Atmospheric stability in Athens, Greece, during winter and summer
B.M. Synodinou\textsuperscript{1} & H.D. Kambezidis\textsuperscript{2}
\textsuperscript{1}Institute of Nuclear Technology and Radiation Protection, NCSR "Demokritos", GR-15310 Ag. Paraskevi, Greece. Email: vana@zeus.int-rpnet.ariadne-t.gr
\textsuperscript{2}Atmospheric Research Team, Institute of Meteorology and Physics of the Atmospheric Environment, National Observatory of Athens, PO Box 20048, GR-11810 Athens, Greece. Email: harry@env.meteo.noa.gr

Abstract

The present study estimates the atmospheric stability for the Athens area based on Pasquill's formulation. The results are limited to examining the stability categories during the months of January (mid-winter term) and July (mid-summer term). These stability classes are examined from a 44-year database consisting of hourly values of wind speed and direction, solar insolation and cloud cover. This data is regularly recorded at the National Observatory of Athens located near the city centre. The results of the work consist of diagrams with mean monthly stability class values during January and July in the period 1953-1996 and the mean daily variation of these parameters for the same months and period. Discussion of how these stability categories influence air pollution in the Athens area is made.

1 Introduction

Stability conditions are among the most important parameters that affect the dynamic processes occurring in the surface boundary layer. They are important factors to taken into account in atmospheric pollution studies. The stability criteria mostly used are the stability category estimations by
Pasquill-Gifford (PG scheme). These are functions of usual meteorological parameters such as wind speed and direction, solar insolation and cloud cover. The pilot work of Pasquill[1] for flat terrain introduced a set of six stability classes (A-F) as function of only wind speed, solar insolation and cloud cover. Gifford[2] later modified these classes in a more usable form. Turner[3] further modified the PG scheme by introducing one more stability class in which estimation of net radiation from solar altitude, cloud cover and ceiling height was made. Later, Turner[4] extended the above work to explicitly express stability class in a more useful form in direct relation to incoming total solar radiation. This scheme, known as the Pasquill-Gifford-Turner (PGT) scheme, has been commented and later reviewed by Pasquill[5] himself, Gifford[6], Hanna et al.[7], Sedefian and Benett[8], Turner[9], Agrawal and Kulkarni[10] and others. The PGT scheme has been the milestone of the works involving stability. Nevertheless, there have also been other methods to determine stability categories in a different formulation or modify the PGT scheme, incorporating recent knowledge about the surface boundary layer behaviour. For instance, Golder[11] developed procedures to relate the stability classes to surface-layer-stability parameters and to directly incorporate surface roughness. Smith[12] presented nomograms (later revised by himself), which related Pasquill stability classes to wind speed and sensible heat flux taking into account estimated surface roughness and wind speed at the reference height of 10 m. Sutherland et al.[13] formulated a semi-empirical expression which relates Pasquill stability category to wind speed and sensible heat flux, through a modified form of the Kazanski-Monin parameter that accounts explicitly for surface roughness. Davidson[14] has given a modified power law representation of the PG coefficients giving an alternative curve to PG graphs. Sedefian & Benett[15], Mitchell[16], Irving[17], Coppalle et al.[18] compared various stability schemes not necessarily proposing that of Pasquill for their specific applications. Draxler[19] experimentally evaluated the accuracy of various diffusion and stability schemes over Washington, D.C.; he found that PGT curves give comparable results to other schemes. Modifications to PGT scheme are also reported for other types of terrain. Hasse & Weber[20] worked on the conversion of Pasquill stability categories over sea. Erbrink & Scholten[21] expressed a new formulation for land and coastal regions in terms of PG stability class indicators. Atmospheric stability has also been studied in complex terrain by various authors (e.g. Hurley[22], Koracin & Enger[23], Synodinou et al.[24], Petrakis et al.[25] examined the application of PGT curves to urban environment and found that they are
still valid). Between the most recent works there is the one by Venkatram[26] who reviewed and commented PGT scheme and extended its curves to include results of surface-layer-similarity studies, extending the work of Golder[11]. He used meteorological parameters such as L (Monin-Obukhov length), \( u^* \) (surface-friction velocity) and \( z_o \) (roughness length) which have to be calculated by other semi-empirical methods (Van Ulden & Holstlag[27]). He presented analytical expressions for only \( \sigma_z \) and demonstrated that PGT curves represent a number of possible vertical curves associated with a surface release. The fact that the most of these modifications are not complete and the usage of non-standard measured meteorological parameters that could introduce more complexity and uncertainties in the determination of stability classes, make PGT method valid in the usual calculations of atmospheric stability conditions. The PGT method also represents the standard basis for comparison, because most applications of local character imply use of this scheme.

