# 7.6 Meteorology and pollution modeling in the Valley of Mexico

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## 1 Introduction

The Valley of Mexico, where Mexico City is situated, is surrounded by high mountains in the east, south and west and to the north by lower discontinuous ranges. More than 3.2 million vehicles burning over 44 million liters per day of Gasoline and Diesel, plus industrial and commercial activities (responsible for about 30% of the GNP), INEGI (1999), generate particles and photochemical pollutants, making Mexico City one of the most polluted cities in the world.

The combination of complex terrain that produces intricate air flows and large amounts of emissions present a challenge for meteorological and air quality modelers.

With the aid of a prognostic air quality model three types of airflow patterns present in the Valley of Mexico are studied: Surface confluence lines over Metropolitan Mexico City where pollutants and photochemical precursors accumulate, vertical circular flows producing vertical fumigation, and surface flows transporting pollution to contiguous valleys. More details and meteorological scenarios describing these flows can be found in Jazcilevich (2003),Jazcilevich (2005) . Also preliminary results linking an air pollution model and an erosion model will be presented.

All simulations are made with the Multiscale Chemistry and Climate Model (MCCM), Grell (2000), implemented for Mexico City, Garcia (2000). The meteorological module of MCCM is based on the widely used MM5, Grell (1994). MCCM includes a module for biogenic emissions. The gas phase chemistry used in this study is RADM2, Stockwell (1990). In the domain of interest a resolution of 3 km is used.

## 2 Surface confluence lines over Metropolitan Mexico City

The time period chosen for the confluence lines study is from January 28 to 30, 2001. As shown in Fig. 1 this scenario corresponds to a high pressure system over the central region of Mexico providing favorable conditions for a typical high pollution scenario. The mean synoptic near surface flow (700mb) over Mexico is dominated by an anti cyclonic circulation over central southern Mexico producing southwesterly winds above 20N and easterlies below 20N. The associated high pressure system dominates most of central Mexico which results in subsidence and relatively dry conditions with clear skies over the Mexican plateau . The transition zone, located around 20N, results in relatively weak surface winds over the Mexico basin with a consistent southeasterly component. This weak synoptic condition is favorable for the development of thermally driven local and regional circulations.

As shown in Fig. 2, at 13:00 LST on January 29, 2001, a southerly wind enters the valley through Chalco. This flow is attracted inside the city because of ascendant currents formed by the heat island. Meanwhile in the northwestern part of the Mexico City Metropolitan Area (MCMA), local surface horizontal flows are also attracted inside the city because of thermal contrast. This situation divides the confluence line in to two branches in the Northwest of the MCMA.

Maximum concentrations tend to accumulate around the confluence line forming sharp concentration gradients depending on the source and strength of the emissions. As the accumulations migrate following the confluence line, they sweep over densely populated areas of the MCMA.

As shown in Fig. 3, in the Western branch of the confluence line, Isoprene, mainly a biogenic hydrocarbon emitted by the northern part of the Las Cruces range,

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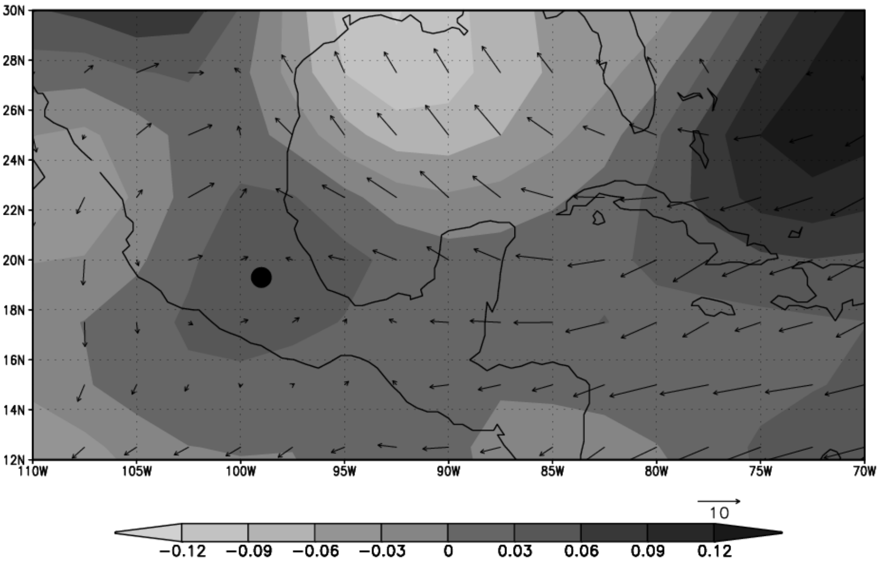


