CLIMATIC VARIATIONS IN THE MOISTURE AND INSTABILITY PATTERNS OF THE ATMOSPHERIC BOUNDARY LAYER ON THE EAST MEDITERRANEAN COASTAL PLAIN OF ISRAEL

Research Note

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Abstract. A long-term record (1964–1995) of radiosonde data observed at the Bet-Dagan aerological station of the Israel Meteorological Service was analyzed to detect possible temporal trends in moisture content and instability of the atmospheric boundary layer. Bet-Dagan is situated in the central part of the south-east Mediterranean coastal plain. During this period surface characteristics in this region have changed drastically due to changes in land use, i.e., urbanization, development of irrigated agriculture and afforestation. The analysis of the radiosonde data reveals a clearly defined, statistically significant, increasing trend in the moisture content, mainly during summer. The stability of the surface layer, characterized by the bulk Richardson Number, shows a decreasing trend since the early 1960s. Relationships between these trends, land-use modifications and possible influence of large-scale influence are discussed.

Keywords: Bulk Richardson Number, Instability, Radiosonde data, Virtual potential temperature.

1. Introduction

Surface characteristics impact on the daytime evolution of instability of the planetary boundary layer (PBL) and the potential for deep convection. Studies have shown that the structure and the dynamics of the PBL are highly sensitive to surface properties, i.e., soil moisture, vegetation cover, surface roughness, albedo and thermal capacity. Extensive changes in land use may have affected surface properties, thus influencing mesoscale atmospheric circulation and promoting the development of deep convection (Pielke et al., 1992; Segal, 1995).

Since the early 1960s extensive changes in land use took place in Israel, especially in the central and southern Mediterranean coastal plains. The rapid growth of population density, extended urbanization, cultivation under intensive irrigation and afforestation have led to drastic changes in surface reflectivity, soil moisture, Bowen ratio and surface roughness. A number of observational studies carried out recently in Israel have indeed shown some changes in climatic characteristics, which, presumably, might be related to changes in surface properties (Alpert and Mandel, 1986; Ben-Gai et al., 1994, 1998). Based on the above changes of surface properties in Israel's coastal plain, two numerical simulation studies, on the effect of land use changes in southern Israel on the local climate, were carried out by deRidder (1997) and Perlin and Alpert (1999).

In the present study, the Bet Dagan (see Figure 1) long term record of radiosonde data was analyzed to detect temporal changes and trend patterns in atmospheric moisture and instability of the PBL, as well as of the stability of the surface layer.

2. Database and Methodology

The data set covers a period of 32 years (1964–1995) and consists of daily soundings carried out at 1100 GMT (1300 LST) in Bet Dagan, the site of the aerological station of the Israel Meteorological Service, located 7 km from the Mediterranean shoreline, 35 m above MSL. The data record consists of temperature, relative humidity, geopotential height, wind velocity and direction at the surface level and at the standard pressure levels of 1000, 850 and 700 mb.

Long term radiosonde data sets may suffer from inhomogeneities and discontinuities due to changes in equipment (sensors and/or receiving equipment) and in data processing procedures. The data must, therefore, be carefully traced for such discontinuities, and corrected, if necessary, especially for trend analysis (Gaffen, 1994). A non-parametric technique for checking radiosonde data for discontinuities was applied (Lanzante, 1996).

2.1. Computational procedure and trend analysis

Trend patterns of air temperature, relative humidity and wind velocity at the above mentioned standard levels for each month of the year and for the whole period of the record were calculated. Additional parameters characterizing the moisture content, instability of the PBL and the stability of the surface layer were also calculated (Stull, 1988; Grell et al., 1993). These are the mixing ratio, virtual potential temperature and Bulk Richardson Number, defined according to Grell et al. (1993: pp. 86–89), as

