Inversion Layer and its Environmental Impact over Karachi

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Abstract

Temperature inversion is one of the most important meteorological phenomena, in which atmospheric lapse rate is inverted i.e. temperature increases with height instead of decreasing. Inversion plays a significant role in disturbing Air Quality of an area where it exists. Karachi is a coastal city, where sea breeze plays an important role to maintain atmospheric temperature. In this paper, an attempt has been made to find out the temperature inversion layer over Karachi during 2000 to 2009 and its impact on air quality. The analysis of inversion on monthly basis has been done using JRA 4-time daily temperature data, which has shown the inversion in winter as well as summer seasons with maximum frequency of inversion in monsoon period (July-September), over Karachi. Greater frequency of night time inversion has also found. The Radio-sonde one year daily data of temperature and wind speed of Karachi is correlated with daily data of haze, mist, dust in-suspension (DIS), visibility and relative humidity to see its impact on air quality. It is observed that the greater frequency of inversion layers at 0000 UTC and 1800 UTC mostly occur in summer months. One of the dominant features is seen in the lower troposphere temperature inversion mostly at 950-850 hPa pressure level.

Key words: Inversion layer, Sea breeze, Relative humidity, Air quality.

Introduction

Karachi is a metropolitan city and located in southern Pakistan on cost of the Arabian Sea and in northwest at mouth of the Indus River. Its geographic coordinates are 24.54 °N and 66.56 °E. Karachi is governed by the coastal arid climate under the influence of land and sea breeze (Shamshad, 1986). Meteorological characteristics at a coastal location are different than those at inland due to sea breeze and land breeze circulation and its impact on local weather, (Panchal, 1993). Karachi lies beyond the reach of both the monsoon and the western disturbance. The coast enjoys the constant sea breeze which keeps the surface temperature moderate. Karachi is known as the city of light. Unfortunately, air pollution is increasing in this city day by day. The aim of present study is to find out relationship of thermal inversion layer with air quality of Karachi city. Air temperature can play an important role in the buildup or dispersion of surface air pollution. As air rises and expands in the atmosphere, the temperature decreases with altitude, this happens under the normal atmospheric conditions or normal lapse rate. In general, lapse rate is the rate of decrease in the value of any meteorological element with elevation. In some cases, temperature falls up to some height and then starts increasing or becomes constant at a height of a few tens of meters to a few kilometers above the ground. The layer in which this increase or stop occurs is known as thermal inversion layer. Temperature inversion is one of the most important meteorological phenomena (Crawford and Ganser, 1961).

Definition of temperature inversion in Air pollution and meteorology temperature inversion is a sub-adiabatic condition in which warmer layer is above the cooler layer. When temperature inversion layer forms, it resists uplifting of the particles from surface to atmosphere because layer acts like a cap in which vertical air movement almost remains nil. A temperature inversion layer usually occurs where the thermal structure is complicated and isotherms are rugged (Nagata, 1979) and air close to the ground does not readily circulate in inversion. It prevents the vertical mixing such atmospheric stability can lead to air pollution. Temperature inversion layers are also called thermal inversions layer or just inversion layer. Normally, air temperature decreases at a rate of 3.5 °F for every 1000 feet (6.4 °C/km) when climb into the atmosphere. When this normal cycle is present, it is considered an unstable air mass and air constantly flows between the warm and cool areas. As such the air is able to mix and spread around pollutants. This is the normal lapse rate or positive temperature gradient. An area where the temperature increases with

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increasing altitude, in that condition temperature inversion create cool air (denser air) below the warm air (lighter air) then atmosphere are unstable in that condition (Walker,1974).

Several observational and quantitative studies on thermal inversion layer notably those by (Devisthle and Willen, 2010; Hosler, 1961; Rao, 1938; Crawford and Ganser; Nagata, 1968, 1979 and Desai, 1968) and various authors worked on this topic. Desai, 1968 worked on the "Causes of aridity and inversion over the desert areas of West Pakistan and neighborhood during the south-west monsoon season". The observation and analysis of temperature inversion layer have never been under taken on Karachi therefore this study has been carried out to investigate the thermal inversion layer over Karachi and its impact on air quality from the period 2000-2009. Criteria for identifying the inversion layers relates to temperature increase with height and do not include cases where the temperature remains constant in a vertical interval (isothermal layer).

