Geo Factsheet

Number 67

FOG - Formation and Hazard

- **Fog** is defined as occurring when visibility is less than 1000 metres irrespective of whether the obscurity is produced naturally by water droplets, or by solid particles, largely from human activity.

- **Thick fog** is a term used by meteorologists when visibility is less than 200 metres. **Dense fog** is a term used when visibility is less than 50 metres. Both thick fogs and dense fogs clearly cause major disruption and can be regarded as **natural hazards**.

- **Freezing** fog is composed of **supercooled** water droplets i.e. ones which remain as a liquid even though the temperature is below freezing point. Feathery crystals of ice called **rime** are deposited on vertical surfaces such as masts, fence poles and overhead wires. A dangerous build up of a rime means that freezing fog can be a major hazard for the electricity supply industry as it brings down overhead wires.

- **Smog** (smoke and fog) occurs where air pollution, largely from the burning of fossil fuels, provides additional particles which act as extra condensation nuclei for the fog to form round. Most large urban and industrial areas used to experience severe, dense smog. This was produced when fossil fuel smoke mixed with fog, thickening it, and, by preventing the sun reaching and warming the ground, prolonging the fog event.

  As a result of legislation such as the **Clean Air Acts** (1956-1960) which led to the development of **smokeless** zones, these thick fogs and smogs are not as common as they used to be in Western Europe but are still very much a feature of Indian, East European or Chinese industrial and urban areas.

- **Photochemical smog** results from photochemical reactions between the ultra-violet radiation from the sun and hydrocarbons and oxides of nitrogen, released by car exhaust fumes, in cities such as Los Angeles. The cities are covered with a dense, yellowish glare which irritates the eyes and throat and leads to asthma – thus causing a **human induced health hazard**. As these smogs are directly related to the quantity and quality of emissions from car exhausts they are a major hazard in most large urban areas, reflecting the **unsustainable** nature of mega cities.

Formation of Fog

For fog to form the lowest layers of the atmosphere must be brought to saturation point.

This may happen in two ways:
1. The lowest layers of the atmosphere are cooled.
2. Extra water vapour is added to the lowest layers of the atmosphere.

Fogs which form through cooling

Four major types of fogs form as a result of cooling processes:

1. **Radiation fog** development depends on the cooling of ground surfaces at night. Radiation fog is confined to land areas, as the daily variation in sea surface temperatures is not ordinarily sufficient to cool the lower layers of the atmosphere to its **dew point** (the temperauture at which air becomes saturated if it is cooled at constants pressure without removal or addition of vapour). However when skies are clear with little or no cloud, maximum radiation occurs. This cools the land surface, which in turn cools the lower layers of the atmosphere forming a marked temperature inversion and very stable air conditions.

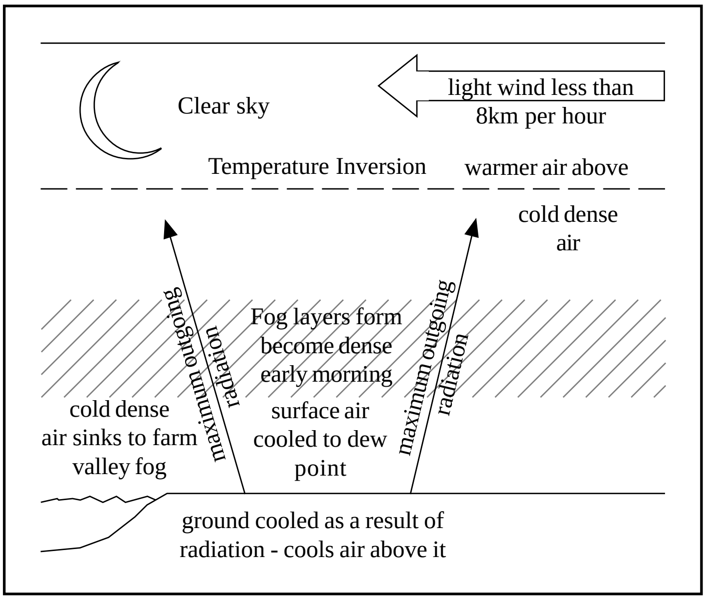
For radiation fog to form the following conditions must be met:

- There must be a sufficiently high relative humidity, with the air temperature not too far above the dew point so that only limited cooling will be required to produce condensation.

