Indian Journal of
METEOROLOGY & GEOPHYSICS

October 1969
Vol. 20 No. 4

551.583 : 539.17 (4+5)

The influence of Nuclear Explosions on the Weather Pattern of Europe and Northern Asia

G. M. N. WICKRAMASINGHE

47, Fitzwilliam Square, Dublin, Ireland

(*Received 24 August 1968*)

ABSTRACT. There were powerful series of atmospheric nuclear explosions in the Novaya Zemlya region of the Arctic in autumn and early winter of 1961; and much more powerful series in the same region during the same seasons in 1962 These have been the most powerful so far.

During the above seasons it is noticed that the pressure and circulation pattern of the troposphere and lower stratosphere in Europe and Northern Asia displayed some abnormal features for the time of year: during and immediately after each series of nuclear explosions the sea level westerly circulation was weak with low cyclonic activity; but the high-level westerly circulation was strong with strong cyclonic activity at high levels and intense anticyclonic activity with blocking at sea level and higher levels, often for long periods. This abnormal atmospheric pattern faded between series of explosions, particularly if there was a long interval between the series

A consequence of this atmospheric pattern has been the development of an extensive cold polar cell over Northern Eurasia by mid-winter of each year. The very cold northerly and easterly winds emitted by this polar cell opposed the warm sea level westerly circulation, and prevented the invasion of temperate latitudes by warm fronts. As a consequence the winters were very cold, and the 1962-63 winter was one of the coldest on record.

With the aid of aerological charts and available information regarding atmospheric nuclear explosions and their influence on the atmosphere, it has been shown that the series of nuclear explosions played a major role in the evolution of the abnormal atmospheric pattern.

1. Introduction

Since 1954 there has been considerable speculation regarding the effects of atmospheric nuclear explosions on the weather. The series of Russian nuclear explosions in the atmosphere over the Novaya Zemlya region in 1961 and 1962 have been the most powerful so far. By strange coincidence the winters that followed the series were particularly severe. The object of this paper is to examine the available data regarding these two series of nuclear explosions and their effects on the atmosphere, in conjunction with the aerological and climatological evidence; and to submit a plausible explanation for the severity of the winters of 1961-62 and 1962-63.

2. Immediate effects of a Nuclear Explosion on the atmosphere

(*a*) *Movement of tropospheric air into the stratosphere after Megaton Explosions*

Immediately after the atmospheric nuclear explosion the fireball ascends and its roughly spherical shape soon changes into a toroid, which undergoes a powerful circulatory movement.

On the assumption that the troposphere is a spherical shell around the earth (a sphere of radius 4000 miles) with an average thickness of 7 miles, its volume is roughly 47,01,56,104 cu. miles. To estimate roughly the volume of tropospheric air transferred to the stratosphere by the Novaya Zemlya explosions it could be assumed that the volumes transferred by the 2, 4, 6, 8, 9, 11, 12, 14, 19 and 26 megaton bursts were roughly equivalent to those transferred by the 3, 5, 7, 7, 10, 10, 10, 15, 20 and 25 megaton bursts (as given in Table 1) respectively, and a fairly close approximation on the conservative side obtained (with the omission of a few low megaton bursts). The equivalence of these explosion yields would be assumed with respect to the effects of shock and thermal radiation also. On this basis, the 1961 series transferred roughly 90,381 cu. miles, about ·038 per cent of the tropospheric circulation of the Northern Hemisphere or ·019 per cent of the earth's troposphere. The corresponding figures for the 1962 series are 118,785 cu. miles, ·050 per cent and ·025 per cent respectively. Between 22 October

TABLE 1

Estimates of tropospheric air transferred to stratosphere

Yield (megatons)	Mean stem height (miles)	Length of stem in stratosphere (miles)	Mean cloud radius (miles)	Mean stem radius (miles)	Height of segment (miles)	Volume of segment (cu. miles)	Volume of stem in stratosphere (cu. miles)	Total volume in stratosphere (cu. miles)
3	17	12	15·5	3·1	2·325	250	362	612
5	17·5	12·5	19	3·8	2·85	461	567	1028
7	18·5	13·5	22	4·4	3·3	715	822	1537
10	19·5	14·5	26	5·2	3·9	1181	1232	2413
15	20·5	15·5	32	6·4	4·8	2201	1978	4179
20	21·5	16·5	38	7·6	5·7	3686	2995	6681
25	22·5	17·5	44	8·8	6·6	5723	4359	10082
30	23·5	18·5	50	10	7·5	8397	5814	14211
32	23·9	18·9	52·4	10·48	7·86	9666	6524	16190
40	25·5	20·5	62	12·4	9·3	16011	9907	25918
58	29·1	24·1	83·6	16·72	12·54	39251	21174	60425

and 5 November 1961, a period of only 12 days, the figures are 76,097 cu. miles, ·032 and ·016 per cent respectively; between 4 August and 28 September 1962 (a period of 55 days) 93,152 cu. miles, ·039 and ·0195 per cent respectively; and between 14 and 28 September 1962 (a period of only 13 days) 53,667 cu. miles, ·022 and ·011 per cent respectively. The 58 megaton explosion of 30 October 1961 moved 60,425 cu. miles of tropospheric air into the stratosphere in a massive air column nearly 16 miles in radius and penetrating about 24 miles into the stratosphere; and, together with the explosions of 31 October 1961, moved about 64,375 cu. miles of tropospheric air into the stratosphere within about 48 hours.

(b) *Temperature excess due to shock-heating*

Although the air in the vicinity of the explosion is more or less simultaneously heated by shock and thermal radiation with a 'complex interaction of hydrodynamic and radiation factors' (Glasstone 1964), the temperature excess due to shock-heating only (disregarding thermal radiation) is considered here.

The rise in air temperature due to shock-heating at various (radial) distances from the point of detonation, about the 600-mb level in the Novaya Zemlya region, are given in Table 2. The figures in the table have been computed from data given in a figure by Glasstone (1964) and the Rankine-Hugoniot equations for a single ideal shock wave, such as the Mach front in an air burst or a single hemispherical fused wave from a contact surface burst. The distances of the peak over-pressures for a W kiloton explosion at the 600-mb level corresponding to the respective peak over-pressures for a 1 kiloton burst at sea level, will be given by (Glasstone 1964) —

$$d = d_1\, W^{1/3} \left(\frac{600}{1000} \right)^{1/3} = .8535\, d_1\, W^{1/3} \quad (2\cdot1)$$

where d_1 is the distance for the 1 kiloton burst at sea level, d the corresponding distance for the W kiloton explosion at the 600-mb level, and 1000 mb the ambient pressure at sea level. This expression is applicable for altitudes not differing by more than a few thousand feet, say about 3/4 mile, from that of the point of burst. The average ambient air temperature in the Novaya Zemlya region at the 600-mb level during the explosions should have been generally about 250°A (—23°C). Then, from the Gas Law for dry air, the absolute temperature T corresponding to an over-pressure p with ambient pressure 600 mb and temperature 250°A is given by —

$$\frac{T \times \rho}{250 \times \rho_0} = \frac{600 + p}{600} \quad (2\cdot2)$$

where ρ is the density of the air behind the shock front and ρ_0 the ambient density. But according to Glasstone (1964) —

$$\frac{\rho}{\rho_0} = \frac{7 + 6p/600}{7 + p/600} \quad (2\cdot3)$$

$$\text{Thus, } T = \frac{(600 + p)\,(4200 + p)}{14\cdot4\ (700 + p)} \quad (2\cdot4)$$

