Ozone Concentration Profiles in the Los Angeles Basin—A Possible Similarity in the Build-up Mechanism of Inland Surface Ozone in Israel

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ABSTRACT

This paper analyzes some measurements of the Southern California Air Quality Study, which collected a comprehensive air quality, meteorological, and emissions database in the Los Angeles Basin. This analysis emphasizes the interaction of the enriched ozone layer existing aloft with the top of the convective boundary layer (CBL) in the early afternoon of warm summer days, leading to downward mixing (fumigation) of the ozone cloud toward the ground. This process was shown to contribute to the high ozone concentrations measured at inland elevated sites. It is suggested that this mechanism also exists in Israel and contributes to the elevated concentrations observed in the summer on the slopes of the Judean Hills. This analogy is based on the similarity between the Los Angeles Basin and central Israel regarding the climate, the local circulation (sea breeze), the orientation of the coast, and the upwind location of ozone precursor sources. The temporal fluctuations of the synoptic configuration persisting over Israel during the summer cause rapid variations in the depth of the CBL inland and its subsequent interaction with an ozone layer aloft.

1. Introduction

Although a trend of decreasing ambient ozone concentrations has been reported in the last decade in the United States (EPA 1993), this secondary pollutant has been recognized in recent years as affecting not only urban areas, but also rural areas on a regional and even global scale (Liu et al. 1987). The concentration dynamics of ozone are significantly influenced by transport processes within the atmospheric boundary layer, resulting in elevated concentrations at considerable distances from urban centers of industrialized countries (Kelly et al. 1986). At times, rural daily average ozone concentrations can even exceed the concentrations measured at upwind urban sites (Eder et al. 1993).

The Southern California Air Quality Study (SCAQS) has undertaken some detailed analyses of the air quality and meteorology of the Los Angeles Basin to improve understanding of the formation mechanism of upper-air ozone concentrations, as well as their transport and impact on surface sites (Roberts and Main 1992). Lawson (1990) presents a comprehensive overview of SCAQS, describing the participating organizations, the field measurements performed, and the sampling locations. An extensive quality assurance program was an integral part of the study (Fujita and Collins 1989). The field study was performed in 1987 and consisted of 11 intensive sampling days in the summer and 6 in the fall.

This paper will analyze some measurements of the SCAQS and suggest a possible analogy between the build-up mechanism of inland surface ozone in Israel and the mechanism existing in to southern California, due to the similarities between both regions (Mediterranean climate, sea breeze, and terrain features). Jehuda Neumann, the pioneer of air pollution meteorology in Israel, was the first to compare the coastal plain of Israel to the Los Angeles region in respect to air pollution (Neumann 1973).

Transport of ozone from the coastal urban area inland was suggested by Steinberger (1980) as one of the mechanisms leading to the high ozone levels often measured during the summer in the Judean Hills around Jerusalem. Furthermore, transformation of ozone precursors within the plume, during its travel from the coast inland under intense solar radiation, was demonstrated by Luria et al. (1984) and confirmed by Lifshitz et al. (1988). Local photochemical generation in a moving plume was also shown to make a substantial contribution in the Detroit metropolitan area (Kelly et al. 1986).

2. Method

Based on the detailed database generated from the extensive SCAQS, four summer days were selected in which surface ozone concentrations exceeded the U.S. National Ambient Air Quality Standard (120 ppb). Concurrent measurements of upper-air meteorological parameters and both aloft (by aircraft) and surface

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ozone measurements were analyzed for three time periods (early morning, midday, and afternoon) during these days. The meteorological measurements included temperature and wind (direction and speed) profiles at six sites lying approximately along a west–east cross section in the Los Angeles Basin (Fig. 1). Profiles of ozone concentration were measured by means of an instrumented aircraft along vertical spirals, between 30 m above ground level and 1500 m above mean sea level, with a 30-m resolution (Roberts and Main 1992). Ozone was measured at six sites along the same cross section, located close to the former sites. A list of the different sites is presented in Table 1.

Since measurements obtained for the four analyzed days show similar characteristics, results will be presented for one representative day. Profiles of ozone concentrations will be displayed as contour lines along the cross section in the Los Angeles Basin.

3. Results

Ozone profiles are presented for three time periods on 25 June 1987: early morning (Fig. 2a), midday (Fig. 2b), and afternoon (Fig. 2c). Concurrent wind profiles are displayed in the same figures, as well as the base and the top of the stable layer aloft (in broken lines), as determined from the temperature profiles. The meteorological and ozone measurements depicted in the figures are instantaneous observations at times within the three 2-h time periods.