- The winds must be light (around 8 kilometres per hour). Under these conditions there is slight turbulence so the cooling is spread upwards to produce fog. If the air is calm only a thin layer of air will be cooled to dew point resulting in either **dew** or **hoar frost**. If the wind is stronger, this will result in increased turbulence, so a greater depth of air will be cooled to a lesser degree, and dew point will not be reached by the end of the night.

Radiation fog is associated with winter anticyclones (with stable, light wind conditions and clear skies) and is at its worst locally in valleys, at the end of the night or early mornings. The air is cooled and seeps into the valley bottoms and hollows as it is colder and denser and gradually fog builds up over the night as the air is cooled to dew point. In spring or summer the nights are not long enough for a thick radiation fog to occur. Thus, radiation fog is most common in late autumn and winter, when there are long nights with more opportunity for the air to be cooled down to dew point. Fig 1 summarises the conditions which lead to the formation of radiation fog.

Fig 1. Formation of radiation fog



2. **High Inversion Fog** occurs frequently in winter. As a result of a warmer air mass (for example a tropical maritime) overlaying colder air at ground level a high level temperature inversion occurs which will form a 'lid'. Any smoke will rise only to the underside of the 'lid' and then spread out laterally to form a blanket and block out the sunlight – in spite of the surface visibility being good. Water vapour condenses on the **hygroscopic particles** of the smoke blanket. High level inversion fog can form even without smoke, but in this case it looks like low stratus cloud. High inversion fog occurs in winter when a mass of

colder air moves in from the North Atlantic and undercuts the warm air above, producing very stable conditions.

3. **Advection fog** occurs when a current of warm moist air moves over a cold surface and therefore its temperature is cooled to dew point.

   Over land advection fogs are most common in winter after a cold spell, when milder moist air arrives from the sea (because of its high specific heat capacity the sea retains its warmth in winter). The cooling of the lower layers of this air mass eventually produces saturation.

   At **sea,** very persistent advection fog can occur where warm air moves across seas cooled by a cold ocean current. Off the Grand Banks of Newfoundland this warm air comes from the south west (Gulf of Mexico) and blows over the cool Labrador current. More usually, sea advection fog occurs when warm air moves off shore from the land over cold water – for example in the coasts of Britain this happens in spring or early summer when the seas are relatively cool with respect to the land.

   Advection fog is very widespread – the precise requirements needed to form radiation fog, such as clear skies and particular wind speeds are not required. The fog may therefore develop at any time of the day.

4. **Upslope fog** occurs when air is forced to rise up the mountain side and is adiabatically cooled as a result of the relief. If saturation point is reached upslope fog – in effect low stratus cloud - may occur. Ideal conditions include a high relative humidity, and a stable air stream which is forced to rise by the relief.

Fogs which form through extra moisture

Two major types of fog occur when extra water vapour is added to the lowest layers of the atmosphere, thus causing dew point to be reached.

1. **Steam fog** is formed when a current of cold air passes over a warmer water surface (the reverse of advection). The water vapour which is evaporated from the warm surface mixes with the colder air and will thus saturate it. The essential condition is that the air is cooler than the water. The fog rises off the water like smoke and is therefore called steam fog. It forms over rivers and lakes and sea areas in winter (these are relatively warmer) especially where they are affected by cold arctic or polar air.

2. **Frontal fog** often forms when rain falls from warmer air into colder air from above thus saturating it. This type of fog is known as **mixing** fog, and is particularly associated with the arrival of a warm front, which is the boundary between warm moist air and cooler air. The process is shown in Fig 2.