TABLE 2

Blast wave characteristics

Temp. (behind shock-front) (°C)	Particle velocity (peak wind velocity behind shock-front) (ft/sec)	Shock velocity (ft/sec)	Peak over-pressure * (lb/sq. in)	Distance in miles from point of burst (at an altitude of 2½ miles of megaton)								
				5	7	10	15	10	25	30	40	58
25	320	1300	7	3·53	3·94	4·44	5·09	5·60	6·03	6·41	7·06	7·99
42	440	1400	10	2·71	3·03	3·41	3·91	4·30	4·64	4·93	5·42	6·14
96	760	1700	20	1·90	2·12	2·39	2·74	3·01	3·24	3·45	3·80	4·30
196	1200	2100	40	1·49	1·67	1·88	2·15	2·36	2·55	2·71	2·98	3·38
343	1700	2600	70	1·09	1·21	1·37	1·56	1·72	1·85	1·97	2·17	2·45
488	2000	2900	100	·92	1·03	1·16	1·33	1·46	1·58	1·68	1·85	2·09
968	3000	4000	200	·71	·79	·89	1·02	1·12	1·21	1·28	1·41	1·60
1927	4400	5400	400	·52	·58	·65	·74	·82	·88	·94	1·03	1·17
3365	5800	7100	700	·37	·43	·48	·55	·60	·65	·69	·76	·86
4803	7000	8600	1000	·30	·33	·37	·43	·47	·51	·54	·60	·68

The temperatures in Table 2 corresponding to the various peak over-pressures at different distances from the explosion, have been roughly calculated for each explosion yield from this expression. But, these temperatures would be obtained in the case of a single fused wave; and, even in this case, only in the layer of air bounded by horizontal **planes** 3/4 miles above and below the point of burst respectively. The over-pressures due to the incident wave at any point would be raised considerably soon afterwards by the over-pressures from the reflected wave, so that peak over-pressures nearly as **high as those from a fused wave could be** attained. Near ground level peak over-pressures from the powerful Mach front would be nearly as high as those from a single fused wave. Thus the temperatures attained at various distances from the point of burst could be assumed to be nearly as high as those due to a single fused wave. After the blast wave has been propagated away and air pressure has returned to ambient, the temperature of the shocked air will be much higher than the original ambient temperature.

The volume of the frustrum of the sphere with the point of burst as centre and radius equal to the distance of the point of minimum temperature 25°C from the point of burst, intercepted by horizontal planes at distances 3/4 mile above and below the point of burst respectively, will give the volume of shock-heated air to, at least, a temperature of 25°C, a temperature excess of 48°C over the ambient temperature of —23°C. With very high temperatures in the interior of the region it is probable that the average temperature within the region would reach a value not appreciably less than 96°C (a temperature excess of 119°C), the temperature of the point about half-way between the point of burst and the point of minimum temperature. It could be roughly estimated that the region enclosed by the frustrum of the same sphere, intercepted by planes 2½ miles above (tropopause level) and 2½ miles below (ground level) the point of burst respectively, would be shock-heated to a temperature of about 25°C. This would be a volume roughly three times the volume heated to an average temperature of 96°C. Table 3 gives the volumes corresponding to these regions for each explosion. Our estimates could only be approximate, for meteorological conditions could modify shock-heating processes (Glasstone 1964).

(c) *Temperature excess due to thermal radiation*

A comparison could be made of the intensity of thermal radiation from the explosion (in cal/cm^2 or ly over the earth's surface beneath the point of burst) with the average intensity of solar insolation (in ly per day). Both are roughly in the same spectral region and in each case direct absorption by the atmosphere is small, but the bulk of the radiation is absorbed by the earth which in turn heats the atmosphere by contact and

TABLE 3

Temperature excess due to shock-heating

Yield (megatons)	Volume with a minimum temp. excess of 48°C and an average temp. excess of 119°C (cu. miles)	Volume with a possible minimum temp. excess of 48°C (cu. miles)
5	57	171
7	75	225
10	95	285
15	117	351
20	142	426
25	169	507
30	198	594
40	230	690
58	301	903

TABLE 4

Temperature excess due to thermal radiation

Yield (megatons)	Cylindrical volume with a minimum temp. excess of 1·5°C (cu. miles)	Maximum temp. excess attained in the interior of the cylinder (°C)
5	9·75	1·75
7	36·10	2·40
10	73·00	3·50
15	126·00	5·25
20	173·50	7·00
25	217·00	8·75
30	258·00	10·50
32	274·50	11·10
40	333·50	14·00
58	455·45	20·10

re-radiation. The average value of the heat energy absorbed by the earth-atmosphere is equivalent to a supply of about 0·30 ly per minute or 432 ly per day of the earth's surface (Petterssen 1958), which is about the average daily rate of undepleted solar insolation less the albedo in the equatorial belt (Haltiner 1957) where the solar beam is nearly vertical; so that a comparison could be made with the vertical component of the intensity of thermal radiation. If all this heat were used to warm up the atmosphere the temperature would rise by about 1·5°C a day. A Novaya Zemlya explosion at an altitude of about $2\frac{1}{2}$ miles, (Glasstone 1964) will give the intensity of (undepleted) radiation, Q, received vertically per unit area of the earth's surface, at a distance D miles from the explosion of M megatons, approximately equal to —

$$\frac{(1\cdot 04)\,(1000\ M)}{D^2} \times \frac{5/2}{D} = \frac{2600\ M}{D^3} \qquad (2\cdot 5)$$

If the right circular cylinder of height 5 miles (upto the tropopause) and circular base, with ground zero as centre and circumference on which the intensity of radiation is Q, is considered a comparison could be made with solar insolation. Then about $3/5\ Q$ is absorbed by the earth-atmosphere allowing for the albedo ; and $(3/5\ Q)\ /432\times 1\cdot 5^\circ$ or $(Q/480)$°C will represent the average temperature excess, T_e, in the atmosphere on the curved surface of the cylinder, assuming that all this energy was used up to heat the over lying atmosphere. Thus T_e from a M megaton burst, corresponding to a point on the earth's surface at a distance D from the explosion, is by Eq. (2·5) represented by —

$$\left\{\frac{2600\ M}{D^3}\right\}/480 \quad \text{or} \quad (65M/12D^3)\ ^\circ\text{C} \qquad (2\cdot 6)$$

A temperature excess of 1·5°C will thus correspond to a value of D given by $D^3 = (65/18)M$. Thus a cylinder of height 5 miles with a temperature excess of 1·5°C on its curved surface will have a

base of radius $\left[\left(65M/18\right)^{2/3} - \left(5/2\right)^2\right]^{1/2}.$

T_e would be a minimum of 1·5°C on the curved surface, would increase radially inwards and theoretically reach a maximum on the axis, corresponding to ground zero or $D = 2\frac{1}{2}$ in Eq. (2·6). Table 4 gives the cylindrical volume of air with a minimum temperature excess of 1·5°C and the maximum temperature excess attained within the cylinder for each Novaya Zemlya explosion. The figures in the table could vary within wide limits due to atmospheric conditions and the nature of the earth's surface beneath the explosion. Some degree of accuracy could be assumed if the cylindrical mass of air was almost stationary and insulated from the remainder of the atmosphere.