Figure 1: Synoptic scale view of mean conditions for the January 2001 episode. The shaded areas are the omega pseudo vertical velocity ( Pa $s^{-1}$ ) at 700 mb and vectors are the near surface winds (m s $^{-1}$).

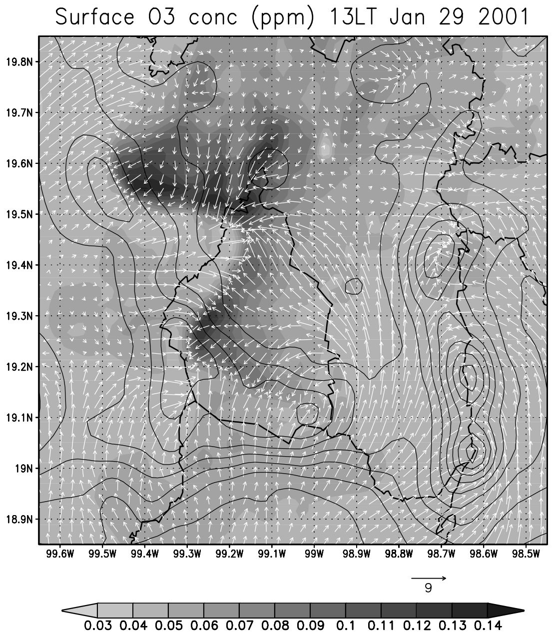


Figure 2: Surface wind field and Ozone concentrations in ppm for January 29, 2001,13:00 LST . Surface wind penetrates the Valley through the Southeast. Highest Ozone concentrations accumulate around the confluence line in the North and Southwest of the MCMA.

meets $NO_x$ emitted by the city. When they meet high $O_3$ concentrations over the confluence are formed. This situation is permitted by the weak synoptic winds allowing thermally driven local currents.

## 3 Vertical circular flows producing vertical fumigation

The time period chosen for the vertical circular flows study is from March, 1997. Similar flows without photochemistry are described in Bossert (1997),Fast (1998). Figure 4 shows a North-East to South-West vertical slice where we can see the vertical wind flow over the MCMA at 21:00 LST, March 2, 1997. A vertical circular wind pattern is revealed. This figure also shows how CO emitted at the surface has been transported first from the center of the MCMA, the area with highest emissions, to the South-West corner of the MCMA. CO is then advected up vertically due to the presence of the Ajusco range. Once on a higher atmospheric layer at a height of about 900 m above the basin floor, it is transported back to the North-East passing over the surface path it covered initially, and finally descends convectively on the North-Eastern corner of the MCMA. CO concentrations in the landing area are significant at about 8 ppm.

To illustrate that we have vertical advection near the mountains followed by a convective downdraft, Fig. 5 shows that the potential temperature isotherm for 312 K is on the same path followed by the pollutants discussed above. Therefore we can conclude that cold air is transported up vertically due to mechanical advection when air parcels are pushed against the mountains and once in the upper atmosphere these parcels tend to descend since they are colder than the surrounding air.

## 4 Surface flows transporting pollution to contiguous valleys

A flow pattern is shown in Fig. 6 where the surface wind and surface concentrations of CO are depicted over the central region of Mexico at 2:00 LST on the 4th of March, 1997. This figure shows how CO is transported through Chalco to the Valley of Cuautla. The pollution in Mexico City influences the air quality of the contiguous valley of Cuautla.