Fig 2. Formation of frontal fog

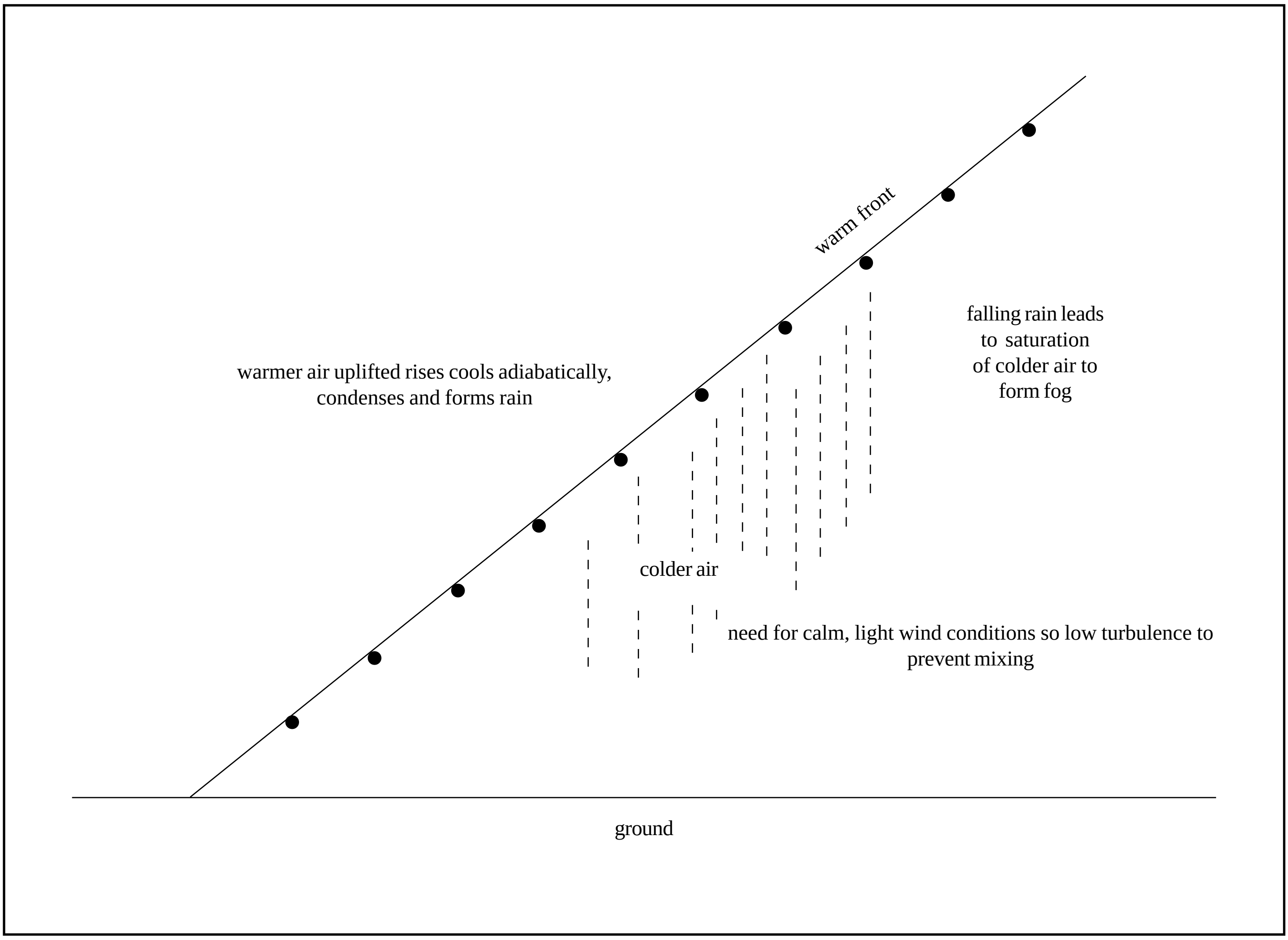


Table 1. summarises the characteristics of the major types of fog.

