WINTER NIGHTTIME TEMPERATURE INVERSIONS AND THEIR RELATIONSHIP WITH THE SYNOPTIC-SCALE ATMOSPHERIC CIRCULATION

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ABSTRACT

The present work aims at examining the association of nighttime temperature inversions and synoptic-scale circulation in the Athens basin. Temperature inversions have a direct impact in the diffusion and transport of pollutants, a fact that highlights the importance of investigating their cause - effect relationship.

For this purpose, randiosonde measurements from the upper-air station in Hellinikon were used to examine the nighttime temperature inversions and surface circulation maps were analyzed in order to classify the synoptic-scale circulation. The period of study is the wintertime days from 2003 to 2010 and the obtained data provide for each inversion its depth in meters along with the corresponding inversion strength in °C.

The classification of atmospheric circulation resulted into 12 circulation patterns (7 cyclonic, 3 anticyclonic and 2 mixed) for a study area covering the greater European region (20° N to 65° N and 20° W to 60° E). The study focuses on the analysis of inversions and circulation patterns frequencies. Inversion days are grouped into categories according to the inversion depth and strength. For each circulation type the frequency distribution of each inversion class is examined and inversion characteristics and mean values are calculated.

It is found that for the 57% of the study period days an inversion is observed and the higher frequencies of occurrence are observed during January. The majority of the inversions are characterized as “shallow” and “weak”, while deeper and stronger inversions are observed during February. Regarding atmospheric circulation, the higher frequencies are observed for the smooth pressure field pattern and particular circulation patterns have higher frequencies for specific months. The association of temperature inversions and synoptic scale circulation shows that the inversion strength is strongly influenced by atmospheric synoptic-scale circulation. The above argument is strengthened by the results of the statistical significance tests and the high mean values of inversion strength for specific circulation types. Conversely, inversion’s depth seems to be independent from atmospheric circulation.

Keywords: Temperature inversions, Atmospheric circulation.

1. Introduction

The study of temperature inversions has always been of great interest due to their ability in inhibiting the vertical motion within the inversion layer. In addition, temperature inversions modulate the pollutants mixing height in the lower troposphere and therefore the examination of the conditions that favor the formation, maintenance and dissipation of temperature inversions is crucial in order to predict air pollution concentrations. Each season presents different inversion characteristics (Kassomenos and Koletsis, 2005) indicating the existence of a connection between inversions and synoptic weather. For example in winter, inversion evolution is forced primarily by synoptic scale circulation (Whiteman *et al*., 1999). Many studies are focused to investigate the cause–effect relationship between atmospheric synoptic conditions and inversions (Hosler, 1961; Prezerakos, 1998; Milionis and Davies, 2008a) while others examine the temperature inversions climatology (Baker *et al*., 1969; Katsoulis 1988; Milionis and Davies, 1992, 1994, 2008b; Nodzu *et al*., 2006; Zhang *et al*., 2011; Kassomenos *et al*., 2014). The present study aims to investigate the association of synoptic conditions and nighttime inversions during winter in a qualitative and quantitative manner.

2. Area of study, data and methodology

The area of study is the Athens basin and temperature inversions are identified from the analysis of Hellinikon upper-air station radiosonde data at 00Z from 2003 to 2010. Hellinikon (37°44΄N, 23°44΄E) is a coastal station situated approximately 300 m from the seashore and 10 km from central Athens at an elevation of 10 m. The inversion characteristics (inversion depth dH and inversion strength dT) are extracted from the IGRA (Integrated Global Radiosonde Archive) database, while the classification of wintertime atmospheric circulation is based on mean sea level pressure maps (MSLP) that cover the greater European area (20°N - 65°N and 20°W - 60°E).

3. Methods

The study is accomplished using a three-step approach. Initially, the temperature inversions are classified according to their characteristics (dH and dT) in four groups respectively (Table 1) and their annual and monthly frequencies of occurrence are analyzed. Additionally, the MSLP fields are classified into distinct circulation patterns based on the location of the high and low-pressure systems and the resulting pressure gradient, focusing on the area of Greece in southeastern Mediterranean. Subsequently the association of temperature inversions and atmospheric circulation is examined from the frequency distributions of dH and dT for each circulation pattern. Finally, the mean and standard deviation of dH and dT are calculated and the ANOVA test is employed in order to test the statistical significance of the results, using the null hypothesis of no difference in the mean values of inversions characteristics for each circulation pattern.