Data and Methodology

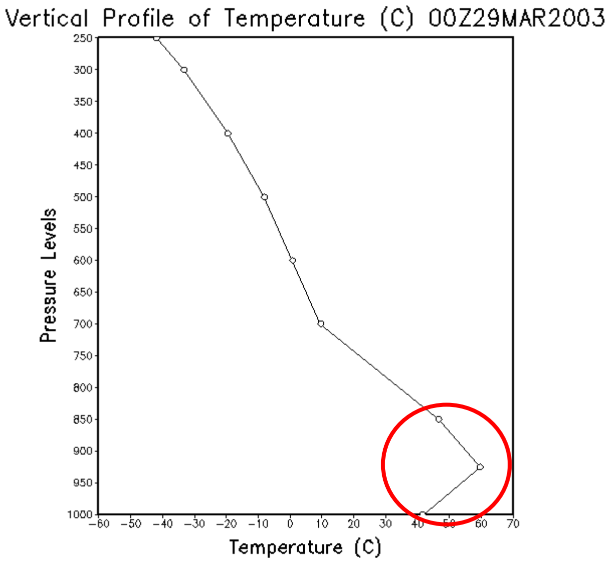
The analysis of thermal inversion layer over Karachi has been carried out by using 4-time daily temperature of Japanese Reanalysis (JRA) data from 2000-2009. The Radio-sonde daily data of temperature and wind from April-December 2009 have been obtained from Climate Data Processing Center of PMD. The daily data of haze, visibility (0000 UTC) relative humidity (0000 UTC), dust in-suspension and mist have been taken from Regional Meteorological Center, Karachi for the year 2009. The inversion layer analysis have been carried out by drawing vertical profile of temperature at 1000 hPa, 950, 900, 850,800, 750, 700, 650, 600, 550, 500, 450, 400, 350, 300 and 250 hPa levels using 4-time JRA data from 2000-2009. The annual analysis has been done in order to calculate the frequency of occurrence of inversion layer in months of January-December. Criteria for identifying the inversion layers are selected where temperature increases with height and do not include cases where the temperature remains constant in a vertical interval or isothermal layer. The GRADS (Grid Analysis and Display System) software is used in the study for plotting the vertical profile of temperature, at all levels. The correlations have been calculated between daily Radio-sonde and air quality data for the year 2009 (April-December).

Radio-sonde Measurements

Radio-sonde measurements provide a vertical profile of temperature, pressure, dew point and horizontal winds and are well suited to study low level temperature inversions. Radio-sonde data of daily temperature over the Karachi have been collected from Climate Data Processing Center (CDPC) Karachi. Routine radio-sonde profiles are made once daily at 0000 UTC at location within Karachi. These observational data from April to December, 2009 have been used in this study and making images of vertical profile of temperature in excel (spread sheet analysis) for finding out inversion layers.

Results and Discussion

Troposphere is the lowest shell of the atmosphere (Mogil, 2008), in which uniform decreases in temperature with height. The troposphere is the part of the atmosphere in which all 'weather' occurs, (clouds, rain, snow, hurricanes and tornadoes). There are generally four types of inversion at different levels (Wolfe, 1985) i.e. subsidence Inversion, Frontal Inversion, Radiation Inversion and Nocturnal Inversion. In this study the surface and subsidence Inversion layer have been considered only at lower troposphere. These are two basic types of low-level inversions (lacobellis et al., 2009). These two low-level types of inversion layers have been identified over Karachi.