In the early morning, high concentrations of ozone generated during the previous day exist in an approximately horizontal layer confined within the stable layer (Fig. 2a). The centerline of the ozone cloud, with concentrations exceeding 250 ppb, is observed at 800–900 m above mean sea level. The base of the stable layer is approximately parallel to sea level, leading to a shallow mixing depth above the Cable Airport Ponoma (CAB) site, which is located in the foothills of the mountains. Weak winds from a continental (easterly) origin are observed above most locations.

Later on, as a result of the increased surface sensible heat flux, the inland boundary layer inflates, reaching its maximum thickness during midday (around 250 m at the CAB site) (Fig. 2b). The inflation rate of the mixed layer increases with distance from the ocean, and its top approximately follows the terrain. When the top of the mixed layer reaches the ozone cloud, the cloud bottom is within a turbulent atmosphere, and part of it is entrained by convective currents toward the ground. The horizontal structure of the ozone layer is disturbed, and the resulting downward mixing contributes to the surface concentrations above 150 ppb, as measured at the Riverside Municipal Airport (RAL) site.

In the afternoon, the top of the mixed layer intersects the cloud centerline above the CAB site (Fig. 2c), enabling further fumigation of the enriched ozone layer toward the ground. Since westerly winds prevail during the afternoon, freshly produced ozone is transported from the urban core and probably also contributes to the concentrations exceeding 200 ppb, as measured at CAB.

4. Discussion

Concurrent measurements of meteorological parameters and ozone concentrations performed by SCAQS over the Los Angeles Basin allowed the existence of an enriched ozone layer aloft and its interaction with the top of the mixed layer to be revealed. Fumigation of the cloud in the early afternoon of warm summer days is, therefore, expected to contribute to the high ozone concentrations measured at inland elevated sites, as supported by previous studies, which estimate the contribution of the downward mixing from 30–40 ppb (McElroy and Smith 1992) to 80 ppb (Lu 1994).

An argument will here be made that a similar mechanism exists in Israel and is one of the contributors to the elevated concentrations (120–130 ppb) often measured in the summer on the slopes of the Judean Hills (Peleg et al. 1994). The analogy is based on the following features.

(a) The climate of both regions is defined as Mediterranean, characterized by a warm summer season during which ozone episodes are recorded.

(b) The solar radiation is intense during the summer in both regions, as expressed for instance by an average of over 7 kW h m^{-2} for the month of July (WMO 1981).

(c) In both cases, the land is situated east of the sea, and the topographical west–east cross sections are alike.

(d) Major stationary emission sources of ozone precursors are located along the coast in Israel and in the vicinity of the ocean in the Los Angeles Basin. Although mobile emission sources are distributed relatively uniformly across the Los Angeles Basin (Fujita et al. 1992) and in the coastal urban area in central Israel, most sources of both types are situated upwind of the elevated terrain.

(e) A marine inversion is persistent during the summer above both regions (Holzworth 1967; Neumann 1973), formed by the interface between two air masses (a cool and humid mass above ground capped by warmer and subsiding dry air).

(f) The land and sea-breeze circulation is an almost daily feature in the summer, both in southern California and Israel. This circulation leads to a similar diurnal behavior of the mixed layer as a function of the distance from the seashore (Neumann 1952; Halevy and Steinberger 1974; Dayan et al. 1988).

(g) An ozone layer exists aloft in the summer above the Judean Hills, as recently detected by Peleg et al. (1995), as well as above the Los Angeles Basin, as found in SCAQS.

In light of those features, one can assume that downward mixing (fumigation) of an elevated layer can also