## 5 Preliminary results of the erosion model

Large agricultural areas are located in the semi-desertic north and northeast of the metropolitan area of Mexico City. Also the dry lake bed of Lake Texcoco occupying an area of about 25 $\text{km}^2$ is located in the Northeast. It is estimated that in the northern areas of Mexico City, 40% of PM10 particles is of natural erosion origin Vega (2004).

The MCCM model has been linked with the Wind Erosion Prediction System (WEPS) erosion model,USDA-ARS-WERU (2001), Skidmore (1999).WEPS provides to the transport module of MCCM the hourly emission of erosion PM10 particles as a function of air speed, humidity, temperature and soil parameters.

Figure 7 shows a preliminary result for the transport of erosion PM10 over the Valley of Mexico, Diaz (2005).

## 6 Conclusion

Meteorological models such as MM5 and air quality models such as MCCM are invaluable tools to visualize, detect and find the location, dynamics and chemical composition of intricate flows formed by the complex orography of the Valley of Mexico.

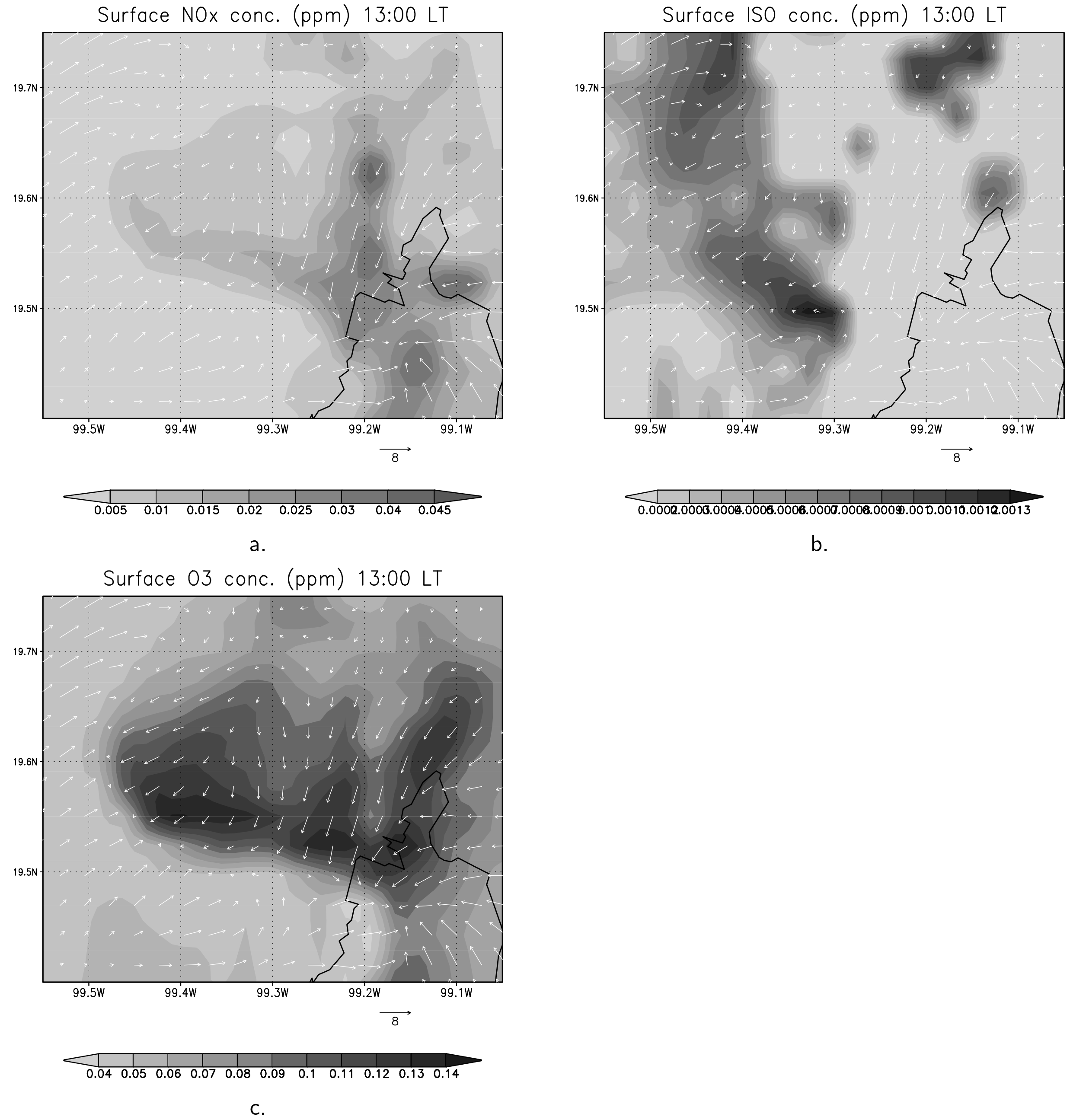
The possible existence of circular vertical flows, the explanation of how peak concentrations are the result of confluence lines over the metropolitan area, how urban areas and forests interact, and how pollution in the Valley of Mexico travels to surrounding valleys are possible through the use of models such as MCCM.

Future work using the link between WEPS and MCCM will shed light on the important role of erosion particles in the air pollution problem of Mexico City.

The information obtained is not only important for meteorological and air quality research, but for urban planners and decision makers.

## Appendix: Statistics

Tables 1 and 2 show a basic statistical error analysis for the January 2001 episode for wind intensity and $O_3$respectively using data provided by stations of the local automatic monitoring network named RAMA. The statistics presented include the index of agreement $d$,



a.

b.

c.

Figure 3: Zoom of the North-Western branch of the confluence line. In(a) $NO_x$ is transported mainly from the MCMA towards the North-West, in (b) Isoprene is transported mainly from Las Cruces to the South-East, in (c) production of $O_3$ on the confluence. All concentrations are in ppm.

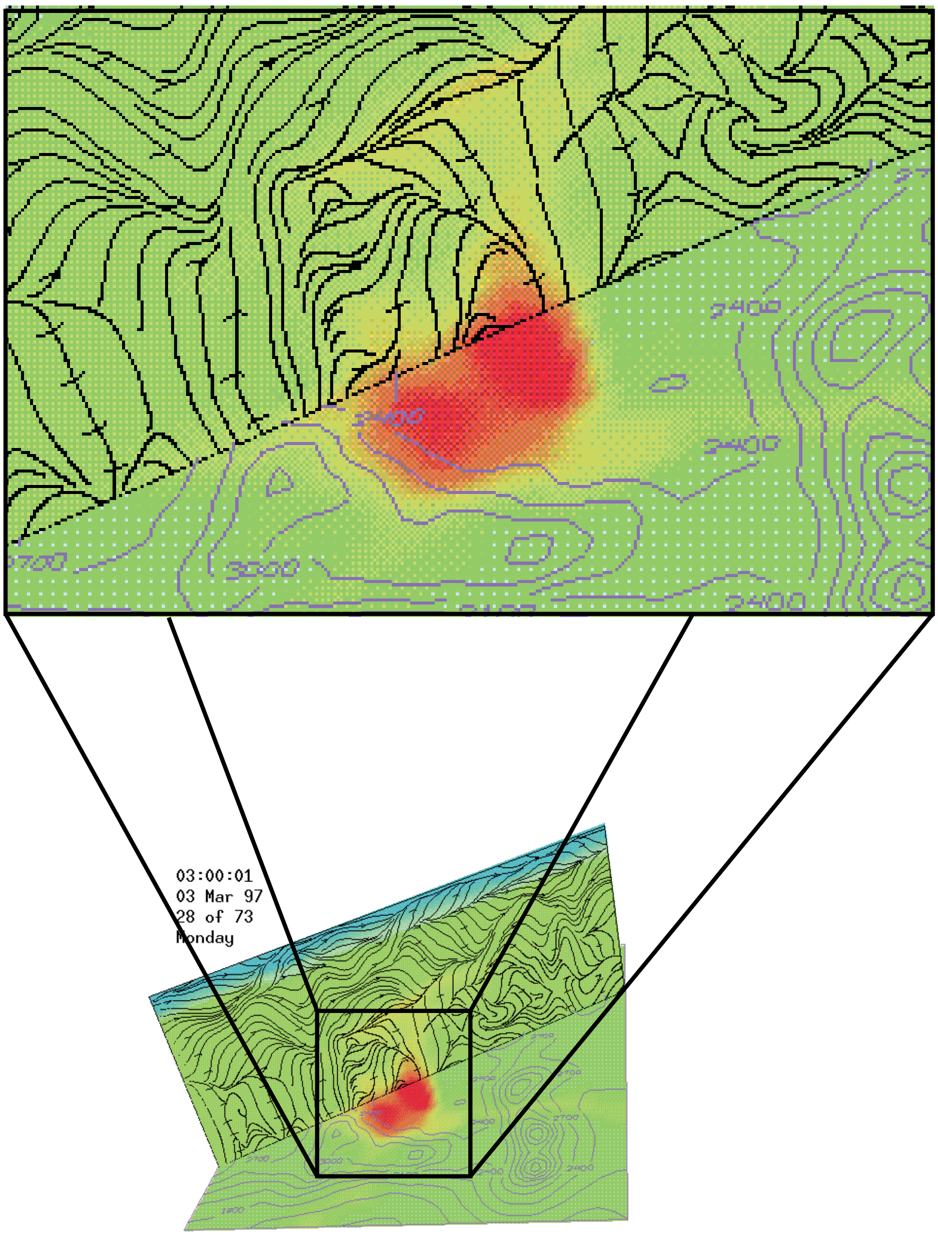


Figure 4: North-East to South-West vertical slice and an enlargement of the area of interest over the MCMA at 21:00 LST, March 2, 1997. A vertical circular wind pattern can be seen transporting CO concentrations. On the landing area the darker color show that concentrations of CO reach 8 ppm.

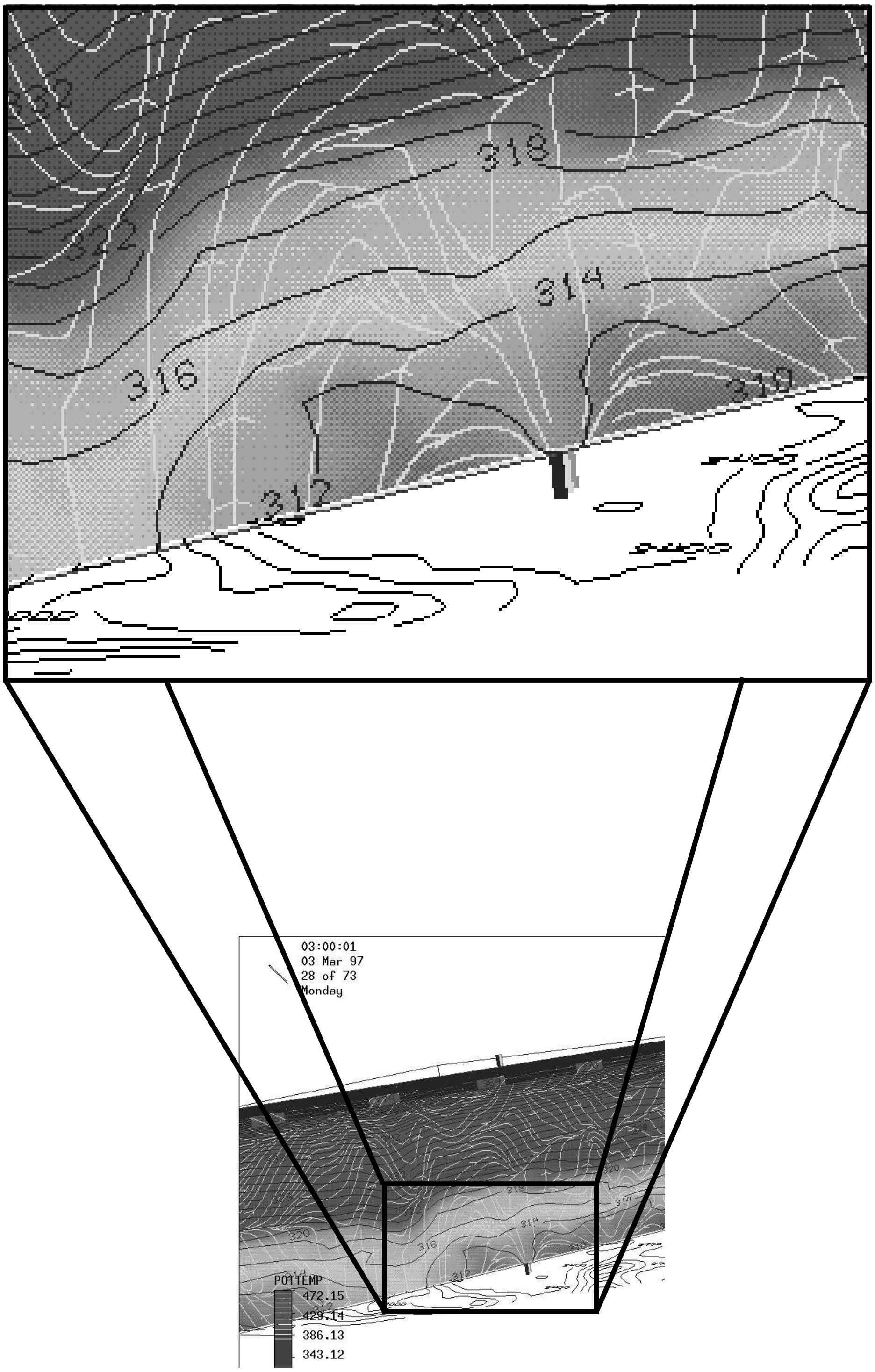


Figure 5: North-East to South-West vertical slice and an enlargement of the area of interest over the MCMA at 21:00 LST, March 2, 1997, showing potential temperatures. The isotherm for 312 K is on the vertical circular path followed by the pollutants.

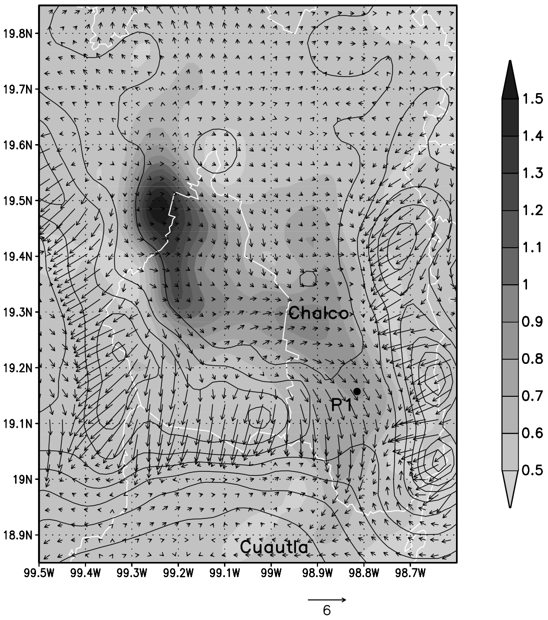


Figure 6: Surface wind flow and CO surface concentrations over the central region of Mexico at 2:00 LST, March 4th, 1997. Note how CO concentrations drain through Chalco to the Valley of Cuautla.

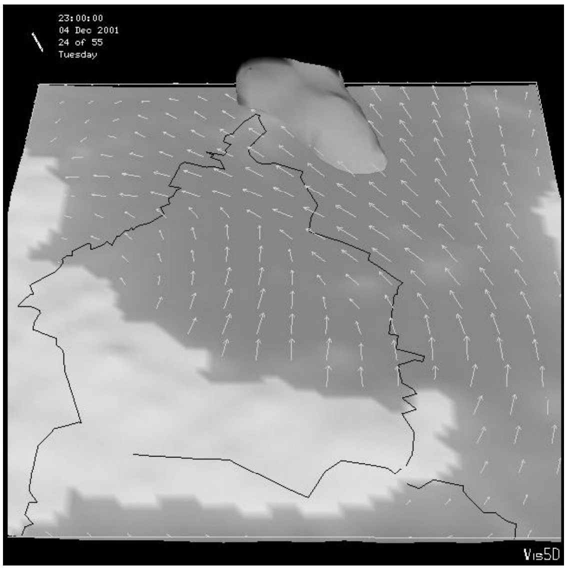


Figure 7: PM10 erosion particles are transported to the metropolitan area from the dry lake bed of Texcoco lake located in the Northeast of Mexico City.

see Willmott (1981), which has an optimum value of 1.0 for perfect agreement between model and measurements.

Table 1: Statistical analysis for surface wind intensity; $CC$ correlation coefficient, $RMSE$ root mean square error, $RMSE_s$ root mean square error systematic, $RMSE_u$ root mean square error unsystematic, $d$ index of agreement

| Station | $CC$ | $d$ | $RMSE$ | $RMSE_u$ | $RMSE_s$ |
|---|---|---|---|---|---|
| Tlalnepantla | 0.43 | 0.65 | 1.21 | 0.73 | 0.96 |
| Acatlan | 0.24 | 0.53 | 1.23 | 0.78 | 0.94 |
| Xalostoc | 0.44 | 0.66 | 1.21 | 0.77 | 0.94 |
| San Agustin | 0.30 | 0.57 | 1.18 | 0.75 | 0.91 |
| C. Estrella | 0.39 | 0.46 | 1.20 | 0.63 | 1.02 |
| Pedregal | 0.46 | 0.58 | 0.84 | 0.46 | 0.71 |
| Plateros | 0.25 | 0.50 | 1.09 | 0.72 | 0.82 |
| Merced | 0.61 | 0.37 | 1.09 | 0.47 | 0.98 |
| Hangares | 0.25 | 0.54 | 1.47 | 1.05 | 1.04 |

Table 2: Statistical analysis for surface $O_3$;$CC$ correlation coefficient, $RMSE$ root mean square error, $RMSE_s$ root mean square error systematic, $RMSE_u$ root mean square error unsystematic , $d$ index of agreement

| Station | $CC$ | $d$ | $RMSE$ | $RMSE_u$ | $RMSE_s$ |
|---|---|---|---|---|---|
| Tacuba | 0.77 | 0.83 | 0.04 | 0.03 | 0.03 |
| Acatlan | 0.74 | 0.82 | 0.04 | 0.03 | 0.03 |
| San Agustin | 0.69 | 0.72 | 0.04 | 0.02 | 0.03 |
| Azcapotzalco | 0.73 | 0.69 | 0.04 | 0.03 | 0.03 |
| Xalostoc | 0.60 | 0.67 | 0.05 | 0.03 | 0.04 |
| Merced | 0.71 | 0.83 | 0.04 | 0.03 | 0.02 |
| C. Estrella | 0.70 | 0.80 | 0.04 | 0.03 | 0.03 |
| Lagunilla | 0.68 | 0.79 | 0.05 | 0.03 | 0.03 |
| Tlalnepantla | 0.79 | 0.86 | 0.03 | 0.02 | 0.02 |
| Pedregal | 0.82 | 0.84 | 0.04 | 0.02 | 0.03 |

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# References

Bossert, J.E.: 1997, An investigation of flow regimes affecting the Mexico City region, *Journal of Applied Meteorology*, Vol. **36**, No. 2, pp. 119-140.

Diaz-Nigenda, E.:2005, