefs. But his resignation was, as it proved, for the best. Basic meteorological research was not encouraged in the pre-war Meteorological Office. Others were to gain. L. F. Richardson's devotion to the cause of peace and to the service of others, which is the hallmark of the Quaker tradition and conscience, prompted him to look to the quantification of conflict within and between nations as an outlet for his scientific talent and energy. He left the Meteorological Office to lecture at Westminster Training College and, later, to become the Principal of Paisley Technical College. His interest in psychology led him to work in such diverse areas as colour perception, the quantification of pain and the analysis of mental processes before concentrating almost exclusively on the mathematics of the psychology of war, leading to his work on generalized foreign politics which he published as a monograph in the *British Journal of Psychology* in 1939. By 1950 he had privately produced two books on microfilm — *Arms and insecurity* and *Statistics and deadly quarrels*. In 1951 he published a note in *Nature* with the title 'Could an arms race end without fighting?'.

Oliver Ashford is careful not to interpose his views between the reader and his subject more than is absolutely necessary but his detailed and objective account of the life of L. F. Richardson suggests that perhaps the greater value of his life will come to be recognized in his analytical studies of war. In that field he was a true pioneer whose contribution is only just beginning to be recognized. In meteorology there were others — and not the least was Vilhelm Bjerknes who predated L. F. Richardson by nearly 20 years in looking to an adequate representation of the observed state of the atmosphere as the first and essential diagnostic step in the integration of the fundamental hydrodynamic and thermodynamic equations, leading on to prognosis. The development of numerical forecasting from Bjerknes' original work was not an evolutionary process through L. F. Richardson. The present-day operational 15-level primitive-equation global model has its foundations in research which began in the early 1950s when sufficient computing power became available to test newly-developed and relatively simple numerical models. As numerical forecasting developed it moved rather more closely to L. F. Richardson's original ideas but numerical forecasting would have taken off in the 1950s even if L. F. Richardson had not published his classic book. It was his vision which remained the inspiration to a later generation.

Thirteen years after the death of L. F. Richardson in 1953, Sir Graham Sutton, in correspondence with G. W. Platzman which was published in the *Bulletin of the American Meteorological Society*, summarized much about L. F. Richardson which is confirmed by the detailed evidence in Oliver Ashford's biography: 'This gentle man was unshakeable in his decision to conduct his life in accordance with the principles of his creed. It may be, of course, that he would not have fitted easily into any team, for it is clear that he was very much the individual worker. But what an inspiration he would have been as a consultant!'

The author poses a question, presents all the available evidence and leaves the reader to decide the answer for himself. Was L. F. Richardson a prophet or a professor or is the author's question unfair to his subject? There is evidence enough in his biography to justify both descriptions as appropriate. There are two quotations on the flyleaf. The first is from Samuel Johnson, of Oliver Goldsmith — 'He touched nothing that he did not adorn.'. The second is from William Wordsworth, of Isaac Newton — '. . . a mind for every voyaging through strange seas of thought, alone.'. The first quotation has an element of the sycophantic which is totally absent from Oliver Ashford's text. The second quotation summarizes, at least for the reviewer on the evidence presented and I suspect for most of the readers of this biography, the personality of L. F. Richardson.

Oliver Ashford's last three words — '. . . searcher after truth' — conclude this admirable biography with a fitting epitaph for its subject.

I. J. W. Pothecary

Books received

The listing of books under this heading does not preclude a review in the Meteorological Magazine at a later date.

Wind as a geological process on Earth, Mars, Venus and Titan, by Ronald Greeley and James D. Iversen (Cambridge University Press, 1985. £35.00, US $59.50) deals with the geological aspects of windblown material. Aeolian processes play an important role in the modification of the Earth's surface and are known to be active on Mars. The book begins with an introduction to aeolian processes and a general overview of aeolian activity on the planets, then goes on to discuss the physics of particle motion and the effects of windblown sand and dust on the topography of the Earth and Mars, together with some speculations about Venus and Titan. The book is written for readers with a fundamental science background and should be of particular interest to students and professionals in the fields of planetary science and earth science.

Weather (second edition), by Louis J. Battan (Englewood Cliffs, New Jersey, USA, Prentice-Hall, Inc., 1985. £17.15) is a basic textbook on general meteorology, which includes a chapter on forecasting techniques. It is well illustrated and written in an easily readable style, which should make it comprehensible to anyone with a rudimentary knowledge of physics.

Principles of remote sensing, by Paul J. Curran (London and New York, Longman, 1985. £11.95) is a textbook intended for graduate and undergraduate students. It discusses the basic theory concerning the interactions between electromagnetic radiation and the earth's surface and goes on to describe the equipment used, and the processing and interpretation of the images which are obtained. The book is profusely illustrated with diagrams and photographs and there is an extensive bibliography.

Looking at weather, by Ingrid Holford (Brockenhurst, Weather Publications, 1985. £1.95) is aimed at anyone who is interested in weather, but particularly teachers and instructors at sports establishments who have to introduce the subject but are not themselves meteorologists. It includes some basic physics with few words but many easily understood diagrams.

Obituary

We regret to report the death, on 29 December 1984, of Thelma Patricia Powell, Scientific Officer in the Observational Requirements and Practices Branch (Met O 1). Miss Powell, educated at Willesden County School, joined the wartime Air Ministry as a Clerical Assistant in 1945, but transferred to become a Meteorological Assistant the following year. Her career was spent within the climatology branches of the Office, initially in M.O.3 as a data quality-control assistant in the manual and early punched-card eras. With the move of the Harrow headquarters she came to Bracknell in 1961. After hydrometeorology was transferred to Met O 8 (Agriculture and Hydrometeorology Branch) she was part of the archival data-processing team for the United Kingdom Flood Studies project, and over the past decade she established a close working relationship with the Water Authorities of England and Wales whilst engaged on technical administration liaison duties in Met O 1.

Throughout her career in the Office she was involved in a variety of social and club activities, ranging from the organization of children's Christmas parties at Harrow, a long association with the Horticultural Society, through to committee membership of the Gramophone and Music Society, of the Camera Club, and from time to time of the main Social and Sports Association.

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