3. The Influence of the Novaya Zemlya atmospheric explosions on the evolution of the abnormal pressuer and circulation pattern of the troposphere and lower stratosphere

Almost immediately after a megaton explosion the shock waves generate strong transient winds with very high peak velocities (ranging from about 220 mph at a distance of 8 miles from the explosion to about 4750 mph at 2/3 miles in a 58 megaton burst — Table 2); and induce a rapid general flow of air away from the explosion. The divergence thus caused in the region of the explosion depresses the isobaric surfaces aloft, creating an upper trough and upper convergence (Palmen 1951). The explosions have taken place about the 600-mb level, and the troughs should have formed above this level. The rapidly ascending radioactive cloud with its powerful, toroidal internal circulation of hot air and gases generates the 'chimney movement' in which a thick column of air, the stem of the cloud moves in its trail into the stratosphere which would commence about the 300-mb level, generating the afterwinds towards the site of the explosion. In high-megaton bursts the cloud and stem are quite massive and penetrate deep into the stratosphere (Table 1); and the whole circulation could be maintained for a long time. A considerable proportion of the heated air in the region of the explosion will be drawn into the 'chimney movement' and enter the stratosphere, thus reinforcing the upward movement of warm air in the region of the explosion. In the case of high-megaton explosions large masses of hot air would be involved (Tables 3 and 4).

Thus the development of the upper trough referred to above, into a depression, which bears a resemblance to a tropical depression in origin and structure in a polar cyclonic upper troposphere and lower stratosphere, predisposed to the formation, development and persistence of troughs and depressions particularly in the season during which the Novaya Zemlya explosions took place is indicated (Palmen 1951, Wexler 1951). There will be a warm central core at least initially, and the pressure gradients between the periphery and central core of low pressure could be strong at the base of the depression. This is indicated by the strong afterwinds reaching 275 mph in a 1-megaton burst and perhaps over 1000 mph in a high-megaton explosion. The mass of hot, turbulent gases ascending rapidly into the stratosphere from the point of detonation will form the nucleus of the central core of the depression; and in the case of a high-megaton burst, the warm central core would be maintained well into the stratosphere (Fig. 1). With the decrease of the pressure-gradient force with height the rising air currents within the depression will tend to flow outwards from the centre, as soon as the centrifugal force exceeds the pressure-gradient force. An increase in the vertical velocity with height may strengthen the radial outflow of air aloft (Dunn 1951). The rising air currents will, however, tend to slow down and eventually subside in the stratosphere due to a lapse in the temperature-gradient, and the air masses will expand laterally as evidenced by the flattening of the radioactive cloud. This will limit the upward extension of the depression.

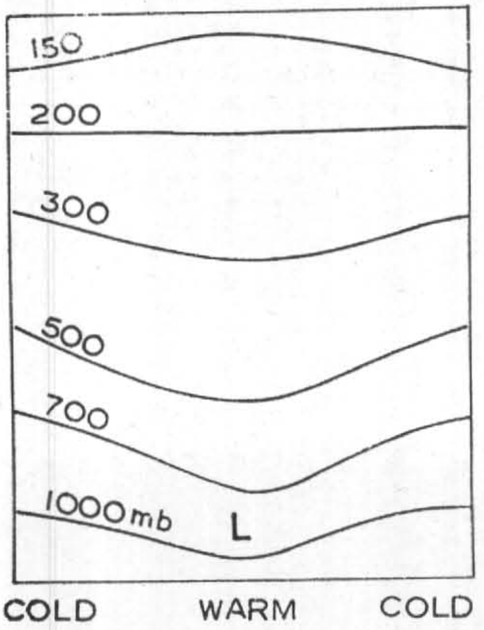

Fig. 1. Vertical cross-section of the isobaric surfaces of a depression

Air heated by shock and thermal radiation to high temperatures in the immediate vicinity of the explosion will be largely drawn into the 'chimney movement' and enter the stratosphere. But large shock-heated air masses further afield with temperatures ranging from 96° to 25°C (Table 2) and even further away with temperatures over 10°C which should form a very considerable proportion of heated air, are likely to drift away from the site of the explosion as transient winds or be embodied in the general circulation and move in the direction of the prevailing winds.

At a minimum average temperature of 25°C the temperature excess of a mass of shock-heated air would be 48°C in the case of the Novaya Zemlya explosions; and warm air advection could take place in all directions at the 700, 600, 500 or 400-mb levels. Advection of warm air aloft is followed by

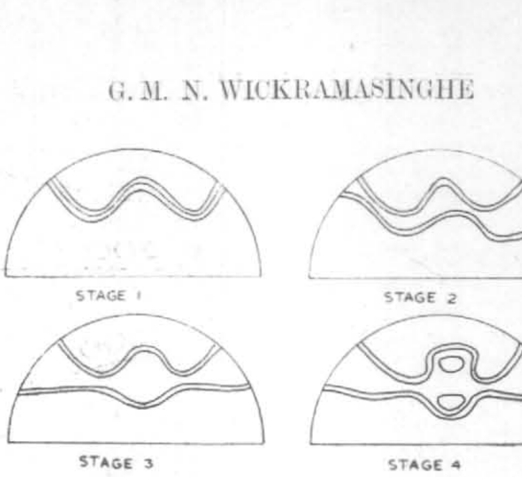

Fig. 2
Pattern (*i*)

pressure rise, and a temperature increase of 1°C corresponds to an increase in the height of the 500-mb surface by 30 m (Nyberg 1948). Shock-heated air masses with a temperature excess of 48°C will thus have the tendency to raise the level of the 500-mb surface by about 144 dekametres — a very high figure. The masses of warm air moving outwards from the region of the explosion will raise the pressure levels around cold air masses over the polar regions to form high-level troughs, which could eventually develop into lows; this process is similar to the formation of high-level troughs at the Polar Front by the movement of warm air masses into colder regions. The cold air at the centre of the trough or low will be surrounded by warm air at the periphery. The advection of warm air towards the periphery of an existing trough or low will increase the pressure at the periphery of the depression, thereby deepening it (Nyberg 1948, Palmen 1951). The appearance or intensification of high-level depressions around the Novaya Zemlya region could be expected after the explosion. Thus a series of explosions in the Novaya Zemlya region will have the tendency to induce the development of a family of high-level depressions around the North Pole, which will tend to intensify and persist in a polar cyclonic upper atmosphere predisposed to the formation, intensification and persistence of depressions; and present the appearance of a long wave pattern in the upper atmosphere around the North Pole.

As already indicated, very large masses of tropospheric air move into the polar stratosphere (Table 1) which is in radiative equilibrium (Haltine and Martin 1957). The transfer of this air to the stratosphere takes place in a very short time, within about 10 minutes of the explosion. This sudden movement of air from the turbulent troposphere into the relatively calm stratosphere of the polar region, especially if very large masses of air were involved, should induce the meridional flow of air from mid and low-latitudes at high levels towards the polar regions to replace the displaced air masses. In the case of quick succession of high megaton explosions the total volume of air transferred to the stratosphere in a short time by the series would be colossal, and would penetrate deep into the stratosphere even up to an altitude of 25 miles (Table 1). In order to maintain continuity an equivalent amount of air from lower latitudes should flow into the polar regions in the upper troposphere and lower stratosphere. This southerly advection will transport northwards over a shallow layer of polar air, the warm lower tropospheric and the cold upper tropospheric and lower stratospheric air of the sub-tropical and tropical belts (Wexler 1951). The southerly differential advection will help to build up ridges between the troughs or lows around the North Pole, such that a true wave pattern with long, deep ridges alternating with long, deep depressions could develop. The northward flow of tropical air from an anticyclonic, equatorial upper atmosphere will favour anticyclogenesis and blocking, with the seclusion of warm highs in high latitudes and cold lows in low latitudes. This pressure and circulation pattern in the troposphere and lower stratosphere during and immediately after the series of Novaya Zemlya explosions in 1961 and 1962 has been confirmed by the daily aerological charts, *Täglicher Wetterbericht* between 10 September and 30 November 1961 and between 5 August 1962 and 10 January 1963.