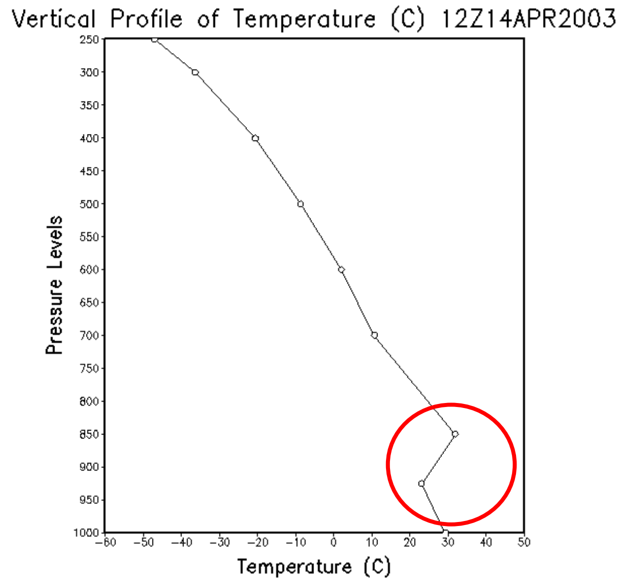


Figure 1: Surface Inversion

Figure 2: Subsidence Inversion

Surface Inversion Layer occurs when the favorable conditions are produced by the radiation cooling at the surface. Typically occurs at night when there are no incoming solar radiation to balance the surface cooling due to outgoing long wave radiation (lacobellis et al., 2009). This type of inversion formed at the ground or at surface and also called Radiation or Nocturnal inversion. Figure 1, is the vertical profile of temperature at 0000 UTC of Karachi in which the circle indicates the inversion layer formed at the surface, the same shows increase in temperature from surface to 950 hPa and when pressure levels at 950 hPa, the temperature decreases according to normal lapse rate. Commonly, that type of inversion is formed when surface of Earth cools faster than air. It mostly formed at night time or in winter season (Devasthale et al., 2010).During day-time surface layer of atmosphere received the heat of conduction and radiation from the earth surface and are warmed, on clear night ground surface radiate heat and cools quickly. Usually the maximum strength of surface inversion is around sunrise (lacobellis et al., 2009). Surface inversion breaks up in day time when sun heats the ground. It plays main role in air quality; resist vertical motion of pollutants trapped below and can not mix with air above inversion.

Subsidence Inversion occurs high above the ground, lifted away from the surface of earth. This type of inversion is found due to sinking of air in high pressure area because high pressure promotes sinking air (Tennekes, 1973) and slow sinking is responsible for development for large number of inversion forms in free atmosphere in Figure 2, are the vertical profile of temperature at 1200 UTC of Karachi in which the circle indicates the temperature inversion formed above the ground in lower part of troposphere. It resists to convection of surface air due to resistance in air below the inversion and causes air pollution.

Annual Analysis

2000 (Mar-Sep)

During the year 2000, the results shown that the inversion layer have been found from March to September. Mogil (2008) have defined that inversion layer commonly found overnight and early morning. Figure 3-a, depicts in months of March and April only one or two inversion events found at 1200 UTC and 1800 UTC. In May and June the inversion was seen at 1800 UTC. During July, August and September the frequency of inversion was higher both at night time and early morning. Frequent inversions were found in July and August, due to subsidence which caused increase in temperatures above the ground in between 950 to 850 hPa levels.

2001 (Jan-Sep)

If the temperature inversion determined mainly or even largely by earth radiation it should have maximum frequency in summer and minimum frequency in winter (Humphreys, 1909). Figure 3-b, shows that January, April and a few cases of inversion were found. On other hand inversion were formed frequently in summer from June to September, because lower atmosphere and surface of earth receive more solar energy during summer therefore in day time and at night time inversion layer were formed due to surface radiated energy in cool nights. Usually results have been shown that inversion formed at 1800 UTC and 0000 UTC night and early morning. Only on 28th March at 0000 UTC, 11th May at 1800 UTC, 28^{th} and 30^{th} June at 1800 UTC identified surface-based inversion due to temperature increase at the surface 1000-950 hPa level. The maximum inversions frequency was record at the time of 1800 UTC in June and 0000 UTC, 0600 UTC, 1800 UTC during July and August.

2002 (May)

May is the hottest month for Karachi, with mean daily maximum temperature is 36 °C. Heat is felt very much with light wind and high humidity (Shamshad, 1986). Figure 3-c shows the variability in inversion layer in comparison with the previous years like 2000 and 2001. Hardly any thermal inversion formed before and after May. Minimum rainy days occurs and weather remains dry during this month (Sadiq, et al; 2009). The inversion formed early in the morning 0000 UTC persist until 0600 UTC after sunrise and weakened during afternoon 1200 UTC and again frequently formed at 1800 UTC at night time.