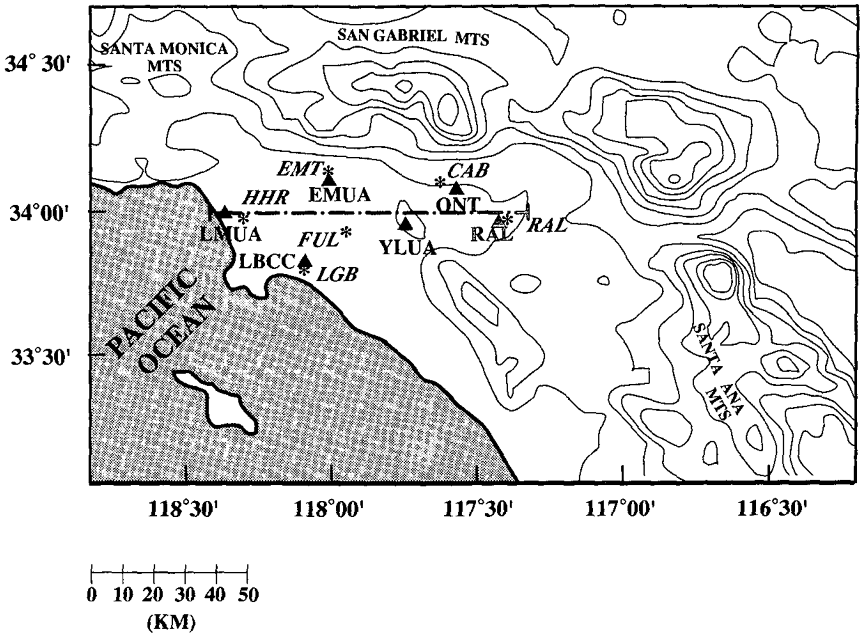

Fig. 1. Southern California Air Quality Study—meteorological and ozone (italics) upper-air sites in the Los Angeles Basin.

contribute to inland ground concentrations in Israel, in addition to the two mechanisms already mentioned (transport and transformation of precursors within the plume). Based on this premise, we will propose a theoretical description of the cyclic mechanism existing during the summer, which leads to the impact of an elevated cloud of ozone on the ground in the Judean Hills around Jerusalem, as illustrated in Fig. 3.

During the summer a main synoptic pattern prevails over Israel, in which a pressure gradient is formed between the barometric trough originating from the Persian Gulf and the subtropical ridge that extends from the central Mediterranean along the African coast toward Israel (Dayan 1986). The resulting flow is westerly, as is the sea breeze. Day-to-day fluctuations of this pressure gradient govern the mixed-layer thickness and its rate of penetration inland. Deepening of the pressure gradient intensifies the resultant westerly winds, whereas its shallowing weakens the gradient winds and leaves the sea breeze as the main contributor. Whenever a steep pressure gradient builds up, the strong westerly winds act as a weak cold front (Fig. 3, panel A1) and penetrate

Table 1. The SCAQS meteorological and ozone measurement sites.

Code	Site name	County	Location
Meteorological sites			
LMUA	Loyola Marymount University	Los Angeles	33°59'N, 118°25'W
LBCC	Long Beach City College	Los Angeles	33°50'N, 118°08'W
EMUA	El Monte—9528 Telstar	Los Angeles	34°04'N, 118°04'W
YLUA	Yorba Linda County Park	Orange	33°56'N, 117°46'W
ONT	Ontario International Airport	San Bernardino	34°03'N, 117°36'W
RAL	Riverside Municipal Airport	Riverside	33°57'N, 117°27'W
Ozone sites			
HHR	Hawthorne Municipal Airport	Los Angeles	33°55'N, 118°20'W
LGB	Long Beach—Daugherty Field	Los Angeles	33°49'N, 118°09'W
EMT	El Monte Airport	Los Angeles	34°05'N, 118°02'W
FUL	Fullerton Municipal Airport	Orange	33°52'N, 117°59'W
CAB	Cable Airport—Pomona	Los Angeles	34°07'N, 117°41'W
RAL	Riverside Municipal Airport	Riverside	33°57'N, 117°27'W

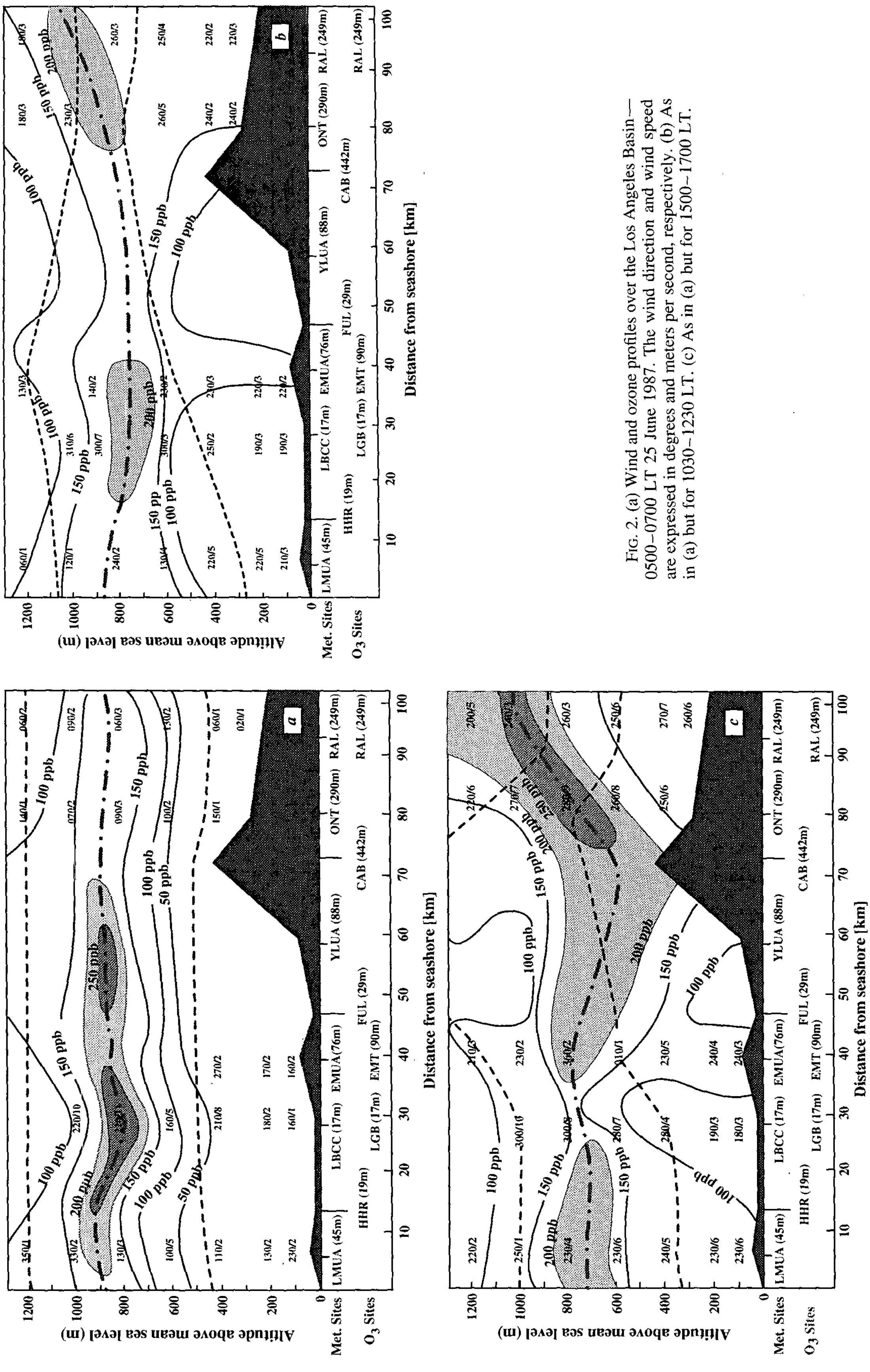

FIG. 2. (a) Wind and ozone profiles over the Los Angeles Basin—0500–0700 LT 25 June 1987. The wind direction and wind speed are expressed in degrees and meters per second, respectively. (b) As in (a) but for 1030–1230 LT. (c) As in (a) but for 1500–1700 LT.