Aerological evidence

About a day or two after each multi-megaton (3 or more megatons) explosion there was high-level trough or low formation at the 500-mb level over Novaya Zemlya; or extension, deepening and intensification of existing depressions over the

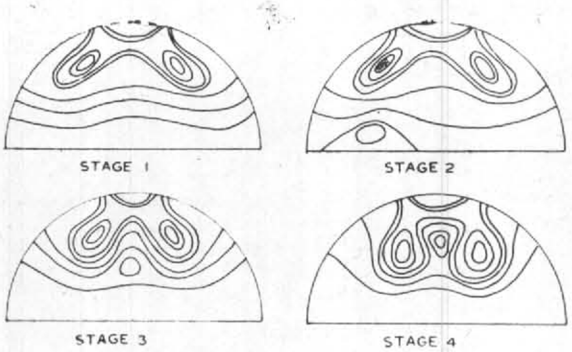

Fig. 3. Pattern (*ii*)

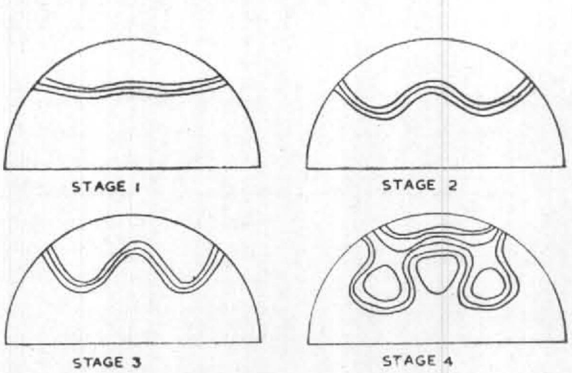

Fig. 4. Pattern (*iii*)

Novaya Zemlya region and vicinity at the 700 mb and higher levels. The depressions extended and intensified if the explosions continued but gradually occluded if they ceased (charts). After a powerful explosion or during and immediately after a quick succession of multimegaton bursts a family of depressions (well depicted on the 500-mb charts and also discernible on the 700, 300 and 200-mb charts) developed around the North Pole and in Northern Eurasia and East Atlantic, north of 40°N, east of 50°W; and particularly over the Novaya Zemlya region (charts). The high-level trough formation was followed by a strong trough and ridge pattern and blocking. The troughs and lows seemed to develop and rapidly extend southwards while ridges with high cells moved in rapidly from the south between the troughs, so that the troughs developed rapidly into cyclones as they extended southwards and the ridges into anticyclones as they extended northwards with the seclusion of warm highs in high latitudes and cold lows in low latitudes (charts). With the development of blocking and anticyclonic activity the sea level circulation weakened with a decline in extent and intensity of sea level depressions (charts, Namias 1950, Namias and Clapp 1951). According to the charts this blocking pattern which will be referred to as pattern (*ii*) — Fig. 3 and which is clearly illustrated at the 500-mb level, particularly during and immediately after the powerful series between 20 October and 4 November 1961 and between 15 and 27 September 1962, was a much more rapid process than the normal blocking patterns (*iii*) and (*i*) — Figs. 4 and 2; and a much larger number of lows around the North Pole with a greater concentration over Eurasia than the North American region than in pattern (*iii*) seemed to precede the development of pattern (*ii*). The depressions in the normal patterns are either associated with well-developed surface depressions or surface highs (Palmen 1951), but there was seldom such association in the case of pattern (*ii*) — charts. Figs. 2, 3 and 4 have been drawn after patterns observed on the 500-mb charts. As suggested earlier, the charts indicate fairly large-scale movement of high pressure areas from low latitudes towards the polar regions from the surface upto the 200-mb level to form the ridges between the troughs particularly during and immediately after the series of high-megaton bursts. The long-wave structures favourable to confluence (Namias 1950), associated with the rapid atmospheric processes of pattern (*ii*) maintained strong, active and sustained confluence of cold air masses of the lows and warm air masses of the highs

TABLE 5

Statistical evaluation of the atmospheric changes caused by the series of explosions

Series	Duration (days)	Total yield (megatons)	Volume transferred to the stratosphere (cu. miles)	Volume with a minimum temp. excess of 48° C due to shock-heating (cu. miles)	Volume with a minimum temp. excess of 1·5°C due to thermal radiation (cu. miles)
1961					
10–22 Sep	13	39	8258	398	148
2–6 Oct	5	21	4562	210	118
20 Oct–4 Nov	16	117	77125	811	810
1962					
5–10 Aug	6	43	26530	270	336
20–27 Aug	8	45	11418	402	345
15–27 Sep	13	136	53667	989	1147
22 Oct – 3 Nov	13	40	12530	329	229
23–25 Dec	3	43	11659	369	292

(charts), creating high-speed jet streams which organised into strong upper-level westerlies (Namias 1947, 1950), in periods during and immediately after series of high-megaton bursts. Confluence could be detected on the charts from the 700-mb level to the 200-mb level. But after cessation of a series the abnormal atmospheric pattern gradually faded off with a strengthening of the sea-level circulation only to reappear on the resumption of the next series.

Table 5 gives the length of the duration of each series and its total yield; and the total volume of tropospheric air transferred to the stratosphere, the total volume of air whose temperature was raised by a minimum of 48°C due to shock-heating, and the total volume of air whose temperature was raised by a minimum of 1·5°C due to thermal radiation during each series. The figures for volume are only approximate but conservative. Table 6 based on the daily charts and which includes periods before, during and after a series, each period with its own pressure and circulation pattern, clearly illustrates the sequence of the abnormal pattern. The figures in the table are only approximate but indicate the general trend. The average percentage area of the North Polar and Eurasian region covered by high (low) pressure systems during a period is the average of the percentages of the region covered by same on the daily charts of the period; the average maximum wind speed (in knots) in the low pressure systems on the daily chart is the average of the maximum wind speeds reached in these systems in the region on the chart, and the average daily maximum wind speed, AMS, is the average of these average maximum wind speeds on the daily charts of the period; the average wind speed in the zones of confluence (of highs and lows) on the daily chart is the average of the wind speeds at the points in the confluence zones of the region on the chart and the average daily wind speed in the confluence zones, ASC is the average of these average wind speeds in the daily charts of the period; and the maximum wind speed in the confluence zones, MSC, is the maximum of the wind speeds in the confluence zones of the region on the daily charts of the period. During series of explosions, particularly the high-megaton series, the area covered by confluence zones from the 700-mb to 200-mb level was very high. But in periods between series of explosions this area diminished, and in the periods before the commencement of the series, each year, this area was quite low (charts).

