Thermally Driven Gap Winds into the Mexico City Basin

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ABSTRACT

A southeasterly flow in the form of a low-level jet that enters the Mexico City basin through a mountain gap in the southeast corner of the basin developed consistently in the afternoons or early evenings during a four-week 1997 winter field campaign. Peak wind speeds often exceeded 10 m s^{-1}. Although these winds have not been studied previously, the observations suggest that they are a regular feature of the basin wind system, at least during the winter months. The jets were found more frequently during the early part of the experiment, when conditions in the basin were generally warmer, drier, and less cloudy, than in the later part when conditions were cooler, more humid, and cloudier. The winds usually were stronger during the early period, also. Temperature measurements from radiosondes launched inside and outside the basin showed a dependence of the gap wind strength on the temperature differences between the two regions. A three-dimensional numerical model was used to simulate the characteristics of the gap flows to provide information on the mechanisms responsible for their development. The maximum speed of the jet usually is reached several hours after the occurrence of the maximum temperature gradient between the basin and the region to the south. An analysis of the momentum balance shows that the gap wind is initiated by a north–south pressure gradient across the gap in the lower boundary layer arising from temperature differences between the warmer basin and the cooler exterior air. Penetration of the gap wind into the basin is caused primarily by horizontal advection. The gap wind plays an important role in the formation of a convergence zone, which can have an important effect on surface air pollutant distributions in the basin.

1. Introduction

Gap winds can be defined as winds that blow through mountain passes or in topographically confined channels and generally occur whenever a pressure gradient is directed from one side of the pass or the channel to the other. Gap winds have been observed in many places; examples include the Strait of Juan de Fuca (Overland and Walter 1981), the Shelikof Strait on the Pacific coast of Alaska (Lackmann and Overland 1989), Howe Sound in British Columbia (Jackson and Steyn 1994), the Fraser River gap near the border between British Columbia and Washington (Mass et al. 1995), Lake Tornetrask in a mountainous area of northern Sweden (Smedman et al. 1996), and the Chivela Pass region in Mexico (Steenburgh et al. 1998). These winds are typically the result of channeling of large-scale flows by the underlying topography and are driven by pressure gradients across mountain barriers that are associated with synoptic systems. They are often characterized by moderate to strong wind speeds (~12–45 m s^{-1}). A different form of gap winds in Japan has been described by Kimura and Kuwagata (1993). These winds appear as part of plain-to-basin wind systems: the Kanto Plain–to–Saku Basin system that is driven over a mountain pass and the Sendai Plain–to–Fukushima Basin system that flows through a valley. These winds are thermally induced and their speeds tend to be more moderate. The Kanto Plain–to–Saku Basin system also is an important mechanism for the transport of air pollutants from coastal areas to inland regions. Synoptic pressure gradients and mesoscale thermal effects can combine to contribute also to the formation of gap winds. A notable example is found in the Columbia River Gorge when heating or cooling of the inland Columbia Basin relative to the coastal areas to the west of the Cascade Range may enhance the flow associated with synoptic pressure gradients (e.g., Reed 1981).

This paper uses observations and numerical modeling to describe some of the characteristics of a gap wind system in the southeastern corner of the Mexico City basin that produces low-level jets and that occurs regularly during the late winter. The available evidence suggests that these winds are generated primarily by temperature differences between the basin and the exterior environment, similar to the wind systems studied by Kimura and Kuwagata (1993). Although the Mexico City gap wind is apparently a regular feature, it does not seem to have been studied prior to the investigations

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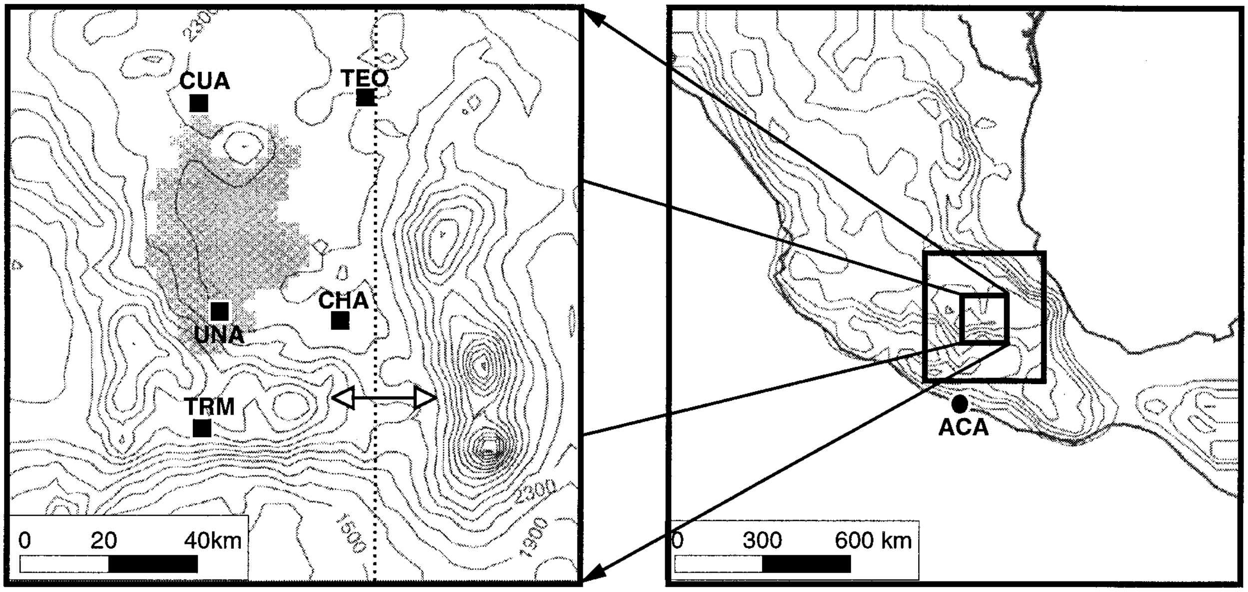

FIG. 1. Topographic map of Mexico and the Mexico City region. The map on the left shows the metropolitan area (shaded), the locations of the four radar wind profiler and radiosonde sites (CUA, TEO, UNA, and CHA) in the basin, the mountain gap south of Chalco (arrow), and the radiosonde site south of the basin (TRM). The dotted line is a cross section along which simulated potential temperature and winds are displayed in Fig. 10. The map on the right shows the nested modeling domains used for the mesoscale modeling described in section 4. ACA denotes Acapulco, from which rawinsondes were launched.

reported here. Its presence was first suggested by computer simulations used to design a measurement network for the experimental campaign described below.