Table 1: Inversion's depth (dH) and strength (dT) classification.

Inversion	Depth (m)	Inversion	Strength (°C)
Shallow	0-50	Weak	0-2
Moderate	50-100	Moderate	2-4
Deep	100-150	Strong	4-6
Very deep	≥150	Very strong	≥6

4. Results

4.1. Temperature inversions

The analysis of the nighttime temperature inversions reveals that at least in half of the winter days an inversion is developed and a uniform monthly frequency distribution is observed (Figure 1a). The classification of the inversions according to the magnitude of dH and dT indicates the prevalence of shallow and weak inversions. In addition, deep and very deep inversions are relatively rare (6% and 4%) a finding also observed for the very strong inversions (Figure 1b and 1c).

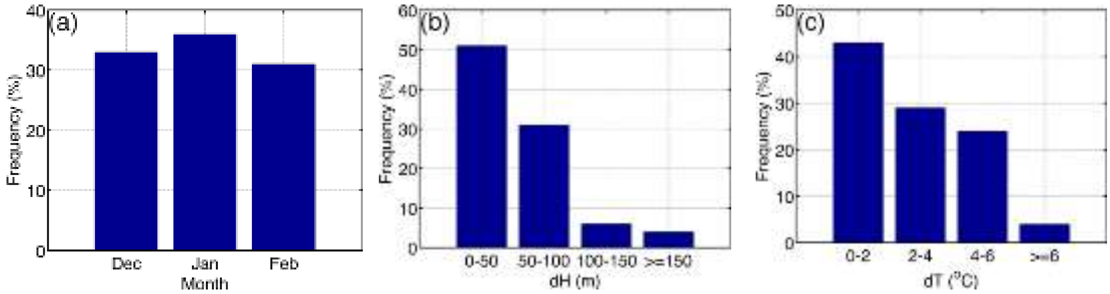

Figure 1: Monthly inversions frequency (a), dH (b) and dT (c) classification frequencies.

4.2. Circulation Pattern Classification

The circulation pattern classification identified 12 patterns, which can be further grouped into 7 cyclonic, 2 anticyclonic, 2 mixed and 1 smooth field pattern. The higher frequency of occurrence is observed for the smooth field pattern (CP12), followed by the CP11 and the CP2, CP4 and CP8 patterns. On the contrary, the lowest frequencies are observed for the cyclonic CP3 and CP5 patterns where the low pressure centre is observed over the Balkans and North Africa patterns respectivly (Table 2).

The analysis of the montly frequencies indicates that specific patterns are favored for specific months. In detail, the CP11 pattern is observed mostly in December (57% of the CP11 days) while the CP2, CP4, CP8 and CP10 occur mainly in January. The CP3, CP5, CP6 and CP9 patterns are favored during February with montlhy frequencies exceeding 55%. Additionally, the CP1, CP7 and CP12 patterns exhibit uniform monthly distributions (Table 2).

Table 2: Description of circulation patterns, overall relative frequency and monthly frequencies of occurrence in percent of each pattern days.

Pattern	Description	Frequency of occurrence			
		Overall	Dec	Jan	Feb
CP1	Low over Northern Italy	8	39	22	39
CP2	Low over Southern Italy or Ionian Sea	9	29	47	24
CP3	Low north of Greece - Balkans	2	29	14	57
CP4	Low over Greece	9	27	43	30
CP5	Low over North Africa	2	17	17	66
CP6	Low over the Netherlands or UK	5	23	18	59
CP7	Low over Baltic sea	8	28	41	31
CP8	High western Mediterranean – Low east of Greece	9	6	56	38
CP9	Low western Mediterranean – High east of Greece	4	21	22	57
CP10	High over eastern Europe	7	36	60	4
CP11	High over central Europe – Low over Cyprus	10	57	30	13
CP12	Smooth Pressure Field	27	40	31	29

4.3. Association of inversions and circulation patterns

The frequency distributions of inversions' dH classification for each circulation pattern are presented in Figure 2a. The analysis reveals that the CP2-CP6, CP9 and CP10 patterns do not include very deep inversions and the CP3, CP5 and CP9 patterns do not include deep inversions. For the CP1, CP2, CP4 and CP6 patterns high rates of shallow inversions (up to 65%) and significant levels of moderate inversions (up to 41%) are observed, while for the CP5, CP7, CP11 and CP12 the lowest frequencies of shallow inversions are denoted. Regarding the inversion dT per circulation pattern (Figure 2b), the CP1-CP6 and CP9 patterns do not include very strong inversions and the CP7, CP9, CP12 exhibit similar distributions with low frequencies for weak inversions (below 28%) and high percent of days characterized by strong inversions (36% up to 41%). Finally, moderate inversions prevail for the CP5, CP6 and CP9 patterns while high frequencies of weak inversions are observed for the CP1-CP4, CP10 and CP11 patterns.