Table 5 and the charts and Table 6 illustrate the connection between the atmospheric changes introduced by the series of explosions and the abnormal atmospheric pattern. In each of the periods, 20 October — 8 November 1961 and 15–30 September 1962 during which the most powerful series transferred large volumes of tropospheric air to the stratosphere and raised the temperature of very large volumes of air by a minimum of 48°C due to shock-heating and by a minimum of 1·5°C due to thermal radiation, in the North Polar and Eurasian regions, the extent and intensity of cyclonic activity at sea level was very low and the sea level circulation very weak, but anticyclonic activity with blocking from sea level upto the

200-mb level was very intense and extensive while cyclonic activity at the 700-mb and higher levels was quite intense and extensive, with very strong and extensive high-level confluence which created very strong high-level westerlies over a very wide area from 700 to 200-mb level; in the period immediately after each series there was a further weakening of the sea level circulation but a further increase in the extent of the blocking highs and a weakening and reduction in extent, due to cessation, of high-level confluence with consequent weakening of the high-level westerlies (Namias 1947); and in the subsequent period there was a further decline in strength and extent of confluence and a further fall in the speed of the high-level westerly circulation, but a gradual increase in the extent and intensity of sea level depressions and a strengthening of the sea level circulation, although the blocking highs persisted in northern regions. During the series between 15 and 27 September 1962 which had the highest yield, the abnormal atmospheric pattern developed on a larger scale than that during the series between 20 October and 4 November 1961. Although the volume of air transferred to the stratosphere was less than in the case of the latter series, the larger number of high-megaton bursts at regular intervals with a large volume of air heated by shock and thermal radiation could have helped to maintain the pattern on a larger scale in periods during and immediately after the series, although the magnitude of change brought about in the existing atmospheric pattern did not differ much in the two cases (Table 6). Actually, high-level confluence was quite active and extensive with a strong high-level westerly circulation throughout the period, 15 September—22 October, although there was considerable strengthening of the sea level circulation in the period 15—22 October. But in the case of the other series there was a sharp decline in strength and extent of confluence and an abrupt fall in the speed of the high-level westerlies after 25 November (charts and Table 6). The charts clearly illustrate the close connection between the high-megaton bursts of September 1962 and the abnormal pattern which developed shortly after the commencement of the series, persisted throughout its duration, intensifying after each explosion ,and persisted until 22 October. In the case of the other less powerful series of 1962 which were nearly of the same yield the pattern developed on a smaller scale during the series; in the period immediately after the series there was a decline in strength and extent of confluence with a fall in the speed of the high-level westerlies, but a strengthening of the sea level circulation.

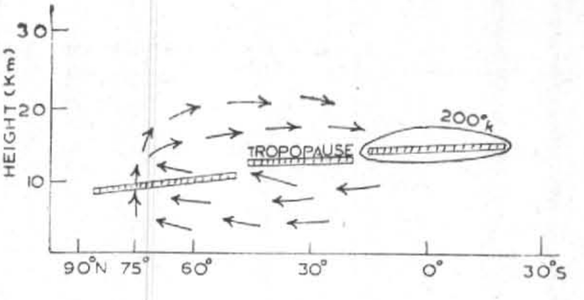

Fig. 5
Model of 'circulation' in the troposphere and lower stratosphere after atmospheric nuclear explosions in the Novaya Zemlya region

In the case of the two series in August, although the first with a single powerful explosion, transferred a larger volume of air to the stratosphere, the larger number of high-megaton bursts at regular intervals with a larger volume of air heated by shock and thermal radiation in the case of the second would have helped to maintain the pattern on a larger scale. But in the cases of series of late October and early November and of December, although the first with a single powerful explosion transferred a larger volume of air to the stratosphere, the larger number of high-megaton bursts during three days with a larger volume of air heated by shock and thermal radiation in the case of the second would have helped the development of the pattern on a much larger scale, so that the magnitude of change effected on the existing pattern was much higher than in the case of the first. In fact the pattern that appeared during the December series was on a larger scale than those during the other three series (charts and Table 6). In the case of the low-yield series of September and early October 1961 the pattern developed on a much smaller scale during the series; and in the period immediately after the cessation of the series there was an abrupt fall in the strength and extent of high-level confluence and a consequent weakening of the high-level circulation but a considerable strengthening of the sea level circulation. During the September series, consisting of several explosions at regular intervals, the pattern developed on a much larger scale than during the lower yield series of October. During the series of September 1961 and early August 1962 respectively the existing atmospheric pattern changed on quite a significant scale (charts and Table 6).

TABLE 6

Statistical assessment of the pressure and circulation pattern in the North Polar region, north of 60°N; and Eurasian region and East Atlantic north of 40°N, east of 50°W

Period	North Polar region, north of 60°N; and Eurasian region and East Atlantic, north of 40°N and east of 50°W				Eurasian region and East Atlantic north of 40°N, east of 50°W			
(1)	Average percentage area covered by low pressure at sea-level (2)	Average percentage area covered by high pressure at sea-level (3)	Average percentage area covered by low pressure at 500-mb level (4)	Average percentage area covered by high pressure at 500-mb level (5)	AMS of low pressure at sea-level (6)	AMS of low pressure systems and ASC at 500-mb level (7)	AMS of the low pressure systems, ASC and MSC at 300-mb level (8)	AMS of low pressure systems, ASC and MSC at 200-mb level (9)
			1961					
30 Aug–9 Sep (no explosions)	42	30	50	23	33	AMS 50 ASC 32	AMS 72 ASC 38 MSC 100	AMS 68 ASC 38 MSC 100
10–24 Sep (period of multi-megaton explosions)	28	56	54	36	20	AMS 55 ASC 43	AMS 90 ASC 57 MSC 130	AMS 82 ASC 53 MSC 120
25 Sep–1 Oct (no explosions)	32	50	53	25	28	AMS 52 ASC 40	AMS 78 ASC 46 MSC 85	AMS 70 ASC 43 MSC 80
2–11 Oct (period of multi-megaton explosions)	29	55	55	34	22	AMS 54 ASC 42	AMS 87 ASC 54 MSC 150	AMS 80 ASC 52 MSC 150
12–19 Oct (no explosions)	40	51	51	28	30	AMS 51 ASC 39	AMS 77 ASC 47 MSC 150	AMS 74 ASC 45 MSC 130
20 Oct–8 Nov (period of high-megaton explosions)	23	68	56	38	18	AMS 60 ASC 47	AMS 100 ASC 73 MSC 175	AMS 90 ASC 63 MSC 150
9–25 Nov (period immediately after a series of high-megaton explosions)	20	70	50	40	17	AMS 62 ASC 48	AMS 93 ASC 68 MSC 130	AMS 86 ASC 60 MSC 130
6 Nov–14 Dec (no explosions)	41	44	52	38	35	AMS 53 ASC 36	AMS 85 ASC 47 MSC 110	AMS 80 ASC 45 MSC 110
15–31 Dec (no explosions)	39	46	38	40	30	AMS 55 ASC 38	AMS 86 ASC 45 MSC 120	AMS 82 ASC 45 MSC 110
			1962–63					
25 July–4 Aug (no explosions)	50	34	40	28	27	AMS 45 ASC 33	AMS 70 ASC 45 MSC 100	AMS 60 ASC 45 AMS 85
5–19 Aug (period including a powerful explosion)	24	58	45	40	19	AMS 56 ASC 44	AMS 88 ASC 60 MSC 150	AMS 78 ASC 58 MSC 100
20–31 Aug (period of high-magaton explosions)	22	62	50	42	17	AMS 58 ASC 46	AMS 97 ASC 65 MSC 130	AMS 88 ASC 63 MSC 110
1–14 Sep (one multi-magaton explosion)	35	50	42	40	23	AMS 53 ASC 45	AMS 85 ASC 60 MSC 155	AMS 78 ASC 58 MSC 155
15–30 Sep (period of high-megaton explosions)	21	68	50	45	16	AMS 65 ASC 52	AMS 108 ASC 77 MSC 180	AMS 100 ASC 72 MSC 140
1–14 Oct (period immediately after a series of high-megaton explosions)	18	73	42	47	15	AMS 63 ASC 48	AMS 98 ASC 72 MSC 160	AMS 90 ASC 66 MSC 160
15–21 Oct (no explosions)	30	60	50	36	16	AMS 58 ASC 46	AMS 95 ASC 67 MSC 180	AMS 90 ASC 61 MSC 130