$$R_B = \frac{g z_a}{\theta_a} \frac{\theta_{va} - \theta_{vg}}{w^2}, \tag{1}$$

where

$$w = \sqrt{(w_a)^2 + (w_c)^2}. \tag{2}$$

In convective conditions, the convective velocity in m s^{-1},

$$w_c = 2\sqrt{(\theta_g - \theta_a)}, \tag{3}$$

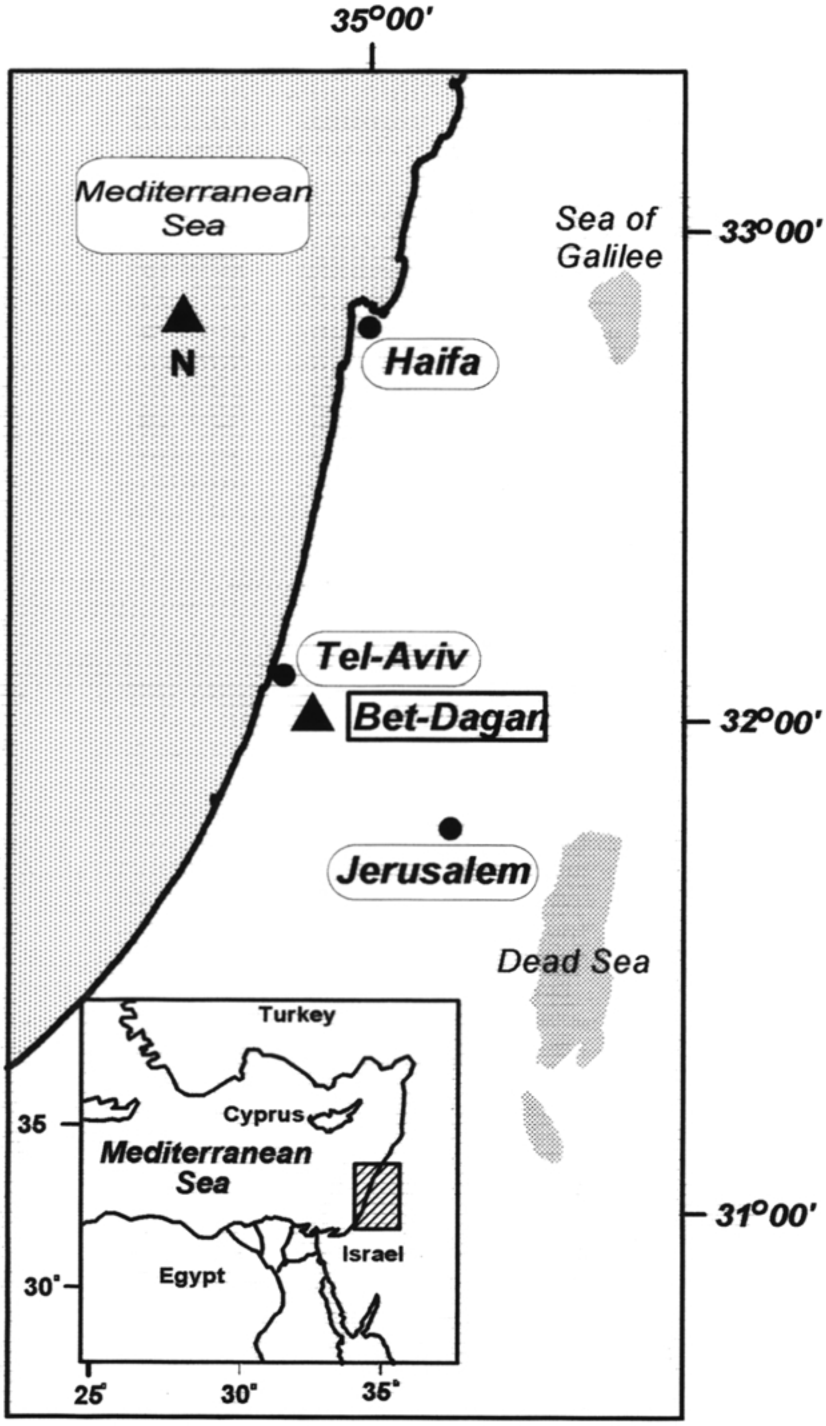

Figure 1. Location of the Bet-Dagan station.

while it is zero under stable conditions. It is important in low wind speeds. The other parameters are defined as; g, acceleration of gravity (m s^{-2}); z_a, geopotential height at 1000 mb (m); θ_{va}, virtual potential temperature at 1000 mb (K); θ_{vg}, virtual potential temperature at ground level (K); θ_a, potential temperature at 1000 mb pressure level (K); w_a, horizontal wind velocity at 1000 mb pressure level (m s^{-1}).

The bulk Richardson number, which was selected to represent the stability of the lower boundary layer (surface to 1000 mb), is accepted for calculation of the instability of the PBL (surface pressure, in more than 99.5% of the days at Bet Dagan, is higher than 1000 mb). The above selected parameters are obviously affected by surface properties. Considerable changes in these properties over a relatively long period of time should be reflected in the trend patterns of these parameters, though one can not exclude external forcing effects.

The observed and calculated PBL parameters, from the surface to the 700 mb pressure level, were tested for trends by linear serial regression analysis as functions of time t throughout the study period, 1964–1995. The statistical significance of the trend slopes were assessed at the 0.05 significance level.

3. Results

The long-term trend patterns of the various parameters are represented by histograms of the slopes of fitted serial linear regression lines.

3.1. Mixing ratio

The moisture content of the PBL (Figure 2a) shows an increasing tendency at all levels during the warm season, with the highest positive trend observed at the 850 mb pressure level during the summer. During the winter season, a negative tendency is observed at the surface layer, with a slightly positive trend at the higher levels. All trend patterns of the mixing ratio during the summer months were found statistically significant at the 0.05 1evel except for the surface layer (Table Ia).

3.2. Wind velocity

An appreciable decreasing trend in monthly mean wind speed is noticed, at all standard levels of the PBL under consideration, mostly at the higher levels during the cool season (Figure 2b). February, July and August show an increasing trend at the surface. Slopes were found statistically significant in most cases (Table Ib).

3.3. Virtual potential temperature

The temporal trend patterns of the virtual potential temperature profile in the PBL are seasonally opposing: increasing during the warm season, and decreasing during the cool season, with the exception of January (Figure 2c). The trends show

TABLE I

Trend values per decade for the surface and standard levels of 1000, 850 and 700 mb for each month of (a) mixing ratio r in g/g $\times 10^{-5}$; (b) wind speed w in m s^{-1}; (c) Virtual potential temperature θ_V in K; (d) bulk Richardson Number (R_B), between the surface and the standard level of 1000 mb. The significance at 0.05 level of the trends is marked by bold numbers. Trend analysis is based on 1964–1995 Bet Dagan radiosonde data in Israel.

(a)

Month	r_{surf}	r_{1000}	r_{850}	r_{700}
1	−9	3	**19**	**13**
2	**−14**	**−14**	**16**	10
3	10	**15**	**27**	**16**
4	3	**16**	**22**	**20**
5	8	**25**	**36**	**29**
6	8	**28**	**45**	**35**
7	**13**	**35**	90	42
8	**29**	**57**	**66**	**47**
9	**18**	**45**	**45**	**32**
10	6	**36**	**38**	**27**
11	**−17**	6	**11**	**11**
12	−10	5	**15**	**9**

(b)

Month	w_{surf}	w_{1000}	w_{850}	w_{700}
1	−0.03	**−0.03**	**−0.36**	**−0.60**
2	0.15	0.00	0.00	**−0.39**
3	**−0.18**	**−0.30**	**−0.60**	**−0.75**
4	**−0.27**	**−0.30**	−0.30	−0.36
5	**−0.12**	**−0.24**	0.00	0.00
6	0.00	**−0.14**	0.00	0.00
7	**0.21**	**0.09**	**−0.18**	**−0.30**
8	**0.09**	0.00	**−0.18**	−0.18
9	**−0.18**	**−0.18**	**−0.27**	−0.06
10	**−0.12**	**−0.21**	**−0.21**	**−0.30**
11	0.00	**−0.15**	−0.15	**−0.36**
12	**−0.27**	**−0.33**	**−0.39**	−0.51

(c)

Month	$\theta_{v\,surf}$	θ_{v1000}	θ_{v850}	θ_{v700}
1	**−0.23**	−0.07	**0.24**	**0.90**
2	**−0.54**	**−0.36**	**−0.39**	**−0.39**
3	**−0.54**	**−0.45**	−0.15	0.012
4	0.24	0.06	**0.51**	**0.60**
5	0.09	0.00	**0.42**	0.39
6	0.00	**−0.18**	**0.36**	**0.42**
7	**0.12**	0.00	**0.21**	**0.30**
8	**0.11**	−0.03	**0.36**	**0.54**
9	**0.27**	0.12	**0.60**	**0.60**
10	**0.36**	**0.27**	**0.51**	**0.54**
11	**−0.27**	**−0.27**	−0.06	0.15
12	**−0.23**	**−0.23**	−0.05	0.05

(d)

Month	R_B
1	−0.020
2	**−0.027**
4	**−0.021**
5	**−0.018**
6	**−0.024**
7	−0.003
8	**−0.015**
9	**−0.024**
10	**−0.027**
11	−0.009
12	**−0.23**