The mean values of dH and dT for each circulation pattern are presented in Table 3. The highest mean dH is calculated for CP7, followed by CP12 and CP8 (greater than 70 m) and CP1 and CP11. The lowest mean dH values are observed for the CP3 and CP10 patterns. Regarding the mean dT for each pattern, the highest value is observed for the smooth field pattern (CP12), followed by the CP7, CP8 and CP9 patterns (from 3 °C to 3.2 °C), while the lowest mean dT values are calculated for the CP4 and CP10 patterns. Finally, the ANOVA results, reveled statistical significant differences for the dT mean values and non-significant differences for the mean dH values for each circulation pattern.

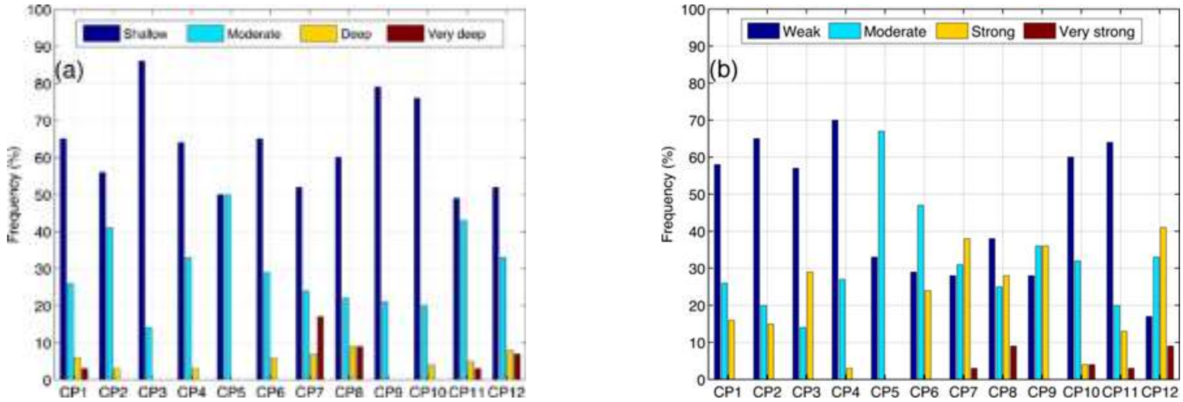

Figure 2: Frequency distribution of dH (a) and dT (b) for each circulation pattern.

Table 3: Mean and standard deviation values of the inversion's characteristics for each circulation pattern

Circulation Pattern	$\overline{dH}$ (m)	σ_{dH} (m)	$\overline{dT}$ (°C)	σ_{dT} (°C)
CP1	64,19	108,46	1,981	1,430
CP2	47,50	24,38	1,932	1,512
CP3	33,57	15,93	2,286	1,599
CP4	45,82	25,52	1,550	1,061
CP5	44,83	16,79	2,033	0,795
CP6	48,00	25,21	2,529	1,133
CP7	133,97	271,14	3,103	1,656
CP8	73,94	99,10	3,053	1,931
CP9	46,21	18,35	3,157	1,598
CP10	38,92	24,79	1,804	1,389
CP11	56,38	36,40	1,913	1,556
CP12	76,16	112,55	3,746	1,628

5. Conclusions

The aim of this work is to analyze synoptic scale circulation through its classification in circulation patterns and inversion activity through its characteristics classification with a final goal to investigate their pronounced causal relationship. Atmospheric circulation in the lower troposphere strongly affects dT. Based on the study results, statistical significant differences are observed for the mean dT values of each pattern. For example for days where a cyclonic pattern such as CP4 is followed by a smooth field pattern the expected inversion dT is at least 1°C higher. Future work could be focused in finding the factors that affect dH and also isolate-quantify the amount of dT for a given inversion layer which is attributed to the existence of a specific synoptic-scale circulation pattern.

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