TABLE 6 (*contd*)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
22 Oct–7 Nov (period with a series including a powerful explosion)	22	64	53	40	22	AMS 62 ASC 50	AMS 100 ASC 72 MSC 150	AMS 94 ASC 63 MSC 150
8–22 Nov (no explosions)	25	59	47	45	20	AMS 61 ASC 44	AMS 97 ASC 70 MSC 150	AMS 92 ASC 60 MSC 140
23 Nov–7 Dec (no explosions)	47	42	50	38	30	AMS 52 ASC 38	AMS 90 ASC 45 MSC 120	AMS 80 ASC 42 MSC 110
8–22 Dec (no explosions)	48	43	49	40	35	AMS 55 ASC 40	AMS 93 ASC 47 MSC 130	AMS 82 ASC 47 MSC 130
23–29 Dec (period of high-magaton explosions)	20	65	54	45	18	AMS 63 ASC 51	AMS 103 ASC 74 MSC 180	AMS 97 ASC 64 MSC 180
30 Dec 1962–10 Jan 1963 (no explosions)	25	60	48	41	22	AMS 57 ASC 47	AMS 96 ASC 62 MSC 150	AMS 88 ASC 60 MSC 130

MSC — Maximum wind speeds in confluence zones

AMS — Average daily maximum wind speeds

ASC — Average daily wind speeds in the confluence zones

A study of the charts of the above-mentioned regions since their commencement indicate that during the months of September, October and November such long periods characterized by so weak sea level westerlies with so poor cyclonic activity, so strong and extensive high-level confluence and so strong high-level westerlies with such prolific formation and extensive development of high-level depressions at the 500-mb and higher levels and so intense and extensive anticyclonic activity associated with blocking at sea level and the 500-mb level as was displayed between 20 October and 25 November 1961 and between 20 August and 22 October 1962 were not evidenced during the last 24 years.

Fallout patterns

The air masses that ascended into the polar stratosphere laden with nuclear debris, should have moved southwards towards the equatorial belt in the lower stratosphere up to an altitude of about 20 or 25 km in order to replace the tropical air masses transferred to polar regions by the southerly advection, thus completing the circulation pattern illustrated in the model in Fig. 5. The injection of large masses of warm air from a series of explosions into the lower stratosphere of Polar Eurasia could strengthen the equatorward temperature gradient in the lower stratosphere (Haltiner and Martin 1957) such that an equatorward flow of air would be maintained in the lower stratosphere during the series as shown in the model.

Fallout pattern seem to lend support to our model (Fig. 5) during and immediately after series of Novaya Zemlya explosions in 1961 and 1962.

Observations of the circulation of the stratosphere, based on the movement of radioactive debris from nuclear explosions, seem to suggest a 'bi-directional diffusive exchange' of polar and equatorial air masses in the stratosphere up to about an altitude of 20 km as postulated by the Spar-Feely model, both advective and diffusive processes being important in the stratospheric circulation (United Nations 1962, 1964). An upward air motion in equatorial regions, followed by a poleward flow at a height of about 30 km, transports radioactive debris injected into the tropical stratosphere towards the polar regions, according to the Brewer-Dobson model; but a southward movement in the lower stratosphere up to about the altitude of 20 or 25 km transports debris injected into the polar stratosphere towards the equatorial belt (United Nations 1962).

Evidence of a strong meridional flow in the lower stratosphere from polar regions towards the tropics soon after Novaya Zemlya explosions is provided by the collection of debris of a Novaya Zemlya explosion injected into the polar stratosphere some time between 10 and 15 September 1961 at 20 km altitude at 30°N on 4 October 1961. The total 'beta activity was about 40,000 dpm/m^3 and later samples showed even higher concentrations' (United Nations 1962), indicating very high concentrations from the Novaya Zemlya explosions of 1961 as far south as 30°N in the lower stratosphere.

The fallout pattern of Strontium-90 in the North Hemisphere up to the end of 1964 is shown in Table 7. For the period prior to 1961 the fallout rate has been averaged out for 10° latitude bands (*c.f.* figs. a—j, United Nations 1962) and finally averaged out for the 80°—60°, 60°—30° and 30°—0° bands. But for the period 1961—1964 the rate has been averaged out for these latter bands from tables of the average rate by 10° latitude bands for 1961, 1962, 1963 in the report of USAEC (*see* Ref.) and from a similar table constructed for 1964 from deposition data for world sites. R_1, r and R_2 represent the ratios of the rates in the 30°—0°, 80°—60° and 30°—20° bands respectively to that in the 60°—30° band expressed as percentages. The principal features of the general pattern of stratospheric fallout between test series illustrated by the table are (*a*) the highest rate in the 60°—30° band with a high percentage of it in the 80°—60° band and a much lower percentage in the 30°—0° band (Glasstone 1964) for about a year after testing, but after that a rise in R_1 and R_2 and fall in r with equatorward movement and cross-equatorial transfer as indicated in 1960, the first half of 1961, in late 1963 and 1964; and (*b*) a rise in all three bands, particularly in 60°—30° band, in spring and early summer but a sharp decline in the last quarter if it was test-free. But for short periods after low yield, surface and or low-latitude bursts in the 30°—0° band or adjacent to it, such as those in late 1958, February, April, December 1960 and April 1961, local and/or tropospheric fallout could raise the rate in that band, R_1 and R_2; and such bursts in the 80°—60° band or adjacent to it, such as those in September, October 1961, and August, October, November 1962 (Glasstone 1964) could similarly rise the rate in that band together with r.

Table 7 indicates that in the period September 1961–April 1962 the rates, particularly those in the 30°—0° or 30°—20° bands, and R_1 anfd R_2 have risen steeply especially during the period January—April 1962, soon after the powerful 1961 series in the 80°—60° band, when compared with corresponding periods after previous tests. In period January—April 1962 R_1 greatly exceeded r which normally exceeds R_1 during such a short period after tests. Tables of fission yields injected into the stratosphere prior to September 1961 and in Autumn 1961 and the polar and tropical stratospheric and tropospheric half-residence times indicate that the fallout in this period in the 60°—30° and 30°—0° bands was largerly from the north polar, lower stratospheric injections of the 1961 series, which contributed about 80 per cent of the November –December 1961 fallout. The table also shows fairly high rates in the 60°—30° and 30°—0° bands with high values for R_1 and R_2 in the last quarter of 1962 instead of the normal sharp decline in such a period; and then a very steep rise in all bands, particularly the 30°—0° and 30°—20° bands, with R_1 much greater than r in the period Jaunary–June 1963. The tables of the fission yields injected into the stratosphere by the 1961 and 1962 Arctic series and the American series in the 30°—0° band in the period May–November 1962 and the half-residence time for fallout indicate that lower stratospheric injections from the 1962 Arctic series contributed the bulk of the fallout, particularly in the 60°—30° and 30°—0° bands, in this period. Debris from the 1962 Soviet tests seem to have predominated until June 1963. The 1961 Arctic tests could have contributed only a small proportion of the fallout in this period; and the American tests only a small fraction of it, the bulk of the debris injected into the tropical stratosphere in late June, July, October and November 1962 moving polewards in the stratosphere to follow the general pattern of stratospheric fallout with little concentration in the 30°—0° band in the period January—June 1963. With the half-residence time of 10 months for the lower tropical stratosphere and 2–6 weeks for the troposphere it appears that a large proportion of the debris moved rapidly equatorwards in the lower stratosphere soon after the powerful Arctic tests in October 1961 and August, September and December 1962 and descended gradually from the lower tropical stratosphere through the troposphere so as to give very high fallout rates in the 30°-0° and 30°-20° bands and a high proportion of the total fallout in the 30°—0° band with high values for R_1 and R_2 in periods January—April 1962 and Janaury—June 1963 respectively (Table 7). This confirms the rapid equatorward flow of large masses of air, laden with a high proportion of nuclear debris, in the lower stratosphere soon after the Novaya Zemlya series of high-megaton bursts in 1961 and 1962, according to model in Fig. 5. The rate in the narrow 30°-20° band, near the latitude of the tropical tropopause gap, would be particularly high due to

TABLE 7

Deposition rate of Strontium–90 in mci/km² for North Hemisphere

Latitude band	Dec 1958 to Feb 1959	1959			Dec 1959 to Feb 1960	1960				
		Mar-May	Jun-Aug	Sep-Nov		Mar-Apr	May-Jun	Jul-Aug	Sep-Oct	Nov-Dec
80°—60°	·34	1·05	·75	·20	·25	·30	·17	·10	·08	·08
60°—30°	1·40	3·26	1·45	·36	·38	·46	·30	·16	·11	·13
30°— 0°	·62	1·06	·33	·08	·21	·33	·19	·11	·07	·09
30°—20°	1·15	2·38	·42	·18	·25	·44	·22	·12	·07	·10
R_1	44·28	32·51	22·75	22·22	55·26	71·73	63·30	68·75	63·63	69·23
r	24·28	32·20	51·71	55·55	65·78	65·21	56·66	62·50	72·72	61·53
R_2	82·14	73·01	28·97	50·00	65·79	95·65	73·33	75·00	63·64	76·92

Deposition rate of Strontium–90 in mci/mi² for North Hemisphere

Latitude band	Jan-Feb	Mar-Apr	May-Jun	Jul-Aug	Sep-Oct	Nov-Dec	Jan-Feb	Mar-Apr	May-Jun	Jul-Aug	Sep-Oct	Nov-Dec
			1961						1962			
80°—60°	·35	·24	·33	·26	·38	·70	·84	1·04	2·12	1·75	1·52	·88
60°—30°	·45	·75	·77	·46	·61	1·54	2·66	3·61	5·34	2·87	2·17	2·24
30°— 0°	·36	·39	·44	·21	·28	·71	1·88	2·55	2·17	1·32	·89	·83
30°—20°	·64	·54	·63	·27	·40	1·07	3·29	4·38	3·53	1·37	1·75	1·44
R_1	80·00	52·00	57·14	45·65	45·90	46·10	70·68	70·64	40·64	45·99	41·01	37·05
r	77·78	32·00	42·86	56·52	62·30	45·45	31·58	28·09	39·70	60·98	70·05	39·29
R_2	142·22	72·00	81·82	58·70	65·57	69·48	123·68	121·33	66·10	47·74	80·65	64·29
			1963						1964			
80°—60°	1·15	2·21	3·56	8·59	2·39	·56	1·05	1·10	2·45	1·84	·80	·37
60°—30°	2·72	8·17	10·41	8·91	3·61	2·51	3·51	5·47	8·72	4·11	1·45	1·33
30°— 0°	1·53	3·82	5·42	2·89	1·88	1·10	2·23	2·31	3·30	1·76	·74	·72
30°—20°	2·59	6·90	8·85	4·35	3·94	1·85	3·60	2·86	5·26	2·58	·92	1·05
R_1	56·62	46·76	52·07	32·44	52·08	43·82	63·53	42·23	37·84	42·82	51·03	54·14
r	42·28	27·05	34·20	96·41	66·20	22·31	29·91	20·11	28·10	44·77	55·17	27·82
R_2	95·22	84·46	85·01	48·82	109·14	73·71	102·56	52·29	60·03	62·77	63·45	78·95

the escape of debris from the tropical stratosphere through the gap (United Nations 1962, 1964; USAEC—HASL 142 and Glasstone 1964).

4. Evolution of the abnormal circulation and its influence on the weather

According to the aerological evidence relating to the North Polar region and Eurasian and East Atlantic region, north of 40° N and east of 50°W, in 1961 rather strong high-level westerlies prevailed during the series of September and early October respectively, but the speed of the high-level westerlies fell abruptly after the cessation of these series; and during and immediately after the powerful series of late October and early November very strong high-level westerlies prevailed but after 25 November the speed of these westerlies fell abruptly; in 1962 strong high-level westerlies prevailed during and immediately after the series in August; but during and after the most powerful series of late September the high-level westerlies were very strong, and before they had time to weaken they gained strength again during the series of late October and early November, but in late November their speed fell abruptly until there was a sharp rise in speed during the series of late December. The blocking highs which developed during the series in each year persisted throughout December.

According to Namias (1947) strong high-level westerlies impede meridional movement of air which takes place aloft, and trap polar air in its source region; and an abrupt fall in the speed of the high-level westerlies with a consequent reduction of centrifugal force results in a northward flow of air from the circumpolar vortex at high-levels. Thus, during each period of strong high-level westerlies, which prevailed over the vast area and through a great thickness of the atmosphere from about the 700-mb to the 200-mb level (charts and Table 6), a thick and extensive layer of Polar air was trapped; and when an abrupt fall in the speed of the high-level westerlies followed, air transported northwards was superposed on the wake of cold polar air which had been imprisoned in its source region by the strong high-level westerlies. As the periods in which strong high-level westerlies prevailed first and then often fell abruptly in speed were almost consecutive (charts and Table 6), there was almost a continuous trapping of Polar air over which more air was superposed, during autumn and early winter of 1961 and 1962 respectively; so that by December of each year there was in the Polar regions and northern Eurasia the build-up of a large reservoir of great horizontal and vertical extent of cold stable air, which had been imprisoned in its source region by strong high-level westerlies and which had grown in extent due to cooling by radiation during its long period of confinement in a region where solar insolation was weakening with the approach of winter. The development of the Polar reservoir or cell was further facilitated by the scarcity in mid and high latitudes of warm fronts which conveyed warm influences to the polar regions and by the blocking highs which impeded the movement of these fronts towards those regions (charts and Table 6).

As the more powerful series took place in 1962 the abnormal pattern developed on a larger scale and consequently the polar cell was more extensive and persisted for a longer period in that year, as illustrated by the extent and intensity of the high cells in the Polar regions and northern Eurasia at sea level and the 500-mb level in the charts, *Täglicher Wetterbericht* and *Grosswetterlagen Mitteleuropas* (monthly charts) in the period December to March. The extent and intensity of the high cells in these charts for the period November 1962 to March 1963 and for the period December 1961 to March 1962 indicate that the polar cell of the 1962–1963 winter was the most extensive (horizontally and vertically) and persistent since aerological records started and that of the 1961–62 winter was much more extensive than the average for the last 24 years. The discharge of this cell in the form of cold polar outbreaks to produce extended index cycles in the period December 1962 to March 1963 gave rise to very cold polar northerly and easterly winds over Eurasia; and the associated blocking highs (Namias 1950), while interfering with the movement of warm fronts into these regions, maintained a cold northerly flow on their eastern flanks. The cold polar winds were so strong as to confine the westerlies and associated warm fronts to a zone south of 45°N (charts), so that the winter was one of the coldest on record. The monthly mean temperature of the region (*i.e.*, the average of the monthly mean temperatures of the stations in this region) between 45° and 80°N and between 25°W and 125°E for the respective months December to March has been the lowest for these months for the last 24 years. The less extensive polar cell of 1961 was considerably depleted by mid January (charts *Täglicher Wetterbericht* and *Grosswetterlagen Mitteleuropas*), so that the very cold weather over nearly the same region which set in by early December prevailed until about mid January. Rather strong westerlies with associated warm fronts, which are not abnormal for the time of year partially replaced the cold polar winds (*Täglicher Wetterbericht*) in late January and early February to give milder weather until about mid February; but the westerlies trapped more polar air to replenish the partially depleted cell, the remnants of which are indicated by the intense high cells on the February charts (*Täglicher Wetterbericht*, and *Grosswetterlagen Mitteleuropas*), so that there was another spell of cold polar outbreaks and associated cold weather in March 1962. The monthly mean temperature of the region referred to above in December 1961 and March 1962 was the lowest for these months, after December 1962 and March 1963 respectively, during the last 24 years (US Dep. Comm.—*see* Ref).

In North America, remote from the site of the nuclear explosions, the weather did not however deviate much from the 24-year seasonal normal during these two winters.

5. Roles played by the nuclear explosions and natural phenomena in the evolution of the abnormal atmospheric pattern

Assuming that the nuclear explosions had not significant influence on the atmospheric pattern it appears that the abnormal pattern (*ii*) with strong high-level confluence and associated strong high-level westerlies and blocking over such a wide area and through such a great thickness of the atmosphere for such extended periods in autumn and early winter could not be attributable to known natural phenomena at the time of year.

In autumn and early winter airmass exchange is rapid and patterns (*i*) and (*iii*) with strong high-level confluence and strong high-level westerlies followed by blocking could prevail only for short periods in mid and high latitudes. But in late winter, from late December to March, extended periods of these patterns could prevail as in the 1946–47 winter which was the coldest winter in Northern Eurasia since aerological records started until 1961. But even in this case the polar cell which developed in late winter was less extensive than those of the winters of 1961–62 and 1962–63, as indicated by a comparison of the sea level, 700 and 500-mb charts, *Täglicher Wetterbericht* and *Grosswetterlagen Mitteleuropas* of the north Polar and north Eurasian regions, during the periods December 1961 to March 1962 and December 1962 to March 1963 with the sea level and 700-mb charts for January and February 1947 during which months the polar cell of 1946–47 winter reached its maximum size; and the monthly mean temperature of the region between 45°N and 80°N and between 25°W and 125°E during the months December to March was much higher than in the corresponding months of the 1962–63 winter, while the same during December and March was higher than in December 1961 and March 1962 respectively. The pattern of development of the high-level depression seemed to exclude the influence of orographic factors also on a significant scale. Patterns (*i*) and (*iii*) with the associated circulation patterns prevailed for short periods from time to time before the commencement of the series, and between and after cessation of the series after pattern (*ii*) faded (charts and Table 6); and, as illustrated by the 500-mb level charts between 21 and 30 December 1962, pattern (*iii*) appeared just before the commencement of the December series, but intensified and changed into pattern (*ii*) during the series.

According to the charts (*Täglicher Wetterbericht*) the prevalent atmospheric patterns since aerological records started were patterns (*i*) and (*iii*). It was only in 1961 and 1962 that the abnormal pattern (*ii*) appeared. The extended periods of three to six weeks of strong high-level westerlies and deep, extensive blocking over a wide area with a concentration of the westerly circulation of temperate latitudes at high-levels during autumn and early winter have been peculiar to these two years (charts). Pattern (*ii*) seemed to entail much stronger southerly advection with stronger high level confluence and stronger high-level westerlies through a greater thickness of the atmosphere than in the case of even the extreme forms of patterns (*i*) or (*iii*). The charts indicate that after every powerful explosion or during every quick succession of multi-megaton bursts the pattern (*ii*) appeared; but faded off gradually after cessation of the explosions and reappeared on resumption. There have been too many such instances for this to be a mere coincidence. The explosions seemed to have been too closely associated with this abnormal pattern for its appearance to be attributed to even a mere problematical behaviour of the atmosphere.

6. Acknowledgements

I must express my deep gratitude to the Irish Meteorological Service, Dublin for providing me with aerological charts, reference books and journals. My thanks are also due to the Institute of Seismology, University of Uppsala for supplying me with information regarding the series of nuclear explosions over the Novaya Zemlya Region.

REFERENCES

Dunn, G. E.	1951	Tropical Cyclones. *Compendium of Meteorology*, pp. 887-901, Amer. met. Soc.
Glasstone, S.	1964	*The effects of Nuclear Weapons*, U.S. Atomic Energy Commission. pp. 1-148. 316-368. 414-488, 671-682.
Haltiner, G. J. and Martin, F. G.	1957	*Dynamical and Physical Meteorology*, pp. 87-156, 415-453. McGraw Hill Book Co.
Namias, J.	1947	*Mon. Weath. Rev.*, pp. 145-152. U. S. Dep. Comm.
	1950	*J. Met.*, **7**, **2**, pp. 130-139.
Namias, J. and Clapp, P. F.	1951	Observational Studies of the General Circulation Patterns. *Compendium of Meteorology*, pp. 551-567. Amer. met. Soc.
Nyberg, A.	1948	*Tellus*, **1**, 1, pp. 44-52.
Palmen, E.	1951	The Aerology of Extratropical Disturbances. *Compendium of Meteorology*, pp. 599-620. Amer. met. Soc.
Petterssen, S.	1958	*Introduction to Meteorology*, pp. 87-106, 160-163; McGraw-Hill Book Co.
U. N., New York	1962	Report of U.N. Sci. Comm. on Effects of Atomic Radiation. General Assembly, Official Records 17th Session, Suppl. 16 (A/5216), pp. 233-271.
	1964	*Ibid.*, 19th Session, Suppl. 14 (A/5814), pp. 11-80.
U. S. Atomic Energy Commission, New York	—	HASL Rep. 131, 140, 142. 146. 161, 165.
U. S. Dep. Comm.	—	*World Weath. Records 1941-50.*
	—	Monthly Climatic Data for the World, 1950-1968.
Wexler, H.	1951	Anticyclones. *Compendium of Meteorology*, pp. 621-628. Amer. met. Soc.