2. Observations

From 23 February to 23 March 1997, a meteorological field campaign sponsored by the U.S. Department of Energy and the Instituto Mexicano del Petróleo was conducted in the Mexico City basin to provide information about boundary layer structure and evolution in

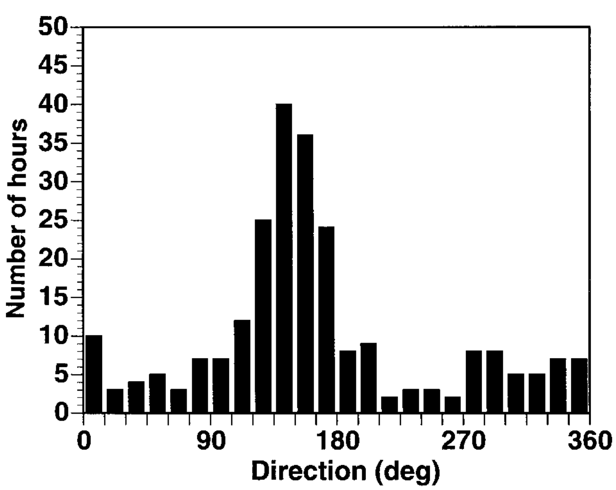

FIG. 2. Distribution of hourly mean wind directions at 144 m AGL at Chalco for 23 Feb–23 Mar 1997.

the vicinity of Mexico City (Doran et al. 1998). Hourly boundary layer wind profiles were obtained from four 915-MHz radar profilers located on the periphery of the basin (Fig. 1) at Chalco (CHA), Universidad Nacional Autónoma de México (UNA), Teotihuacan (TEO), and Cuautitlán (CUA). Temperature and humidity profiles were measured with radiosondes launched five times per day (0800, 1100, 1330, 1630, and 1930 LST) at the four profiler locations, two times per day (1330 and 1630 LST) at Tres Marias (TRM), located at approximately 2800 m above mean sea level (MSL) on the southern slope of the mountains forming the south border of the basin, and three times per day (1330, 1630, and 1830 LST) at a location about 70 km northeast of Mexico City. The radar profilers operated continuously but sonde launches were not made on Sundays.

The most persistent wind feature observed during the four-week field campaign was a low-level southeasterly jet located north of the mountain gap in the southeast corner of the basin. The profiler located at the Chalco site, about 15 km to the northwest of the gap, was situated there specifically to measure this phenomenon, which had been predicted during the design phase of the experiment. The most common direction for the gap winds at the lowest range gates of the profiler was approximately 150° (Fig. 2). For the purposes of this paper, a jet is said to occur whenever three conditions are met: the largest hourly averaged wind in one of the bottom three range gates of the profiler [144, 241, or 337 m above ground level (AGL)] has a direction between 105° and 210° and is at least 6 m s^{-1}, above this level the