2003 (Jan-Dec)

Inversion due to surface heat loss appears in the initial stage of winter (Thadthil, Gosh 1992). Figure 3-d, shows that the inversion occurred at Karachi generally starting from the January. In this year a few cases of winter inversion have been identified from December-February at night and evening time. From March- May inversion identified at night, early morning and at evening time. Surface inversion also formed in these months. As Karachi is close to the sea so in March its weather is cooler in the day and warmer in the night (Shamshad, 1986), where as sea breeze start from March. The average frequency of inversion layers formed in June at 1800 UTC. Here in July no inversion was formed. In August gradually frequency and increased till September. In December inversion frequency reached the minimal at 1200 UTC and 1800 UTC.

2004 (Feb-Jun)

Desai (1968) said that in desert areas the inversion layer formed due to large scale subsidence. In figure 3-e, a few cases of inversion layer found in February and March, no inversion found in April, similarly during the months of May and June inversion at 0000 UTC, 0600 UTC and 1800 UTC was identified. The inversion frequencies varied from days to nights. The results have been shown that frequency of inversion increase at night time and decreased during the day hours. Also only subsidence inversion was found.

2005 (Jan-Oct)

During 2005, the results mid it clear that the highest frequency of occurrence was during mid summer, while the lowest was during late fall and early winter. According, Johnson and Baker (1997), inversion frequently occurred in summer comparatively than winter season. Figure 3-f, in January, March, April and May except February very few inversions occurred in this year. The maximum frequency of inversions formed from period June to August. So inversion layer commonly have been identified after sunset and before sunrise. How ever 4th April and 14th May surface-based inversion occurs at 0000 UTC. Except that whole of subsidence elevated inversion has been formed.

2006 (Apr-Sep)

Over Karachi temperature inversion occurs during April to September (Rao, 1938). During year 2006, the frequency of inversion increased in the months of May, June and July and all of subsidence inversions formed, that type of inversions mostly happened in summer due to advection of warm air (Devasthale et al., 2010). Figure 3-g, the maximum inversion frequency occurred in July when the highest Relative humidity occurred in this month. July is the most humid month (Rao, 1938) and inversion frequency sharply decreased in August and September.

2007 (Jan-Sep)

In 2007, January and April only one-day subsidence inversion event occurred at and 0600 UTC. As in Figure 3-h, no inversion was found during February and March and in May frequency mostly occurred at night and after sunrise where as in June no inversion layer was found. Inversion layer was found most frequent and well marked in July and August (Rao, 1938), from July to September mostly vertical profile of temperature dominated by subsidence inversion. On 31st August at 1200 UTC surface-based inversion layer have been found.

2008 (May-Sep)

The greater inversion frequency has been identified in July early in the morning, after sunrise and at night time. Night time temperature inversion increases daily minimum temperature (Ramaswamy, 2001). Usually temperature increase in June and July, frequencies of inversion decreased from August onward in this year. Surface-based inversion layer most likely happened in winter (Devasthale et al., 2010). In figure 3-i, following inversion layer frequency have shown that thermal inversion occurs greater in summer, smaller in winter and all observations are subsidence inversion layer.

2009 (Apr-Oct)

The temperature inversions at Karachi occurs later in the year June onwards (Malurakar 1949).The inversion layer observed from April-October are presented in figure 3-j. The greater frequency of surface-based inversion layer has been found in April and May at 0000 UTC and also observed in June at 0000 UTC. In the months of July-September, the subsidence inversion formed and maximum frequency was noticed at the time of 0600 UTC after sunrise. September and October are generally warmer over the coast (Shamshad, 1986).Surface-based inversion layer frequently formed in October and mostly at night time.

May and June are the transition months between winter / summer monsoon, where inversion exist after sunset and early morning, mostly, at 1800 UTC and 0000 UTC. They are usually dry months and characterize with high temperature, aridity and strong winds caring the dust particles. These dust rising winds and dry haze envelope over the city. The maximum subsidence prevails in the south west of Pakistan due to high pressure, causing strong squall wind and violent dust storm (Saif et al., 2010). According to Tindale and Pease (1998) winds transport the dust particles to the Arabian Sea from desert region of Iran and Pakistan.

Radio-sonde

Radio-sonde provided the database for earlier investigations into inversion frequencies (Hosler, 1961). For finding out thermal inversion layer using daily data of temperature from Radio-sonde. Iacobellis et al., 2009, stated that the Radio-sonde daily temperature data are well suited to study low level temperature inversions. Routine radio-sonde profile were made once daily at 0000 UTC at Karachi. Radio-sonde observations have shown the inversion from April to October in figure 4(a), increasing the frequency of inversion in May throughout the year, radio-sonde data is available in between 150 hPa interval, one value present at 1000 hPa then second reading at 850 hPa and data did not shown which type of inversion formed either surface-based or subsidence inversion layer. The comparison of data sets, JRA 2009 and radio-sonde 2009, show the thermal inversion from April to October, but did not show on same days except a few in May.