There are not a lot of statistical analyses of stability class persistence in the literature. Among them the following works can be cited. Satyanarayana & Agrawal[28] presented the long-term pattern of Pasquill stability categories in the N.E. region of India. Agrawal & Satyanarayana[29] analysed the long-term trend of percentage occurrence of stability classes in the north of India. Viswanadham & Santosh[30] also studied the relation between atmospheric stability and parameters of the surface-boundary layer over S. India. The atmospheric stability in Greece, regarding the Athens basin, has been studied mainly during the last years by Lalas et al.[31], Synodinou et al.[26], Petrakis et al.[27]. A work by Amanatidis & Zerefos[32] can be cited for the Thessaloniki area in N. Greece.

Aim of this paper is to statistically analyse stability conditions in the Athens basin during January and July, the typical months of winter and summer in Greece. A data set of 44-year hourly values of wind speed, solar radiation and cloud cover is used. In the present work Pasquill stability criteria are considered; these criteria are modified in such a way that the climatic conditions of Greece are taken in account.

2 Topography - Data collection

Athens is located in a basin of area about 450 km\(^2\) surrounded on three sides by hills and mountains and at the southern part by the sea with about 3.5 million inhabitants. A great number of industrial activities within Greater Athens Area (GAA), in combination with a high daily
traffic are the main reasons for the serious air quality problems encountered in Athens; such air pollution episodes occur during calm periods in spring and summer.

The meteorological data used in this study is measured at the National Observatory of Athens (NOA, latitude 37° 58' N, longitude 23° 43' E, 107 m a.m.s.l.). NOA is located on the top of the small hill of Nymphs near the city centre 5 km from the coast. The data set comprises 44 years (1953-1996) of mean hourly values of wind speed and total horizontal solar radiation. Cloud cover is measured at NOA three times per day (0800, 1400 and 2000 h LST). These values are considered constant three hours before and three hours after the time of observation, except for that at 2000 h, that is considered valid until 0400 h.

3 Methodology used

The calculation of the stability classes according to Pasquill criteria, using NOA's wind velocity, solar radiation and cloud cover data in the mentioned period, followed a modified formulation proposed by Synodinou & Varsamis[33]. The modification concerns the finer subdivision of wind speed and solar radiation daytime intervals considered in the original Pasquill scheme. According to PGT method two values of stability class for the same interval can often be computed. This can sometimes produce dubious results, because in dispersion calculations one has to be able to define one stability class per interval for further calculations. Moreover, the fact that high amounts of solar radiation are generally received in Greece throughout the year, and big changes in the incoming total solar radiation can be registered in short times, especially during morning hours, dictated the need to further subdivide the solar radiation intervals of the Pasquill scheme. Further, subdivision of wind speed intervals was necessary since large values of solar radiation with small values of wind speed correspond to much more unstable conditions and large values of wind speed with small values of solar radiation correspond to more stable conditions. In this way increased wind speeds and reduced solar radiation values correspond to more stable conditions. The stability classification scheme used in this study is shown in Table 1.

4 Results and discussion

Figure 1 shows the daily variation of the stability categories in January and July. Figure 2 shows the diagram of the mean monthly variation of
Pasquill atmospheric stability categories for January and July. Note that the stability class numbers on the y-axes in both Figures are decimals because of the averaging procedure. The dashed lines in Figure 2 are best

Table 1. Determination of modified stability class PGT scheme; ws is the wind speed in ms\(^{-1}\), R the total horizontal solar radiation in Jcm\(^{-2}\) and CL the cloud cover in octals. In this work the stability categories A-F are referred as numerals in the range 1-6. WS1-WS6 and R1-R5 refer to wind speed and solar radiation intervals used in this work.

<table>
<thead>
<tr>
<th>Intervals</th>
<th>R1</th>
<th>R2</th>
<th>R3</th>
<th>R4</th>
<th>R5</th>
<th>CL ≥ 4/8</th>
<th>CL ≤ 3/8</th>
</tr>
</thead>
<tbody>
<tr>
<td>WS1</td>
<td>A</td>
<td>A</td>
<td>B</td>
<td>B</td>
<td>D</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>WS2</td>
<td>A</td>
<td>B</td>
<td>B</td>
<td>C</td>
<td>D</td>
<td>F</td>
<td>F</td>
</tr>
<tr>
<td>WS3</td>
<td>B</td>
<td>B</td>
<td>B</td>
<td>C</td>
<td>D</td>
<td>E</td>
<td>F</td>
</tr>
<tr>
<td>WS4</td>
<td>B</td>
<td>B</td>
<td>C</td>
<td>C</td>
<td>D</td>
<td>D</td>
<td>E</td>
</tr>
<tr>
<td>WS5</td>
<td>C</td>
<td>C</td>
<td>D</td>
<td>D</td>
<td>D</td>
<td>D</td>
<td>D</td>
</tr>
<tr>
<td>WS6</td>
<td>C</td>
<td>D</td>
<td>D</td>
<td>D</td>
<td>D</td>
<td>D</td>
<td>D</td>
</tr>
</tbody>
</table>