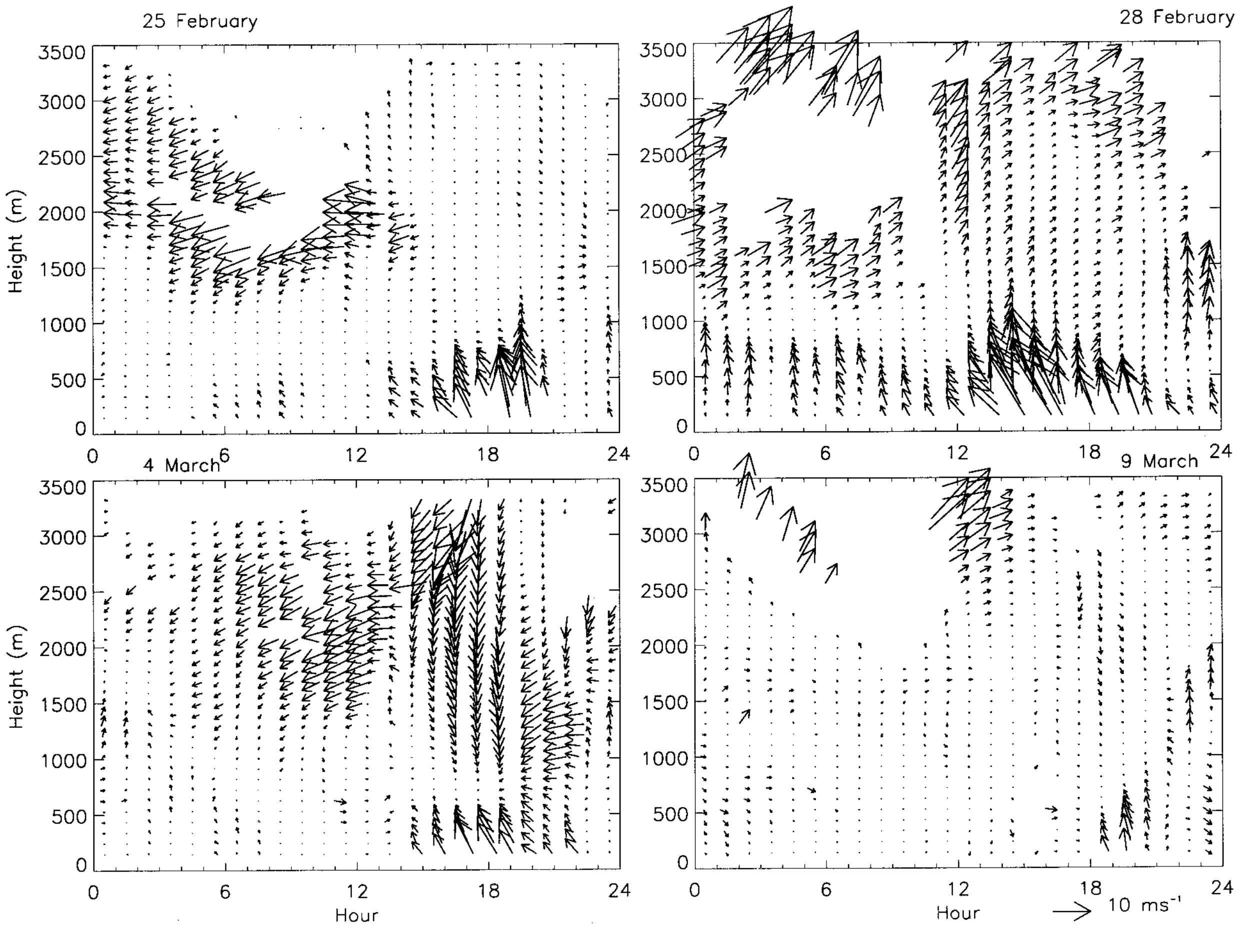

FIG. 3. Wind velocity profiles measured by a radar wind profiler at Chalco for four days, showing the development of a low-level jet on each day.

velocity in the direction of this maximum decreases by at least 4 m s^{-1} in the first 1000 m AGL, and these features are found in the hours 1200–2100 LST. Out of 29 study days, 5 were eliminated from consideration because of disturbed weather in which the prevailing winds in the lowest 1500 m were sufficiently strong either to obscure a jet (for southerly winds) or to significantly impede its formation (for winds with a northerly component). Of the remaining 24 ''undisturbed'' days, a jet was observed for 1 or more h on 20 days, 83% of the total.

At Chalco, a jet often developed in the late afternoon and lasted until after sunset. On days with southerly ambient winds, the jet could appear several hours earlier. Figure 3 shows examples of jets that formed on 4 days (25 February, 28 February, 4 March, and 9 March 1997). For most of the times shown, the winds in the lower boundary layer were very light, which also was typical for the other three profiler sites. In each case there was a period in the afternoon and evening when moderate to strong winds, sometimes in excess of 10 m s^{-1}, developed, however. The jet that occurred on 9 March was weaker than the other three cases and first appeared shortly after sunset. The jets that occurred on 25 February, 4 March, and 9 March are examples of late-afternoon or early-evening formation. In each of these cases, the winds in the lowest 1500 m were weak prior to the onset of the jet. In contrast, on 28 February, moderate southerly winds were seen in the lower boundary layer throughout the morning hours, and the jet began to appear shortly after noon. On 4 March, a jet can be seen even in the presence of relatively strong northerly ambient winds, although the southeasterly flows in the jet did not extend as deeply here as in the two previous cases. It is interesting to note that the profiler data at UNA (not shown) revealed little or no evidence of well-developed wind systems from the south in the afternoons or evenings, indicating that the flows into the Mexico City basin from the south at these times are channeled through the gap rather than over the mountains.

The maximum wind speeds in the lowest 1000 m almost always were observed at one of the lowest three range gates (144, 241, or 337 m AGL) of the wind profiler. Figure 4 shows composites of the vertical variation of the normalized jet velocities, where the nor-

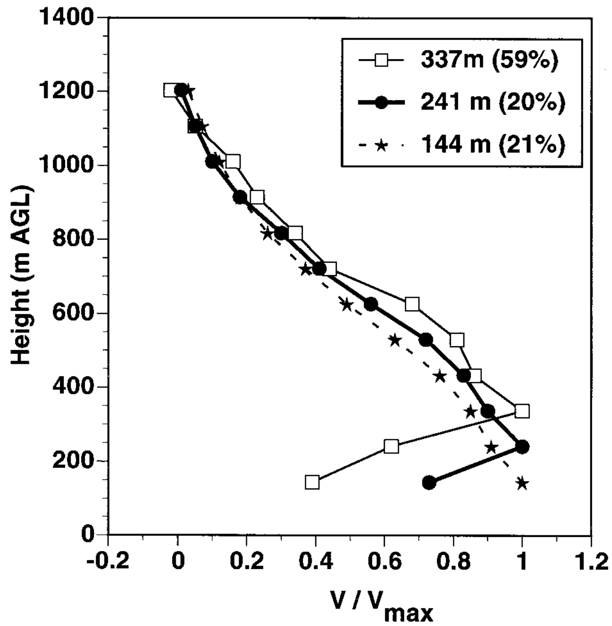

FIG. 4. Composite profiles of normalized wind velocities for 66 h of observed jets. The composite have been divided into three classes according to the height at which the maximum velocity is attained (see legend). The normalization has been done with respect to the maximum velocity for each hourly profile.

malization has been done relative to the maximum jet velocity for each hourly profile. For 66 h when a jet was observed, the jet peaked at 337 m AGL 59% of the time, with the remaining peaks nearly equally distributed between the two lower range gates. Between 400 and 1200 m AGL, the normalized profiles look similar to each other regardless of the height at which the maximum velocity was observed. There was a weak tendency for jets with the largest peak velocities to reach their peak values at the lowest elevation; the mean and standard deviations of the peak velocities at 144, 241, and 337 m AGL were 10.1 $\pm$ 2.3, 9.0 $\pm$ 2.1, and 8.8 $\pm$ 2.5 m s^{-1}, respectively.

During the experiment, a surface meteorological station at Teotihuacan recorded wind and temperature data. These data may be considered to be more representative of the conditions in the interior of the Mexico City basin than are measurements from Chalco, because the Teotihuacan site is well removed from the mountain gap to the southeast. Figure 5 shows plots of the temperature and humidity values measured there. Days on which a jet was observed are indicated by arrows; the strength of the jet (cf. next section) is indicated by the size of the arrow. It can be seen that jets were more likely to develop and usually were stronger during the early part of the experiment, when conditions were generally warmer and drier, than in the later part of the experiment, when conditions were cooler and more humid. More cloudiness was also observed later in the experimental period (Doran et al. 1998).

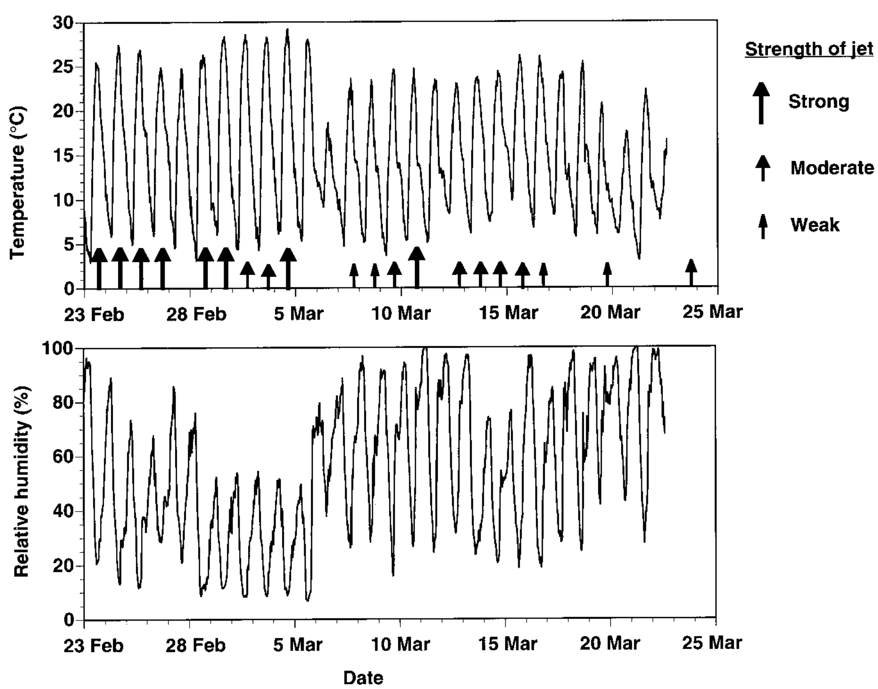

FIG. 5. Near-surface temperature and humidity values at Teotihuacan during the measurement period. Days on which a jet was observed are indicated with an arrow. The length of the arrow for each case indicates the strength of the jet observed on that day: strong, moderate, or weak.

3. Thermal forcing

Because of the tropical location, high altitude (average basin floor elevation of approximately 2250 m MSL), and the semiarid surface characteristics of the Mexico City basin, daytime warming in the basin is strong, especially in the dry season when central Mexico often is dominated by anticyclonic synoptic flows that give rise to relatively clear skies over Mexico City. Radiosondes launched inside the basin during the field campaign frequently showed a rapid growth of the mixed layer between 1100 and 1330 LST, with mixed-layer depths reaching 2500–3000 m AGL in the afternoon, accompanied by a considerable increase in temperatures. The valley to the south of the basin is at an elevation of about 1500 m MSL and is generally wetter and more vegetated than the basin. A horizontal temperature gradient was expected to exist between the air inside the basin and the air to the south at altitudes that correspond to the elevation of the basin and the mixed layer above it. It was hypothesized that this temperature gradient and its associated pressure gradient were largely responsible for the southeasterly winds that flow from the valley, form a jet through the mountain gap, and continue into the basin.

To test this hypothesis, we tried to relate the strength of a jet to the magnitude of the temperature gradient between the basin's boundary layer and the air at corresponding heights outside the basin to the south. An examination of numerous wind profiles obtained by the Chalco profiler suggests some sensitivity of the jet's features to the direction and magnitude of the prevailing winds. Thus, it has been problematic to come up with a satisfactory quantitative definition of the strength of a jet, because it can be difficult to isolate a jet from the ambient winds, particularly if the latter are relatively strong. It also is not obvious how to compare a jet that persists for many hours but with relatively light winds with one that has stronger winds but only occurs for an hour or two. In the end, we simply defined three categories of jets. A jet was classified as strong if the maximum wind speed in any of the lowest three range gates (144, 241, or 337 m AGL) was greater than 10 m s^{-1} and decreased by at least 8 m s^{-1} by 1000 m AGL. The requirement that the maximum wind speed decrease by this amount helps to distinguish the jet winds from ambient flows with a southerly component. If the maximum wind speed at the lowest three levels was less than 8 m s^{-1}, the jet was classified as weak. (In all but one case, days with a weak jet also showed small decreases in velocity at 1000 m, with decrements of less than 6 m s^{-1}.) All other jets were classified as moderate.

We estimated the temperature difference between the basin's boundary layer and the air at corresponding heights outside the basin in two ways. In the first, we used the averaged temperatures measured between 2800 and 3200 m MSL at Tres Marias (elevation 2800 MSL) on the south side of the mountain slope to the south of the basin and the averaged temperatures measured at Cuautitlán, Teotihuacan, and UNA over the same elevation interval. We did not use the Chalco temperature profiles, because the other three sites were felt to be more representative of ''interior'' points for the Mexico City basin, whereas the Chalco site might be affected by cooler, ''exterior'' air flowing into the basin in the early afternoon. In fact, the inclusion of the Chalco values would not significantly affect our findings. The relationship between the valley–basin temperature difference at 1330 LST and the strength of the gap wind on that day is shown in Fig. 6. A positive temperature difference indicates higher temperatures inside the basin. The symbols represent strong, moderate, weak, and no jet. Because no soundings were taken on Sundays, and because the data recovery from the Tres Marias soundings was not as complete as for the sites in the basin, temperature differences are plotted only for the 16 days on which both the Tres Marias and the interior soundings were available.

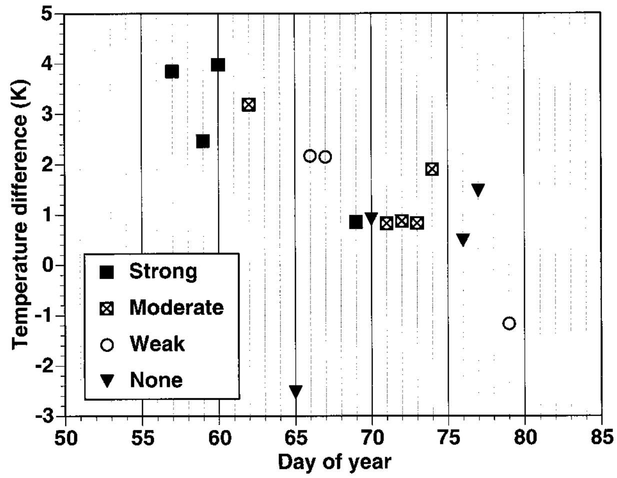

FIG. 6. Dependence of the strength of the gap wind on the temperature difference between the Tres Marias site and the average of the Teotihuacan, Cuautitlán, and UNA radiosonde sites. The temperature differences are computed over the height range 2800–3200 m MSL.

For our second measure of temperature differences between the basin and the exterior, we used the temperature data from the 1800 LST radiosondes launched at the Mexico City airport and at Acapulco, located on the southern coast of Mexico. Temperatures from the two soundings were averaged between 2250 and 3150 m, and the differences between these averages were computed. The results are shown in Fig. 7. Again, because of missing soundings at the two sites, results from only 15 days are shown.

In Figs. 6 and 7 it is evident that there is a general trend toward smaller temperature differences as the experiment progresses, which is consistent with the differences in the meteorological conditions between the earlier and later parts of the observation period that were noted above. Strong jets are more likely to be associated

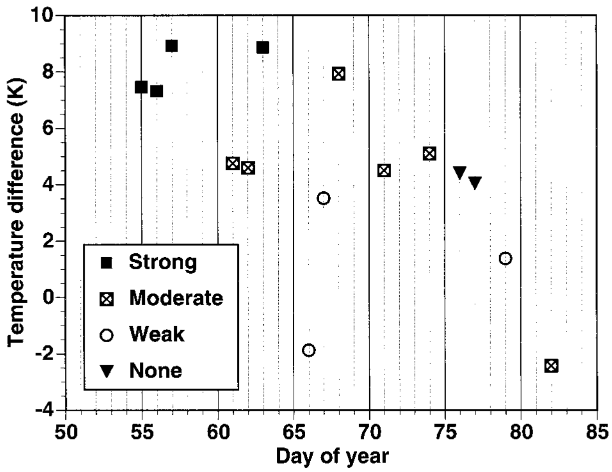

FIG. 7. Dependence of the strength of the gap wind on the temperature difference between the Mexico City and Acapulco rawinsonde sites. The temperature differences are computed over the height range 2250–3150 m MSL.

with the larger temperature gradients, and smaller temperature gradients are more likely to produce a weak jet or no jet. There is considerable scatter, however, and the temperature differences computed here are only rough indicators of the likely strength of a jet. The temperature differences between Mexico City and Acapulco seem to be somewhat more useful than those between the Mexico City basin and Tres Marias in this regard. One ideally would like to compute a temperature difference between the Mexico City basin and the exterior areas to the south from the height of the basin floor to some reference height in the mixed layer. This is possible with the Acapulco sounding but not with the Tres Marias sounding, because the latter site was located nearly 600 m above the basin floor. This factor may account for some of the additional scatter in the Mexico City–Tres Marias plot (Fig. 6). Alternatively, the thermal forcing responsible for the formation of the jet may be more closely associated with regional-scale circulations than with more local ones, and the regional-scale temperature differences would be better represented by the Mexico City–Acapulco temperature differences. This feature also would be consistent with the analysis of the basin wind and temperature patterns by Whiteman et al. (2000). The Mexico City–Acapulco temperature values were obtained at 1800 LST, however, several hours after the gap winds typically develop. Thus, they are an imperfect indicator of the strength of the thermal forcing earlier in the afternoon, which may account for some of the scatter in Fig. 7.

4. Numerical modeling

To study further the mechanisms responsible for the development and propagation of the gap winds, a nonhydrostatic numerical model [the Colorado State University Regional Atmospheric Modeling System (RAMS); Pielke et al. (1992)] was used. RAMS is a primitive equation, regional-scale model. It employs a terrain-following coordinate system and a two-way interactive nested grid structure. Subgrid-scale turbulent diffusion is parameterized using a level-2.5 scheme (Mellor and Yamada 1982) with a prognostic turbulent kinetic energy equation and a diagnostic length scale. Turbulent sensible and latent heat fluxes and momentum fluxes in the surface layer are evaluated based on Louis's (1979) formulation. A multilayer soil model developed by Tremback and Kessler (1985) is used to predict diurnal variations in soil temperature and moisture. RAMS also contains a cloud microphysics package and a cumulus parameterization scheme, neither of which were activated for this study. Clouds, however, were allowed to form in areas of supersaturation based on a diagnostic scheme. The Chen and Cotton (1983) short- and longwave radiation schemes, which consider the effect of clouds but do not include the effects of aerosols on radiation, are used to determine radiative heating and cooling.

The modeling domain consisted of three nested grids with horizontal grid spacings of 36, 9, and 2.25 km, respectively. The outer grid included the central Mexico Plateau, part of the Gulf of Mexico, and the western Pacific Ocean, and the innermost grid encompassed the vicinity of the Mexico City basin (Fig. 1). All three grids had 42 vertical levels, stretched from a grid spacing of 50 m near the surface to 1500 m above 10 km. Simulations started at 0600 LST and ended at midnight. The model was initialized using National Centers for Environmental Prediction Aviation Model analyses, standard rawinsonde observations, and the additional upper-air observations provided by the field experiment. Hourly wind profiler data at UNAM, Cuautitlán, and Teotihuacan were assimilated into the model simulation with a four-dimensional data assimilation (4DDA) nudging procedure (Fast 1995) to reduce errors in the simulated wind field, but no nudging was done with the Chalco profiler data. Because the nudging was restricted to three sites at distances of 25 km or more from Chalco and the nudging coefficients were small, the 4DDA had little or no direct effect on the development of the gap winds. The model often developed southerly winds over the mountains to the south of Mexico City (which were not observed) in addition to the gap winds, however, and the 4DDA nudging helped to suppress this behavior.