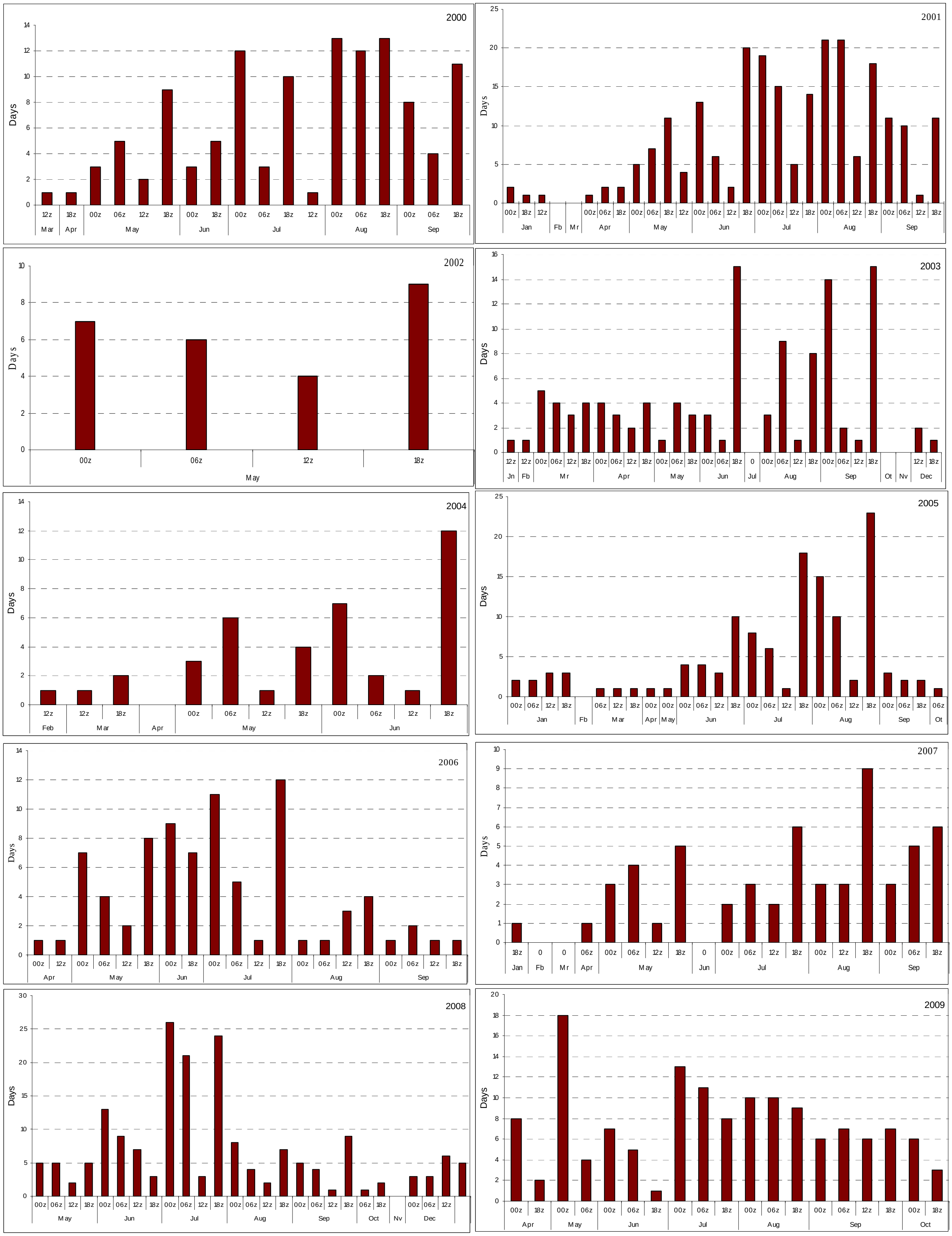


Figure 3: Average frequency of Inversion Layer calculated from Japan Reanalysis dataset during the years 2000–2009