Table 1. Summary of Fog Characteristics

TYPE OF FOG	SEASON	TYPE OF AREAS AFFECTED	MODE OF FORMATION	MODE OF DISPERSAL
RADIATION FOG	WINTER i.e. long cool nights – widespread by dawn	Inland areas, especially low lying basins, valleys, moist areas with high relative humidity in evenings.	Cooling due to radiation from the ground on clear nights when the wind is slight. Typically during anticyclones.	Dispersed by sun's radiation i.e. 'burnt off' or dispersed by increased wind.
ADVECTION FOG OVER LAND	WINTER or SPRING	Often widespread in inland regions.	Cooling of warm air (e.g. PM or AM air mass) by cold ground (after a cold spell).	Increased wind produces a lift in the cloud base. The fog is dispersed by the gradual warming of the ground.
OVER SEA	SPRING and early SUMMER	Sea and adjacent coasts 'sea fret' along east coast of England.	Warm air is cooled by passage over a colder sea e.g. warm winds blow out from land to sea.	Dispersed by change of air mass. Often very persistent.
HIGH INVERSION FOG	WINTER	Largely industrial areas. Initially at higher levels i.e. 500m but can spread downwards.	Cold air over land by higher level warm air – inversion associated with extreme stability of blocking anticyclones.	Very persistent indeed when it spreads down to form dense surface fog.
UPSLOPE FOG	At ALL SEASONS	Higher ground (looks like low stratus cloud).	Air blowing up a mountain side or gradually sloping plane is cooled.	Increased winds.
FRONTAL FOG	At ALL SEASONS	Higher ground (looks like low stratus cloud).	Rain falls from warmer air into colder air. Lowering of the cloud base along the line of the front.	Dispersed as the front moves and brings a change of air mass.
STEAM FOG	WINTER	Riverine areas and lakes, rises from water like steam up to a height of 20m.	Reverse of advection fog. Current of cold air passes over warmer water areas.	Dispersed as air warms up. Usually only forms in early mornings.
SMOG - INDUSTRIAL	WINTER during anticyclones	Near industrial areas and large combinations.	Forms similarly to radiation fog pollution particles form nuclei on which droplets can form.	Dispersed by wind increase or by convection. Inversion lid leads to very persistent fog in stable anticyclonic air.
SMOG PHOTO - CHEMICAL	Especially in SUMMER sunlight	Associated with high car use in large urban areas in basins.	Results from photo-chemical reactions between ultra violet radiation from the sun and hydrocarbons and nitrogen oxides.	Very persistent indeed. Can be dispersed by strong winds.

Fog as a hazard

Fog is a hazard to land, sea and air transport. The table below summarises how fog disrupts transport.

Mist/Haze (5000m visibility)
Ships and aircraft affected – need to use radar.

Aviation Fog (1000m visibility)
Aircraft landing affected on basically equipped airports and aeroplanes.

Thick Fog (200m visibility)
Road, rail and aircraft on the ground delayed.

Very dense fog (50m visibility)
Severe disruption to most transport.

In order to combat the effect of fog costly adaptations such as ATL systems for aircraft, radar for ships and at airports, and sophisticated safety signalling for trains are in place. Only on the roads is there no 'idiot proof' system of accident prevention.

Statistics show that in reality only 6% of serious injury accidents occur on motorways, and 4% overall occurred as a result of poor visibility in mist or fog. However, because these accidents happen at speed (70mph+) they do tend to be large scale and newsworthy. In all cases excessive speed for the bad conditions is the cause.

Fog 'black spots' occur, i.e. when fog is a common hazard, on Britain's motorways, for example on the M25 near Gatwick Airport, or on the M1 at Junction 10 or M6 Junction 15. These are usually associated with local waters, valley bottoms, or even hill tops, or in the case of Junction 15 (M6) the industrial pollution from Stoke-on-Trent. The fog is of patchy thickness and tends to lead to perceptual disorganisation. Remedial actions included fog warning and speed restrictions operated from a control centre, convoys of vehicles escorted by police in extreme conditions to keep speeds down, as well as low pressure sodium lights for fog-prone motorways. High level conventional lighting can create a luminous glare in foggy conditions due to the scattering of light by the fog droplets. More recently, sophisticated in-car radar systems can warn the driver if they are too close to the vehicles in front. Driver Education Campaigns also reinforce these safety measures.

A major problem is that fog is very difficult to forecast; it is localised in its distribution and also variable in thickness, with a sudden onset spatially.

Whilst fog used to be a major hazard for railway operations before modern signalling, it is still a major concern for aircraft operations, resulting in cancelled flights, diversions and lost revenue in spite of increasingly sophisticated automatic landing equipment on planes and at airports. Fog is also responsible for numerous air crashes of light planes from small airfields.

Fog continues to be a serious hazard at sea despite modern navigational aids. In crowded sea areas such as the Straits of Dover nearly 75% of all collisions happen when the visibility is under 4kms.

Smog can be a serious health hazard. The occurrence of the thick London fogs – known as 'pea soupers' always led to a high incidence of heart and lung disease.

***Exam Hint** - Almost all candidates attempt to define fog but many appear to believe that there is only one type of fog. Far too often, the only example given is that of Los Angeles and, even in this example, the details of smog formation are poorly understood.*

Case study
Los Angeles photo-chemical smog

The results for the Air Quality Index for Los Angeles would suggest that nearly 100 days were recorded as 'very unhealthy', with a further 110 being recorded as 'unhealthy'.

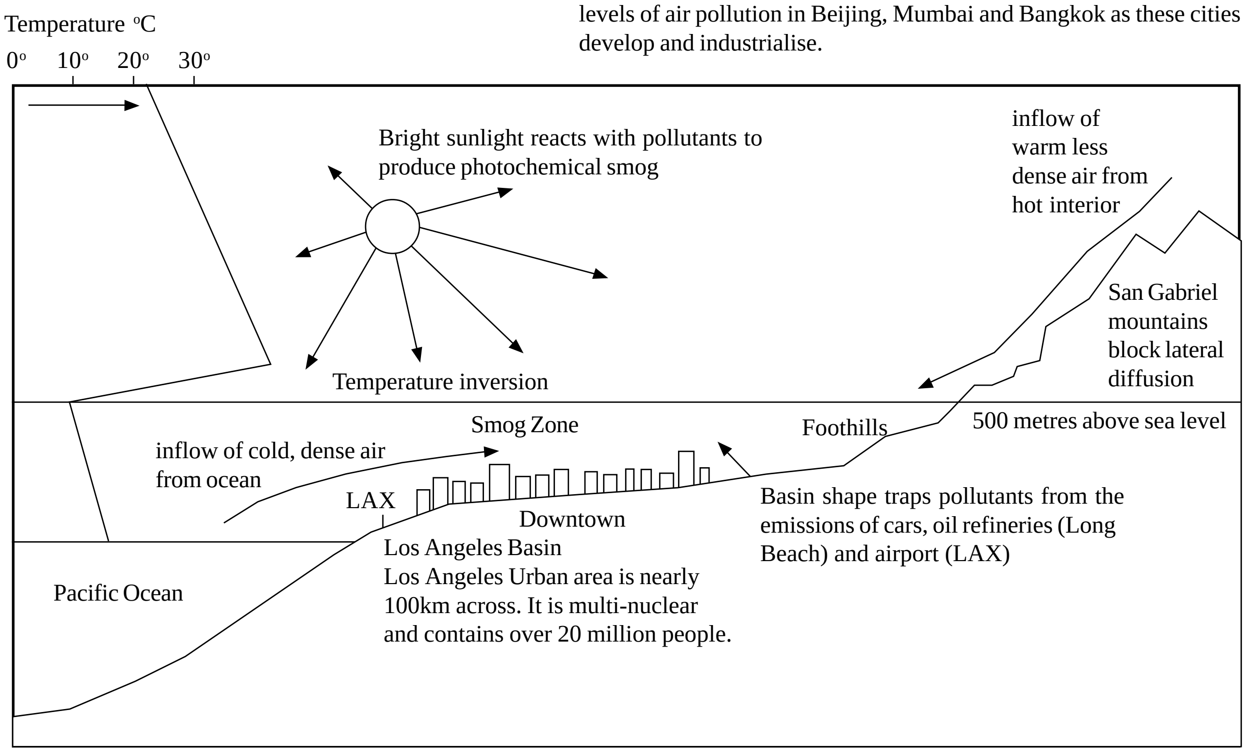
In Los Angeles over 90% of journeys are made by car, with 160 million km a day being driven on a 200 km network of freeways. The problem began in the 1940s. Year-round sunshine and warm temperatures (range 16°-32°C), and light winds, especially in summer, are climatic features which have led to pleasant living and ideal development conditions for industries such as films and aerospace. However, these same climatic features combine with the basin site and the emissions of the most vehicle-dependent city in the world to produce photochemical smog and some of the worst air pollution in the world (Fig 3).

The serious smog problem is made worse by the bright sunshine (ultraviolet radiation) which energises the reaction which transforms gaseous wastes in photo-chemical smog – a brownish, yellowy haze which damages vegetation, irritates eyes and chests and generally threatens human health. The distribution of smog varies daily, and seasonally. Sources of air pollution include car fumes, oil refineries and factories in the S/SW coastal area and east in the San Fernando valley. Secondary problems include the formation of low level ozone.

Solutions to the problem include emission controls on vehicles exhausts (in the 1950s two million cars produced more smog than today's 10 million). As 60% of the smog comes from cars, further emission controls with even higher standards, plus use of electric vehicles and LPG cars are planned. Public transport strategic plans led to the development of new rail networks, improved bus routes and also extensive car pooling systems, but as the city spreads these schemes fail to keep pace with development.

Most world mega cities have similar problems to Los Angeles, with Mexico City's air quality being even worse. A great concern is the high levels of air pollution in Beijing, Mumbai and Bangkok as these cities develop and industrialise.

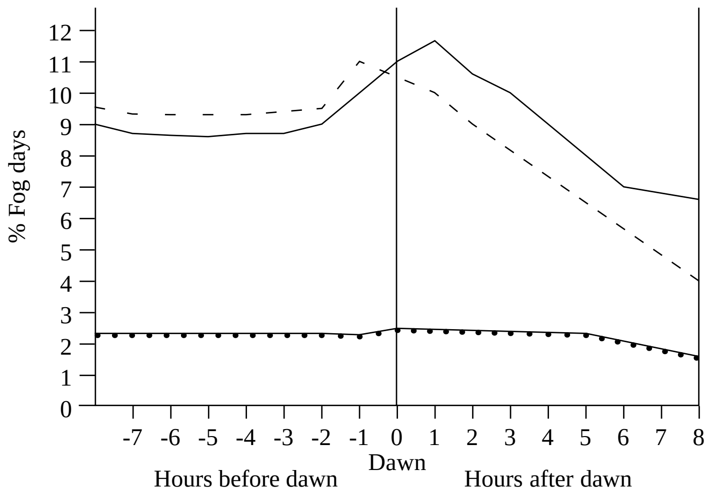
Fig 3. Formation of smog in Los Angeles



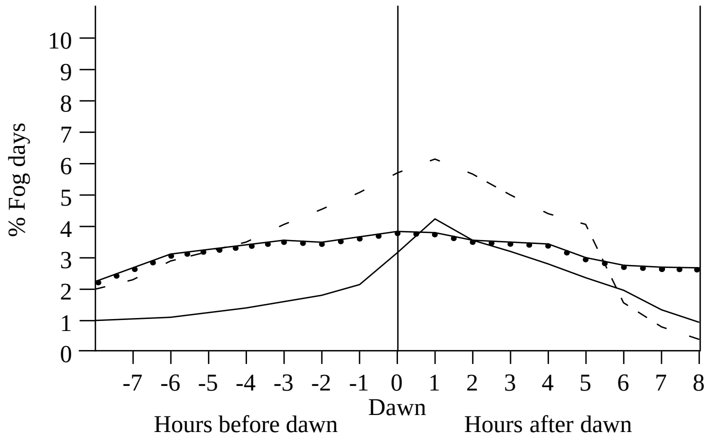
Practise Questions

Study the graphs below

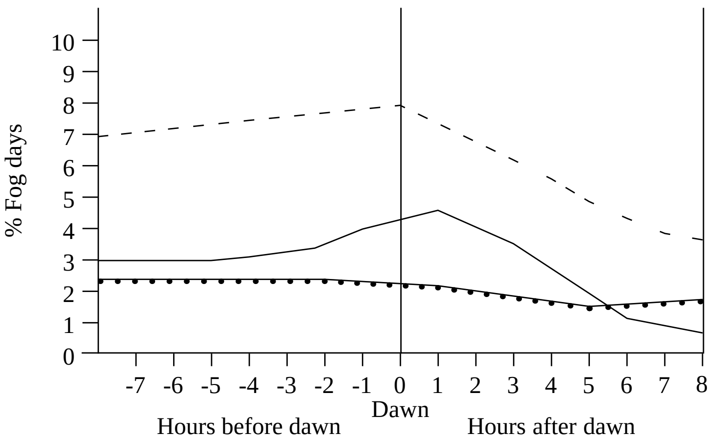
Winter half year 1957-1966

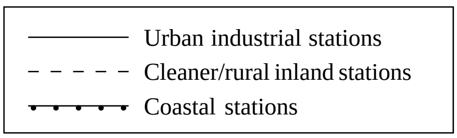


Summer half year 1957-1966



Winter half year 1986-95





1. Explain why the maximum period of fog formation is just after dawn in both winter and summer. (5)

2. Describe and suggest reasons for the differences in the pattern shown for coastal areas. (5)

3. Describe and give reasons for any differences in the occurrence of fog at the smoky and inland sites in the winter half year and the summer half year. (10)

Answers

1. Hint - think about the process of cooling to dew point.

2. Hint - think about the type of fog - especially advection fog.

3. Hint - think about the impact of fossil fuels especially 1957-1966 was only just after Clean Air Acts (1956)
   Winter - more fuel burned. Think why this would cause more fog.

Acknowledgements;
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