The model was used to simulate the development of gap winds on 5 days and was successful in predicting the formation of a low-level jet on each day. It had a tendency to miss the time of formation by 1–3 h, with larger discrepancies when the jet formed early in the afternoon, but the duration of the jet was predicted reasonably well. In addition, the model's predictions of the maximum speeds in the jet could sometimes be off by several meters per second. Part of the difficulty may be associated with a lack of knowledge of the surface con-

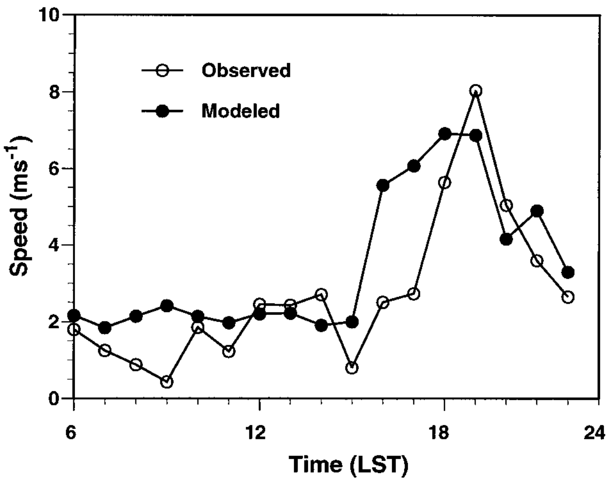

FIG. 8. Comparison of the simulated and observed time evolution of the wind speeds at a point near Chalco north of the mountain gap for 9 Mar 1997. The simulated winds are averaged over the lowest 500 m of the atmosphere.

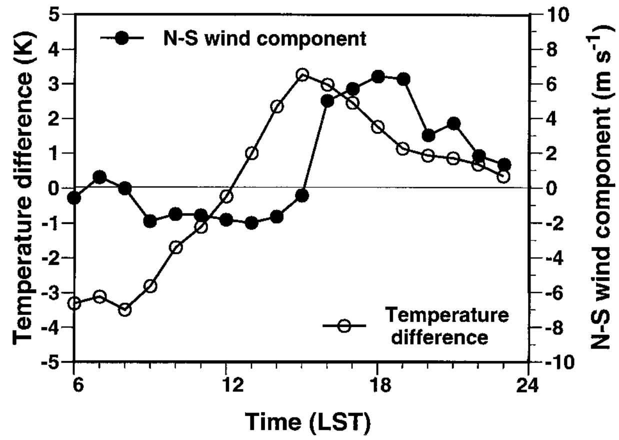

FIG. 9. The relation between the simulated north–south wind speed component near Chalco and the temperature difference between the Mexico City basin and the region to the south of the gap for 9 Mar 1997. The temperature difference is computed over a horizontal distance of 29 km centered on the gap. Wind components and temperature are averaged over a 500-m layer.

ditions—vegetation, soil type, soil moisture—both inside and outside the basin. More likely causes of the errors are problems with the model's handling of subgrid-scale roughness elements and with the turbulence closure scheme over the mountainous terrain. Thus, although the simulations of gap flows yield useful qualitative comparisons with observations, the quantitative comparisons are generally not as favorable.

5. Results and discussion

In the following discussion we use the results of a simulation for the 9 March case (Fig. 3); the weak ambient winds throughout this day simplify the analysis. For the analysis it is convenient to consider the behavior of the gap winds averaged over the lowest 500 m. Figure 8 shows a comparison of the simulated and observed wind speeds for this 500-m layer at Chalco. The agreement is reasonably good, although the simulated winds begin to increase somewhat earlier than do the observed ones. Figure 9 shows the relation between the simulated north–south component of the winds and the simulated temperature difference across the gap, with the wind component and temperatures again averaged over a 500-m height interval and the temperature difference calculated over a north–south horizontal distance of 29 km centered on the gap. The air in the basin becomes warmer than the air to the south of the basin starting about an hour after noon, and the temperature difference reaches a maximum value of approximately 3 K around 1500 LST. In the late morning and early afternoon, there is a weak flow from the north. Wind speeds are on the order of 2 m s^{-1} and are relatively steady, but they begin to increase rapidly, and the winds turn to come from the south shortly after the maximum temperature difference is reached. The wind speed continues to increase in the afternoon, reaching a maximum of nearly 7 m s^{-1} near sunset around 1800 LST. As the cooler air passes through the gap, the temperatures in the basin near the gap are reduced. During the early evening, the whole basin cools rapidly. The gap winds contribute to this cooling, but other factors, such as the convergence of regional-scale circulations onto the Mexican Plateau across strong horizontal potential temperature gradients between the basin atmosphere and its surroundings, are also responsible (Whiteman et al. 2000). During the evening, the temperature difference remains small, and the wind speed drops from its peak value around sunset to about 1 m s^{-1} near midnight.

Figure 10 further illustrates these features by showing potential temperature contours and wind vectors at three times along a north–south cross section through the gap (dotted line in Fig. 1). The initial temperature gradient between the basin and the region to the south, the development of a jet in midafternoon, and the propagation of cooler air into the basin in the early evening all are evident.

Figure 11 shows the individual components of the momentum balance for the north–south wind component averaged between 1600 and 2000 LST in the lowest 500 m AGL as a function of the north–south distance from the center of the gap. The three dominant terms are the contributions from the pressure gradient, advection, and vertical turbulent mixing. Two other terms, the Coriolis force and the 4DDA term, essentially are negligible. (The 4DDA term is zero over most of the cross section except at the northern end where the wind profiler data at Teotihuacan were assimilated.) South of the gap, a positive contribution from the pressure gradient dominates the negative contributions from advection and diffusion, causing the wind to accelerate through the gap. North of the gap, the pressure gradient force decreases rapidly, and the advection term

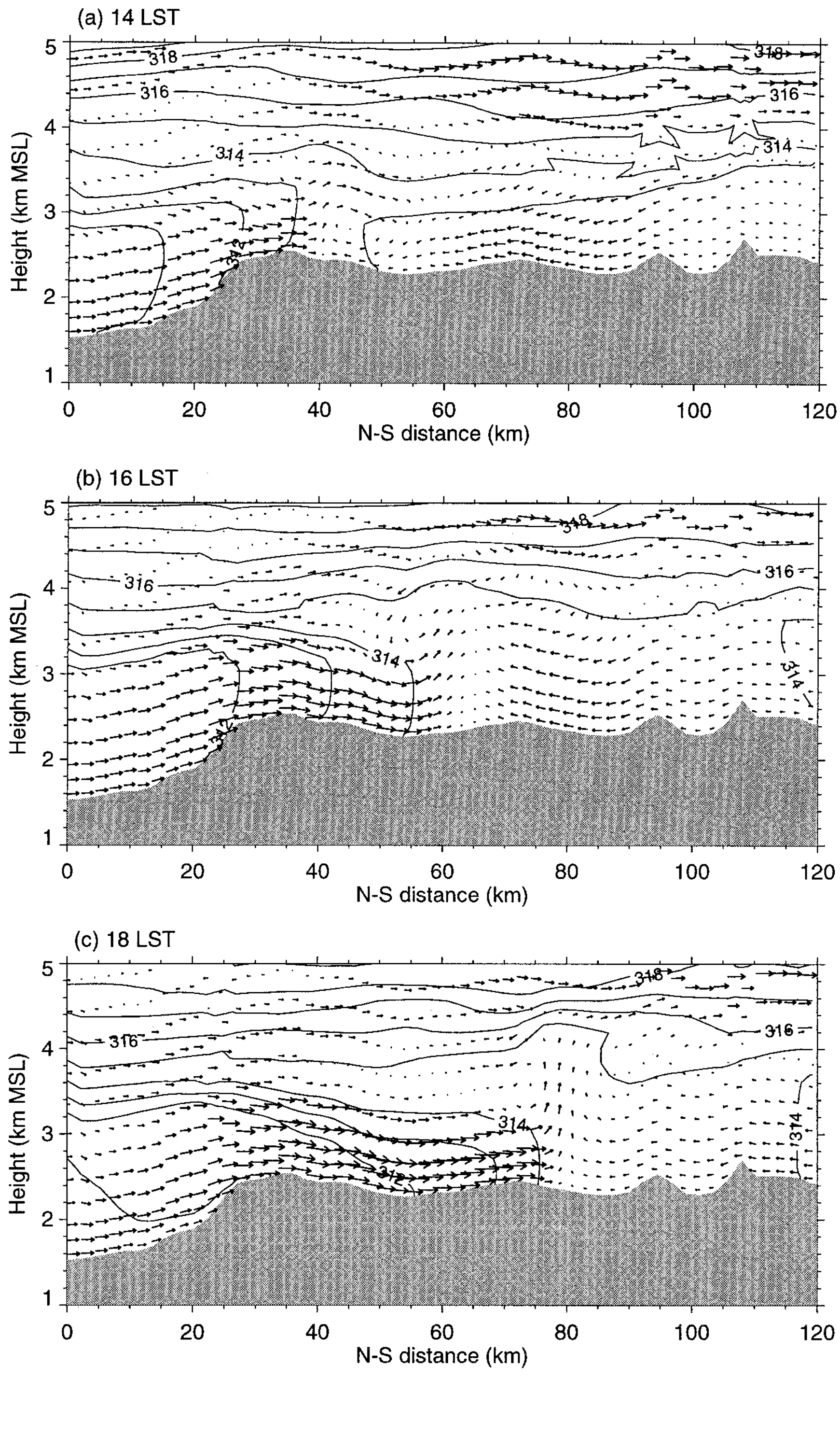

FIG. 10. Simulated potential temperature contours and wind vectors along a north–south cross section through the gap (dotted line in Fig. 1) for three times on 9 Mar 1997.

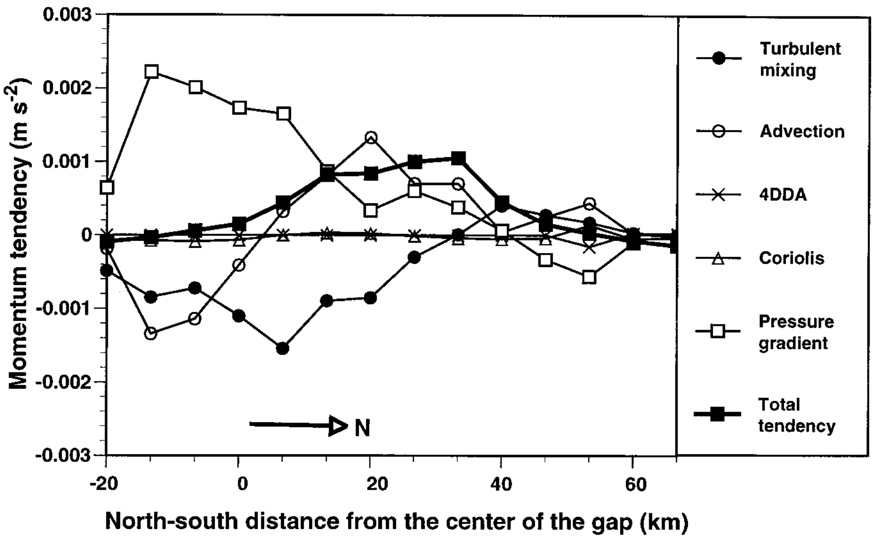

FIG. 11. Simulated north–south variation of the contributions to the momentum balance for the v (north–south) component of the wind for 9 Mar 1997, averaged from 1600 to 2000 LST.

becomes positive and is the main term responsible for the propagation of the gap wind into the basin. In the northern part of the basin, the pressure gradient force becomes negative because the air to the north of the basin is cooler than the air inside. The total tendency term in this region is also negative, consistent with the development of a northerly wind that begins to enter the basin.