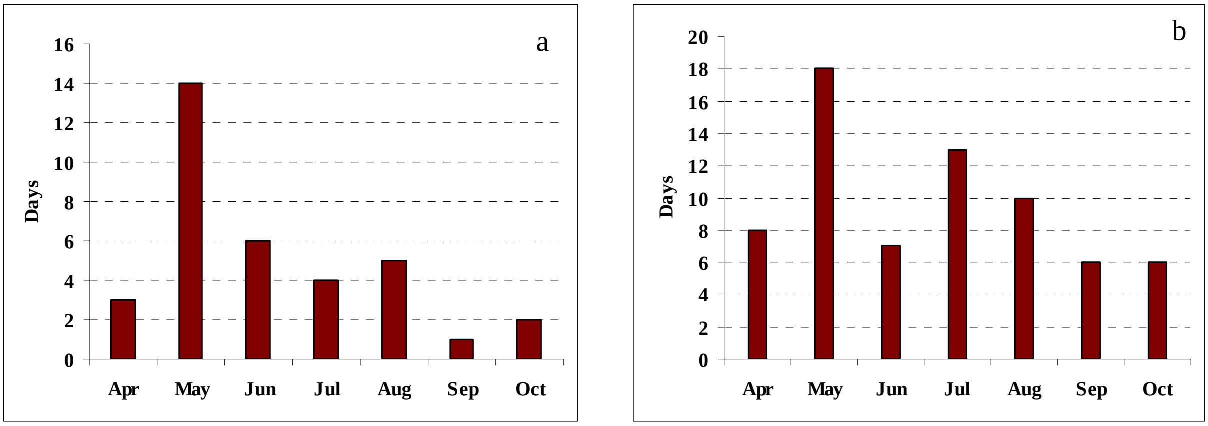


Figure 4: Daily frequency of Inversion Layer computed from **(a)** Radio-sonde observation at Karachi (0000 UTC) agreed with maxima in May seen from **(b)** JRA dataset (0000 UTC)

Thermal Inversion Layer Impact on Air Quality

Thermal inversion layer plays an important role in determining concentration of air pollution (Pokhrel, 2002), traps the pollutants near the ground and leading to poor air quality. Concentration of air pollution depends strongly upon vertical gradient of temperature or inversion strength (Iacobellis et al., 2009). It has been known that when ever temperature inversion formed it influenced atmospheric stability, resist the vertical mixing of air and atmospheric conditions becomes unstable, inversion acts like a cap 125% decreasing mixing ratio. Under such conditions dust rising affect the quality of air. If the relative humidity of the air is high, it can contribute to the formation of clouds, fog, haze or smoke, water droplets in the atmosphere mix with dust particles resulting in diminished visibility in the inversion layer. Generally visibility refers to the greatest horizontal distance at which prominent objects can be viewed with naked eyes. Towards the end of summer monsoon season haze remains prevalent in the afternoon and reduced average visibility (Shamshad, 1986). For comparison of thermal inversion computed by radio-sonde with meteorological data of visibility, haze, mist (moisture) and dust in-suspension were obtained from Regional Meteorological Center Karachi. Visibility was taken at 0000 UTC for analysis. The meteorological codes used for visibility were 92 to 97. Visibility is reduced by the severity of fog, mist, haze, dust and smog (Chung et al., 1998). The analysis shows the weak correlation between inversion layer and weather data. The visibility at inversion dates 96 code shows that visibility in these days ranged between 4 km and 10 km and only few hazy days were reported in inversion days.

Wind Speed

Wind speed data from radio-sonde at surface and 850 hPa show that the average wind speed in inversion days is greater than monthly average wind speed. Figure, 5(a, b) shows that the wind speed in inversion days at surface ranging 2-8 knots and 15-33 knots at a pressure level 850 hPa. In this paper the study area is located at a coastal region and has known that wind plays a significant role in the formation and dispersion system. In low level inversion, the strong gusty winds on the surface generate which carry dust particles. As the barotropic conditions prevail in such cases above the ground, therefore a condition of dust in suspension prevails which decreases the quality of air drastically. Desai, 1968, find out inversion over West-Pakistan during summer monsoon due to different air masses, our analysis results have been shown that inversion present over south-Pakistan (Karachi) in summer monsoon season. The annual mean frequency of thermal inversion layer at Karachi is about 32.5% at 0000 UTC, 22.6% at 06 UTC, 7.9% at 1200 UTC and 36.5% at 1800 UTC respectively. Results estimate that surface-based inversion present in Karachi about 5% and subsidence inversion about 95% respectively.

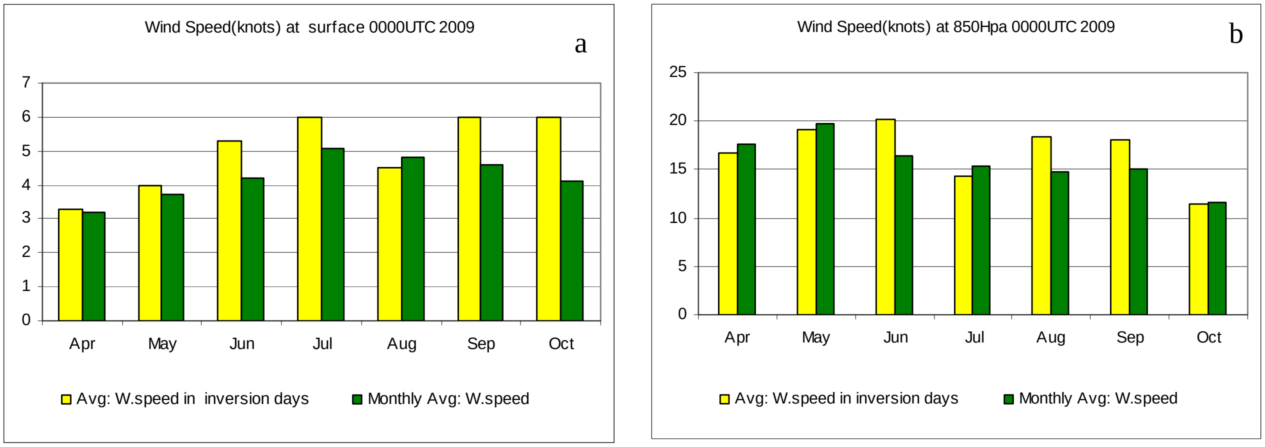


Figure 5: Relationship of normal and actual wind speed (Knots) at **(a)** surface and **(b)** 1500 feet above the surface i.e. 850 hPa during inversion days

Topography being an important factor, the inversion layer at Karachi is a local phenomenon. They form due to convergence of sea breeze and land breeze because different temperatures between land and sea in summer in the evening and night when surface of earth cools due to sea breeze cold air lies beneath warm air and shut off any convection between warm and cold air causing a situation of the low-level inversion. Night time inversions frequently formed and disappear in day light hours. Climatologically Karachi is a semiarid region and large potential evaporation occurs in semiarid region (Wolfe, 1985), in Karachi day time emission of smoke from chimneys of factories and earth emitted long wave radiation at night time to contribute the formation of inversion layer and greater relative humidity values increase the thickness of inversion layer at night time. When sunrise heat exchange traps in inversion layer water droplets (moisture) evaporates from inversion layer because available moisture change very quickly after sunrise. Resultant layer loose the thickness so that inversion layer are thinner or disappear in day time. Temperature inversion layer formed when condensation process occurs at night time and disappear in day light hours when evaporation process occurs after sunrise.

Conclusion

The observations and results of the study are summarized as follow:

- One of the dominant features revealed was the lower troposphere temperature inversion over Karachi generally at 950-850 hPa pressure level.
- Maximum inversion formation frequencies have been found in summer (monsoon season July-September) and minimum in winter.
- Subsidence inversion observed 95% and 5% of surface-based inversion found.
- Annual inversion occurrence frequency is significantly higher at 1800 UTC about 36.5%, at 0000 UTC about 32.5%, at 0600 UTC is 22.6% and 7.9% at 1200 UTC.
- Mixing of the cold air reduced the strength of inversion layer and same time it deepens so that smaller frequency obtained at 1200 UTC cold sea breeze started in afternoon.
- Low level inversions gives rise to strong dust raising gusty winds which produce dust in suspension condition in metropolitan area of Karachi.

Recommendations

Further research need on thermal inversion layer and variability of inversions year-to-year, in future work we will determine the strength of inversion layer and its influence on climate change of Karachi.

References

Chung, Y. S., H. S. Kim and B. Yoon, 1998: Observation of Visibility and Chemical composition Related to Fog, Mist and Haze in South Korea Dept. of Environmental Sciences/Korea-China Centre for Atmospheric Research Korea. Water Air and Soil Pollution, (111), 139-157.

Desai, B. N., 1968: Causes of Aridity and Inversion over the Desert Areas of West Pakistan and Neighborhood during the South-West Monsoon Season. Proc. Indian Acad. Sci. (68)103-107.

Devasthale, A., U. Willen, K. G. Karlssonand and G. Jones, 2010: Quantifying the Clear-Sky Temperature Inversion Frequency and Strength over the Arctic Ocean during summer and Winter Seasons from AIRS Profiles. Journal Atmospheric Chemistry and Physics (ACP), (10), 2835-2853.

Hosler, C. R., 1961: Low-level Inversion Frequency in the Contiguous U.S. Mon. Wea. Rev., (89)319–339.

Humphreys, W.J., 1909: Vertical Temperature Gradient of the Atmosphere Especially in the Region of Upper Inversion. The Astrophysical Journal, (xxix), 14-32.

Iacobellis, S. F., J. R. Norris, M. Kanamitsu and M. Tyree, 2009: Climate Variability and California Low-Level Temperature Inversions. California Climate Change Center, Scripps Institution of Oceanography, 1-48.

Johnson A. B. and D. G. Baker, 1997: Climatology of Diffusion Potential Classes, For Minneapolis–St. Paul, Journal of Applied meteorology,(36), 1620-1628.

Rao, P. R. K., 1938: Weather Forecasting For Aviation with Special Reference to Local Forecast, (1), 129-138.

Malurkar, S. L., 1949: Nor’ Westerns in Bengal, 5-6.

Mogil, H. M., 2008: Climate Education Update, Atmospheric Radiation Measurement Climate Research Facility, U.S Department of Energy.

Nagata, Y., 1979: Shallow Temperature Inversions in the Pacific Ocean Near Japan. Journal of Oceanography Society of Japan, (35), 141–150.

Panchal, N. S., 1993: On Set Characteristics of Land/Sea Breeze Circulation and it’s Effect on Meteorological Parameter at a Coastal Site’s. Atmosfera, (6), 155-162.

Pokhrel, S., 2002: Climatology of Air Pollution in Katmandu Valley, Nepal.

Ramaswamy, V., 2001: Temperature Trends in the Lower Atmosphere, The U.S Climate change Programe,Chapter 1, 1-28.

Sadiq, N. and I. Ahmed, 2010: An Empirical Microclimate Analysis of Costal Urban City, Pakistan Journal of Meteorology, 6(12), 57-63.

Saif, U., M. Hasan, F. K. Khan and A. Bari, 2010: Climate Classification of Pakistan, Balwois ,Ohrid, Republic of Macedonia, 1-47.

Shamshad, K. M., 1986: The Meteorology of Pakistan, Climate and Weather of Pakistan. 135-160.

Tennekes, H., 1973: A Model for the Dynamics of the Inversion Above a convective Boundary Layer, Journal of Atmospheric Science, (30), 558–567.

Thadathil, P. and A. K. Gosh, 1992: Surface Temperature Inversion in the Arbian Sea during Winter, National Institute of Oceanography, Journal of Oceanography, (48), 293-304.

Tindale, N. W. and P. P. Pease, 1998: Aerosols over the Arabian Sea: Atmospheric

Transport Pathways and Concentrations of dust and Sea salt, Deep-Sea Research II, (46), 1577-1595.

Walker, J. M., 1975: On Summer Atmospheric Processes over south-west Asia

Department of Maritime Studies, University of Wales Institute of Science& Technology, Cardiff, United Kingdom, (5), 491-496.

Wiker, P. and R. A. Baxter, 2010: The Quality of Air, Radio-sonde case study, constant upper Air Measurement, Meteorological Technology International June 2010, 70-73.

Wolfe, D. E., 1985: Thesis, Early Morning Evolution of the Convective Boundary Layer at the Boulder Atmospheric Observatory Department of Atmospheric Science, Colorado State University F t . Collins, Colorado, 1-160.

Joseph YV. C. and H. Ganser, 1961: Spring Temperature Inversion. California Agriculture, 15 (2), 7-9