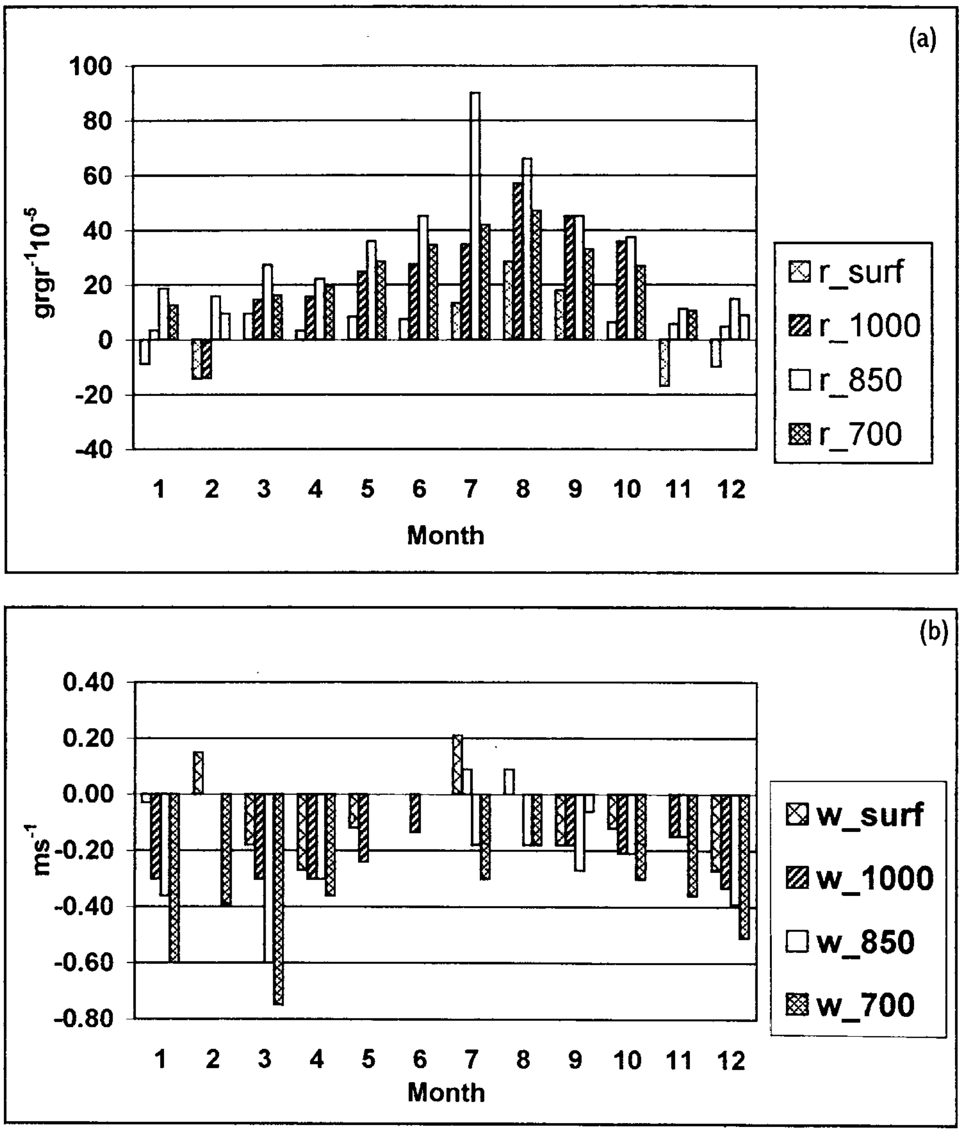

Figure 2. Histograms of the trend values per decade at the surface and standard levels of 1000, 850 and 700 mb of: (a) Mixing ratio r in g $g^{-1} \times 10^{-5}$; (b) wind speed w in m s^{-1}; (c) virtual potential temperatures θ_V in K; (d) bulk Richardson Number, between the surface and the standard level of 1000 mb.

nearly the same magnitude for all summer months, except for July. The statistical significance of the trend slopes of the virtual potential temperature at the 0.05 level is also indicated in Table Ic.

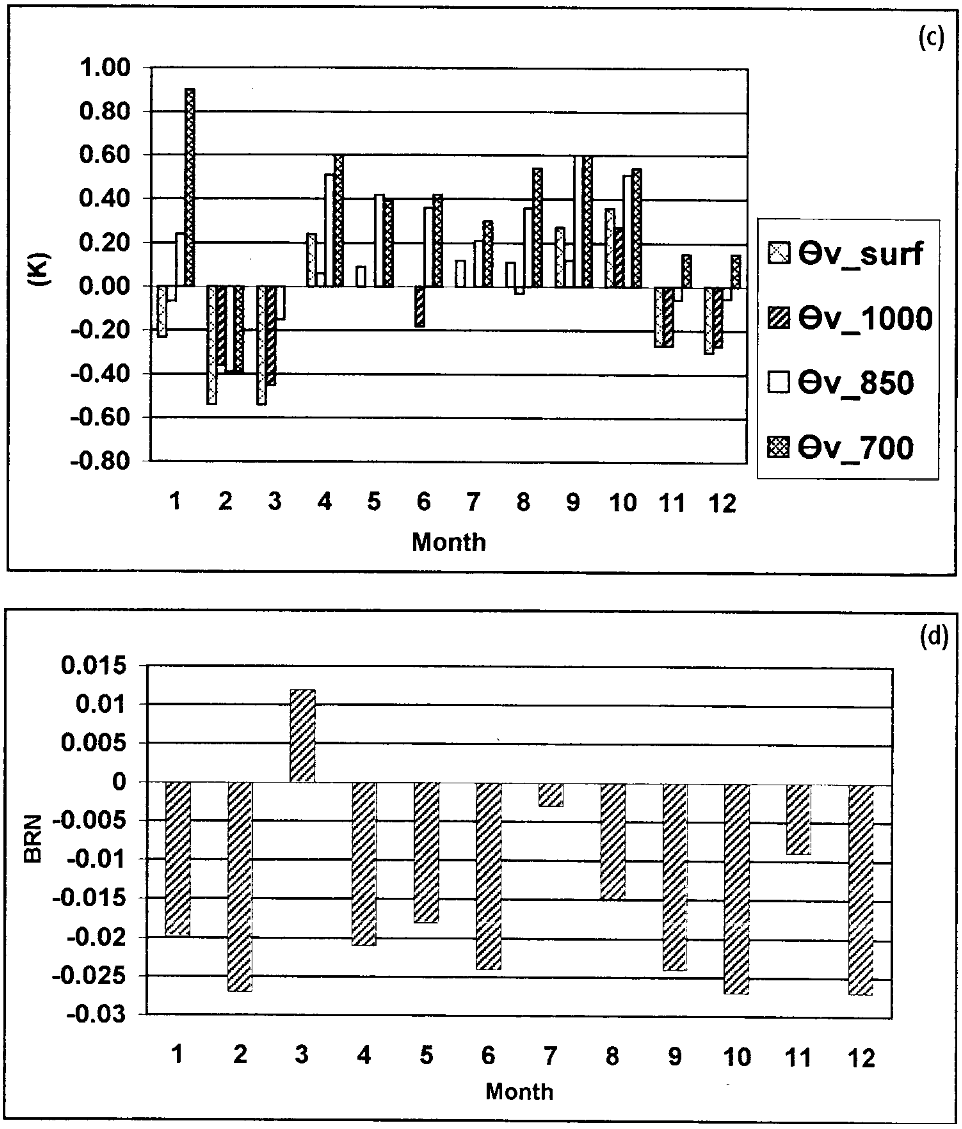

Figure 2. Continued.

3.4. BULK RICHARDSON NUMBER

Increasing instability of the daytime surface boundary layer between the surface and 1000 mb pressure level is expressed by the decreasing trend of R_B (Figure 2d). This trend seems to be explained by the different trend patterns of the virtual potential temperature which determine the buoyancy term, and the wind speed which determines the mechanical term (Equations (1)–(3)). During winter months, the virtual potential temperature shows a stronger decreasing trend at the surface than at 1000 mb, while wind velocity decreases more at 1000 mb than at the surface. The opposite occurs in the summer. In any case during the winter (except for March) and during summer, R_B is negative.

4. Summary

The results of this study show significant temporal changes in the parameters defining the moisture content, wind velocity and the instability at the bottom of the PBL in Bet Dagan radiosonde data. Moisture content has increased and wind velocity has decreased, especially at the upper pressure levels, resulting in increased instability and more favorable conditions for convection. These results are in agreement with the models of deRidder (1997) and Perlin and Alpert (1999) and with observational studies (Alpert and Mandel, 1986; Ben-Gai et al., 1994, 1998; Mandel, 1986).

These changes seem to be partly the result of the increase in evaporation due to land use changes that took place in the central and southern coastal plains in Israel during the last decades. Enhanced irrigated cultivation, decreases in albedo and increases in surface roughness lead to increased net radiation balance available to the surface. The direct effect of the increased surface evaporation is to destabilize the atmosphere with respect to deep convection. The tropospheric heating associated with this enhanced deep convection further enhances the convection, which triggers a positive feedback. However, it should be stated that the pronounced changes found also at the 850 and 750 mb levels which are frequently above the PBL, suggest that large scale climate change took place. This requires further study, involving comparisons with radiosonde trends in neighboring countries.

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