WS1: ws ≤ 2
WS2: 2 < ws ≤ 2.5
WS3: 2.5 < ws ≤ 3
WS4: 3 < ws ≤ 4
WS5: 4 < ws ≤ 6
WS6: ws > 6

R1: R ≥ 50
R2: 50 > R ≥ 37.5
R3: 37.5 > R ≥ 25
R4: 25 > R ≥ 12.5
R5: 12.5 > R

Figure 1. Mean daily variation of stability class during January (solid line) and July (dotted line) in GAA (1953-1996).
fits. It is seen that in January the atmosphere is slightly stable i.e. stabilities just over 4 with an exception for 1994 when mean stability is just less than 4. In July the atmosphere becomes more unstable (stability less than 4), as anticipated. From the best-fitted (dotted) lines in both months an almost 20-year cycle can be detected. This 20-year stability variation may be attributed to the 22-year solar magnetic cycle that can influence some weather parameters.

![Graph showing average annual variation of stability class during January (upper solid line) and July (lower solid line) in GAA (1953-1996).](image)

Figure 2. Average annual variation of stability class during January (upper solid line) and July (lower solid line) in GAA (1953-1996).

The daily variation of the mean atmospheric stability conditions in the Athens area ranges from 2.7 to 5.5 in January and 1.9 to 5.5 in July, as seen from Figure 1. Nighttime stability is about 5.5 (very stable conditions) in both months. Daytime stability "drops" to low values of 2.7 in January and 1.9 in July, i.e. very unstable atmospheric conditions. The time of minimum is different for the two months. Very unstable conditions are reached during winter at around midday and at 0900h LST during summer. This is anticipated; in winter lower temperatures and higher amounts of cloudiness result in less turbulent surface layer, which comes to its highest activity around midday. During summer months higher solar insolation and temperatures combined with clear skies produce high turbulence in the lower layers of the atmospheric boundary layer as early as a couple of hours after sunrise. This situation explains the frequent air pollution episodes occuring during summertime. Unstable air in the lower parts of the troposphere gives rise to temperature inversions, which trap air pollution below.
Neutral stability is achieved in the evening (1700-2000 h LST in the winter and 1900-2000 h LST in the summer). This occurs as the atmosphere turns from unstable to stable conditions. Knowledge of the time of this event is very important to air pollution studies and simulations; most of air pollution modellers consider neutral conditions or near neutral ones throughout the day.

Few similar results to this study are reported in the international literature. Coppalle et al.[18] give a relation of air pollution dispersion parameter relation to Pasquill stability values in urban areas; Satynarayana & Agrawal[28] give the frequency of occurrence of Pasquill stability classes in N.E. India; Agrawal & Kulkarni[10] compare atmospheric stability as determined by various methods; finally Agrawal & Satyanarayana[29] give the diurnal and seasonal frequency of stability class occurrence over N. India.

5 Conclusions

Atmospheric stability is a measurement of tendency to suppress or enhance existing turbulence. Atmospheric stability is related to both wind shear and vertical temperature structure, but it is generally the latter that is used as an indicator of the condition. Atmospheric stability governs the dispersion of the air pollutants. For these reasons, the present study attempted the estimation of the average atmospheric conditions in Athens, a city with air pollution problems, for January and July during a period of 44 years (1953-1996).

The analysis of this work revealed the influence of the 22-year solar magnetic cycle on atmospheric stability. Furthermore, neutral or near-neutral conditions seem to occur in January in general, but certainly in the examined period (except for January 1994 when weakly unstable conditions prevailed). On the contrary, unstable conditions are prevailing in July and generally during summertime.

The daily variation of the atmospheric conditions consists of high values (stable conditions) in the nighttime and low values (unstable conditions) in the daytime. Neutral or near-neutral conditions are expected in the evening when the atmosphere passes from unstable to stable conditions.

References

278 Development and Application of Computer Techniques to Environmental Studies


280 Development and Application of Computer Techniques to Environmental Studies


