CHAPTER 3

INVERSION PERSISTENCE AT LONG KESH, NORTHERN IRELAND

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Air temperature normally falls with increasing height above ground level. Under certain meteorological conditions, however, the reverse can occur, producing a layer of air in which temperature increases with height. This phenomenon of an inversion of temperature in the boundary layer of the atmosphere can exert a strong control over ground-level concentrations of atmospheric pollutants by restricting the depth of air throughout which they are mixed. Accordingly it is significant in the field of industrial location, in particular chimney design, and merits special investigation as regards height, strength, persistence and frequency of occurrence.

The most common situation giving rise to a temperature inversion is that which occurs due to nocturnal cooling of air in close proximity to a cold ground surface. Where clear skies encourage maximum outgoing radiation the feature is enhanced, particularly in light winds, perhaps sufficiently to survive the turbulent and thermal mixing of the following day. Continuation beyond two or three days is rather unlikely since the conditions favouring outgoing radiation at night also favour maximum incoming solar radiation during the day. In any case, from a pollution viewpoint, the effect of surface-based inversions is small in relation to their numbers since emissions from large sources either occur above or can penetrate these rather shallow features. In these circumstances persistent surface inversions can restrict downward mixing and actually have a beneficial effect on ground-level concentrations.

It is, however, with inversions based in the free air that this investigation is concerned. In general these are of two types, frontal and subsidence, originating in depressions and anticyclones respectively. Variations of these occur, most notably in the case of pre-frontal subsidence that can produce a smaller inversion below the level of the frontal one. It may be this lower one that is the effective trapping level. Sulphur dioxide which is trapped aloft by any inversion may ultimately be returned to ground level. This downward mixing often follows the break-up of an inversion by turbulent mixing and high ground-level concentrations frequently accompany such periods of fumigation. The longer the inversion persists, the greater the build-up of pollution beneath it, and consequently the greater the potential for an air pollution episode of the types widely documented, e.g. Holzworth (1972) and Martin (1964).

Previous investigations

Despite its obvious importance, relatively little work has been done in the field of inversion persistence. More emphasis on forecasting occurrence is apparent, as, for example, in the work of Shellard and Hay (1961). On the basis of one year's radiosonde data from two Atlantic weather ships the relationships between the occurrence of both frontal and subsidence inversions and various synoptic features were used to derive rules for the prediction of inversion occasions. Though 90 per cent successful for non-frontal cases, the technique found only limited application since the information needed most for air pollution studies related to inversion height and duration, rather than prediction of a likely occurrence alone.

Hardy (1973) compiled an exhaustive tabulation of inversions at Cardington based on ten years' data obtained from a tethered balloon. Unfortunately, limitations imposed by the maximum height of ascent (1200 m) and by instrumental problems make these data rather biased. Many ascents were either cancelled or curtailed during periods of high wind speeds or when a risk of lightning or icing was present. Accordingly, complete data up to 1200 m were obtained for only 28.5 per cent of the study period. Despite this, inversions were found to be most frequent and persistent during winter and autumn. More marked seasonal differences were observed at Cardington than at Long Kesh. This undoubtedly reflects the contrast in location between the two sites, as well as the limitations of a tethered balloon sampling only the lower levels of the atmosphere most affected by ground influences.

Table 1. Inversion occurrences at Kiev 1956-60

	Altitude (km)					
Duration (hours)	0-0.1	0.1-0.25	0.25-0.50	0.50-1.0	1.0-1.5	1.5-2.0
<12	614	616	524	363	344	426
12-24	259	373	244	174	208	221
24-48	22	27	49	61	70	34
48-72	1	4	12	24	12	3
72-96		3	3	14	7	1
96-120			3	6	2	
120-168			4	4	2	
168-216				3		
>216				1		