Although the basin air generally was warmer than the air outside, radiosondes launched at the four basin sites showed a relatively uniform temperature distribution inside. Thus, the thermally induced pressure gradient is largest near the gap and decreases greatly farther inside the basin, where the basin air appears to be well mixed both vertically and horizontally. In this region, horizontal advection then plays a more important role than the pressure gradient in the movement of the gap wind to the north. The contribution of the vertical turbulent mixing term to the momentum balance is negative in the 500-m jet layer, resulting from the friction drag and downward momentum transport to the surface.

Figure 12 shows plots of near-surface wind vectors at 1400 and 1800 LST. At the earlier time, the gap wind is just beginning to make its way into the basin, and at the latter time it has penetrated a considerable distance to the north. As the gap wind enters the basin, it tends to turn to the west while continuing to propagate to the north. The gap winds appear to play a role in keeping the southeastern portion of the basin relatively clear of pollutants. A convergence zone forms where the southeasterly flow meets the flow from the northern part of the basin. The strength of the convergence, its timing, and the location of the convergence zone will change, depending on the relative strengths of the two wind regimes. Other studies (Zhong et al. 1997; Fast et al. 1997; Fast 1998; Fast and Zhong 1998) have shown that this convergence can have a significant effect on the spatial distribution of surface pollutants in the basin.

There are some notable similarities between the flow features described here and those shown by Kimura and Kuwagata (1993) for the Kanto Plain–to–Saku Basin and the Sendai Plain–to–Fukushima Basin regions in Japan. In their study and ours, a basin provides an elevated heat source that creates a pressure gradient sufficient to draw cooler air through a gap in the mountains that surround the basin. The flows begin in midafternoon and persist until the early evening or later. The flows into the basin described by Kimura and Kuwagata are coupled to sea breezes that penetrate inland for distances on the order of 50 km or more. In our case, the gap winds appear to be one aspect of a regional-scale plain-to-plateau circulation pattern that develops over the Mexico Plateau as described by Whiteman et al. (2000).

6. Conclusions

Measurements of winds during February and March of 1997 at a site just north of a gap in the mountains in the southeast corner of the Mexico City basin showed the presence of gap winds in the afternoon or early evening that developed on over 80% of the days with relatively undisturbed weather. These winds formed a jet up to 1 km deep with peak speeds often exceeding 8–10 m s^{-1} in the lowest few hundred meters and developed in response to temperature gradients between the basin and the region to the south. On some days, the temperature differences between Mexico City and Acapulco on the southern coast reached almost 10 K at 1800 LST at heights corresponding to the lowest 900 m of the atmosphere over Mexico City. Temperature differences in the early afternoon between the Mexico City basin and

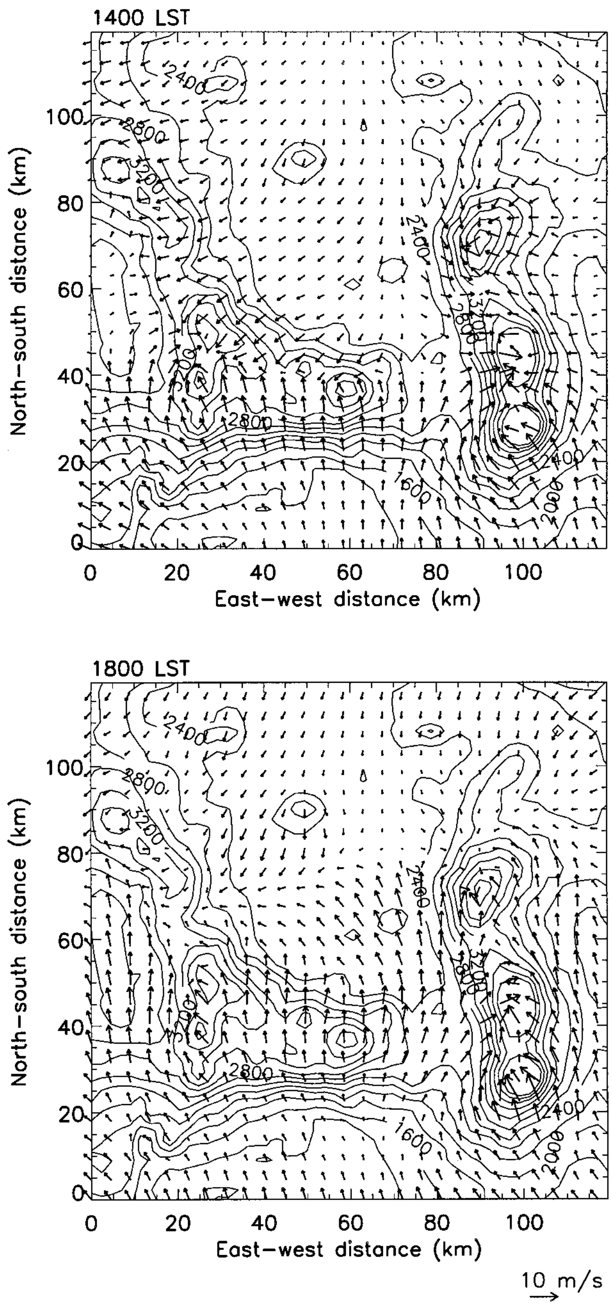

FIG. 12. Simulated near-surface winds in the Mexico City basin at 1400 and 1800 LST on 9 Mar 1997. Wind vectors are shown at every second grid point to avoid clutter. Contour interval is 200 m.

Tres Marias on the southern flank of the mountains forming the south border of the basin approached 4 K (computed over a more limited height range of 400 m, because the elevation of the Tres Marias site was nearly 600 m greater than that of the basin). There was a tendency for a stronger jet to occur on days with larger temperature differences; these larger differences were, in turn, associated with generally warmer, drier, and less-cloudy conditions over the Mexico City basin. Numerical simulations show that a thermally induced pressure gradient is the dominant term in the momentum balance near the gap but that advection is primarily responsible for the northward propagation of the gap winds farther into the basin. The thermal mechanism that generates the gap winds appears to be similar to that found in the study of Kimura and Kuwagata (1993) for two regions in Japan, suggesting that similar phenomena may be found in other mountain basins. As the gap winds encounter air flowing from the north, a convergence zone is formed in the Mexico City basin that can affect the spatial distribution of pollutants there.

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