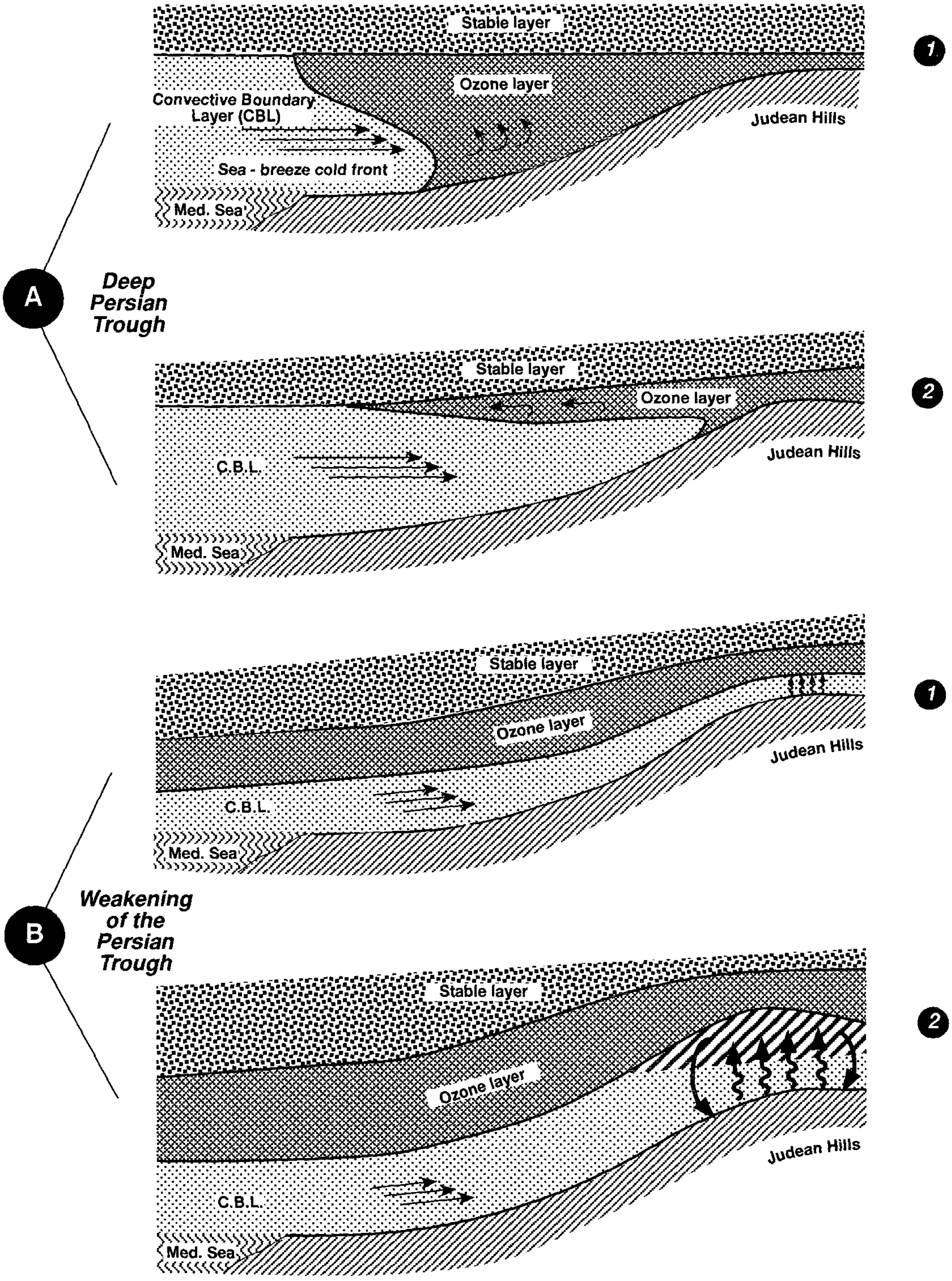

FIG. 3. Schematic drawing of the proposed mechanism causing ozone fumigation inland in Israel: (A1) weak cold front pushing inland, (A2) undercutting and lifting of the enriched ozone layer, (B1) rapid inflation inland of the reduced convective boundary layer (CBL), and (B2) penetration of the inland inflated CBL into the ozone layer and ozone fumigation toward the ground.

far inland, undercutting the mixed layer polluted by ozone from the previous day (Fig. 3, panel A2), as is also mentioned in SCAQS for the Los Angeles Basin. In this way part of the mixed layer containing ozone is pushed upward and is isolated from the ground. If the pressure gradient weakens on the following day due to a synoptic development, the westerly winds weaken. The cooling effect of the cold and moist air from the sea is consequently reduced, and the convective boundary layer inflates rapidly (Fig. 3, panel B1). A typical rate of inflation at midday in the summer in Jerusalem is 400 m per hour, as measured by means of a lidar system (Hashmonay et al. 1991). When the top of the mixed layer reaches the elevated ozone cloud, the latter is penetrated by convective currents (Fig. 3, panel B2), and parts of the cloud are entrained toward the ground in a fumigation process (Venkatram 1977).

Although the cyclic mechanism described above has yet to be confirmed by further measurements of temperature and ozone profiles, it relies on the well-known temporal fluctuations of the synoptic configuration observed over the region and helps to provide a comprehensive explanation for the elevated concentrations of ozone often measured inland during the summer.

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