Table 2. Persistent inversions at Kiev 1956-60

Duration (days)	*No.*
2-3	56
3-5	39
5-7	10
7-9	3
>9	1

Winter and autumn maxima were also noted by Voloshin (1973) using radiosonde data for Kiev, which also enabled discrimination between lower radiation and higher subsidence inversions. Of course climatic contrasts with the British case are obvious. Table 1 shows that 4738 inversion occurrences were observed during the four years of which 39 per cent were below 250 m and lasted for less than a day. These were obviously surface features and indicate the suitability of the continental Ukrainian climate for radiation type inversions. Surface inversions were not persistent and were generally dissipated by noon on the day following. Even in winter they lasted only three to four hours longer than their summer counterparts. Of the persistent inversions, 109 lasting for over two days occurred (Table 2), enabling some degree of comparability with the Long Kesh data.

Data selection criteria

One feature of Voloshin's results is that only 1 per cent of inversions seem to persist over three days, a seemingly unlikely situation in such a continental climatic regime. This could be a consequence of the selection criteria which may have resulted in a fragmentation of episodes into more numerous occurrences of shorter duration at the various heights. Inversions rise and fall, coalesce and divide, disappear and reappear often without any obvious cause, resulting in great difficulties for anyone seeking to explain their behaviour. The relatively recent development of acoustic radar sensing has, however, proven to be extremely useful in this respect, in monitoring short-term changes in both stability and inversion behaviour in the lower atmosphere.

Acoustic energy propagating upwards through the atmosphere is reflected by turbulent fluctuations of temperature and wind velocity. By analysing the returned echo the monostatic sounder gives an indication of the changes occurring, in both lapse rate and dynamic stability, along the path of the transmitted pulse. This produces a record with a considerable contrast range which can be closely related to the temperature structure of the air through which the pulse passed. The principal advantage of acoustic sounding is its capability of providing a virtually continuous record. In contrast, the radiosonde provides only a twice daily sample and is subject to systematic errors due to a time lag in the response of its pressure and temperature sensors (Wyckoff et al. 1973).

Despite these drawbacks, however, the data source for this study was based on the twice daily (00 h and 12 h) radiosonde ascents at Long Kesh, Northern Ireland. In part, this choice reflected the absence of an acoustic record over a sufficiently long period. However, the practical difficulties involved in using acoustic data were also considered an obstacle to achieving results comparable with research elsewhere. In particular the interpretation of such a record would have involved a considerable degree of subjectivity, the consistency of which would have been difficult to maintain over a long time-period.

The failure of the radiosonde to provide a continuous spectrum of data necessitates making the assumption that an inversion persists in the intervening period between successive ascents where it is observed. Since this is not necessarily the case over a 12-hour period then this implicit assumption must be seen as a weakness in the present study. However, examination of the intermediate wind observations made at 06 hand 18 h suggested that, for the vast majority of cases, a wind shear with altitude existed, indicative of the probable continuance of inversion conditions. This would seem to suggest that the assumption of persistence between ascents has some validity and does not preclude the derivation of meaningful results from this source.

Methods of analysis

Much of the previous work outlined earlier involved a method of analysis based on the occurrence or otherwise of inversions within fixed altitude bands. Where an inversion oscillated across these boundaries, moving from one band into another, fragmentation of the episode resulted. A method avoiding this was sought which would enable an inversion to be followed in its path through the various atmospheric levels and a truer picture of inversion persistence to be obtained. It was found that this objective was best achieved when the following simplifications were applied to the data.

(i) Only the lowest 4000 m of the atmosphere were considered.

(ii) Surface inversions were ignored except where they formed part of another inversion period with a mean level in the free air.

(iii) When more than one inversion existed only the lowest one was considered.

(iv) Inversions were allowed to vary in height (mid-height) by up to 1000m during successive observations and still remain part of the same episode.

(v) Allocation into height categories was on the basis of the mean altitude during the whole of the episode.

A method of analysis incorporating these restrictions produced a series of inversion episodes over the six-year period. Each episode was characterised by its duration and its mean altitude. Aggregation of the episodes yielded a contingency Table from which other information could be deduced.

Results and analysis

Table 3 summarises the results obtained. At all altitudes the number of inversions decreases with increasing duration, almost half the episodes lasting for only one observation. Short durations like this are probably largely accounted for by frontal inversions, which, even if they can be identified for a day or two, rapidly change elevation and seldom persist except in the case of almost stationary fronts. Single observation inversions occur in each layer with the following frequencies: 51 per cent (0.25-0.5 km), 27 per cent (0.5-1 km), 37 per cent (1-2 km), 63 per cent (2-3 km), and 88 per cent (3-4 km). This suggests that inversion persistence decreases above and below the layer 500-2000 m. In particular, the level between 500 and 1000 m shows a pronounced tendency for persistent inversions; 13 per cent of those lasting more than two days lasted a week.

Table 3. Inversion occurrences at Long Kesh 1971-77

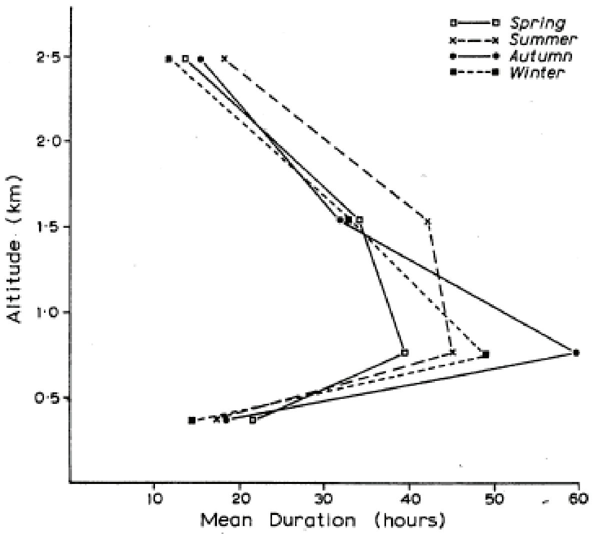
Duration (hours)	*Altitude (km)*				
	0.25-0.5	0.5-1.0	1.0-2.0	2.0-3.0	3.0-4.0
<12	51	41	175	164	91
12-24	23	32	96	58	9
24-48	20	26	86	25	3
48-72	7	21	52	7	
72-96		12	24	3	
96-120		6	17	1	
120-168		7	20	1	
168-216		5	3		
>216		2	1		

A breakdown of Table 3 into its seasonal components can be seen in Table 4. In terms of the number of inversions there is no significant difference between the seasons, with roughly the same number occurring at all times of the year. This contrasts markedly with the Ukraine and reflects the all year round influence of the sea on the climate of the British Isles. In addition to the effect of the sea other influences can be identified.

If inversions persisting over two days are considered then summer stands out from the other three seasons as having up to 25 per cent more in this category. On closer examination these fall mainly in the 1000-2000 m range. Good summers in the British Isles are characterised by high pressure systems which either extend or break off from the summer Azores anticyclone. This would produce the fairly persistent inversion described.

For each height category a spread of inversion durations ranging from less than 12 hours to over nine days is obtained. From this the mean duration of episodes whose mean inversion height lay at that altitude can be calculated. These values can be seen at the foot of Table 4. They are however, more informative if plotted adjacent to each other and this has been done in Fig. 1 in order to illustrate seasonal variation. The increased frequency in summer again stands out. Apart from this the only obvious seasonal differences relate to spring and autumn frequencies from 500-1000 m. During the spring the sea around Ireland is at its warmest in relation to the land. This introduces elements of instability into the lower atmosphere, causing an increased incidence of unsettled weather, hindering the development of long inversion periods. By contrast, in autumn, the sea temperature is close to air temperature, no marked instability exists, and blocking anticyclones are common in the stable conditions which characterise the season. This would explain the contrast between spring and autumn durations which is observed.

Figure 1. Variation of mean inversion duration with height and season



Where an inversion lasts three or more days it is almost certainly in association with subsidence from a slow moving anticyclone. This can quickly be confirmed by a glance at surface pressure data for these periods. The behaviour of the inversion during these periods closely mirrors the movement of the high pressure system, falling to a minimum height as subsidence reaches its peak, then rising as the anticyclone moves away. A sample study revealed the height difference between entry and mean minimum level to be of the order of 1400 m. The lowest level reached, on average about 1000 m, occurred between two and three days after entry. The rate of descent thus agrees well with that found by Holzworth (1972) for the principal subsidence inversion during the Thanksgiving Week episode in New York, between 0.6 and 0.8 cm s^{-1}.

Table 4. Seasonal occurrences of inversions at Long Kesh 1971-77

Duration (hours)	*Altitude (km)* 0.25-0.5				0.5-1.0				1.0-2.0				2.0-3.0				3.0-4.0			
	Sp	S	A	W	Sp	S	A	W	Sp	S	A	W	Sp	S	A	W	Sp	S	A	W
<12	16	10	13	12	14	7	13	7	52	40	45	38	55	43	32	34	22	13	33	23
12-24	4	6	8	5	5	7	7	13	21	22	27	26	15	13	17	13	1	1	4	3
24-48	8	6	4	2	8	10	4	4	20	22	22	22	7	5	8	5			2	1
48-72	4		2	1	6	3	7	5	12	15	12	13	4	3						
72-96					1	4	2	5	7	8	3	6		2	1					
96-120					2		2	2	3	4	6	4		1						
120-168					1	2	3	1	7	8	2	3								
168-216					1	1	2	2		2	1									
>216							1													
Total	32	22	27	20	38	34	41	39	122	121	118	112	81	67	58	52	23	14	39	27
Mean	21.8	17.5	18.0	14.7	38.4	44.8	53.9	48.3	33.2	41.1	30.9	32.5	13.5	16.8	15.0	11.9	6.5	6.9	8.8	8.4

Persistent inversions whose mean level is below about 700 m might represent cases where, for at least part of the time, the inversion falls close to ground level. This is significant from a pollution viewpoint since it greatly restricts the mixing layer over a wide area. For one four-day occurrence in 1974, when the Long Kesh subsidence inversion fell close to ground level, sulphur dioxide concentrations at Linwood, a semi-rural site in western Scotland, were 315, 225, 222, and 228 µg m^{-3}. This compares to a long-term average of 52 p.g m-s. On the basis of Table 3

about one in four persistent inversions might be expected to fall to near ground level.
The trapping of pollutants below this falling inversion lid can be visualised. If, however, intermittent surface inversions exist at the same time then, as these latter inversions are dissipated each morning, successive periods of fumigation occur. This was pointed out by Halstead (1976) and is clearly visible in Holzworth's (1972) data for the Thanksgiving Week episode. Similar conditions have been observed in west central Scotland on several occasions in the last six years, frequently exacerbated by the effect of cold air katabatic flows from the surrounding uplands and moorlands.

Conclusions
Problems of classification make for difficult comparisons between areas in terms of their inversion characteristics. Nevertheless, it is likely that Long Kesh is fairly representative of much of the north-western quadrant of the British Isles. As far as frequency is concerned inversions seem to occur about three days out of five, mostly between one and two kilometres in height, but occur with the greatest persistencies lower down, between 500 and 1000 m. Variations in seasonal frequency are slight and may relate to fluctuations in the importance of thermal and dynamical factors both in the air and adjacent sea, though this requires further study. Certainly, an investigation of anticyclonic occurrences would help towards understanding this and also the behaviour of inversions during such episodes. The importance of the latter has been demonstrated by Halstead (1973) for managing air pollution concentrations in enclosed basins. In general, greater knowledge will facilitate a better use of the dispersive capabilities of the atmosphere, something increasingly important in the future.

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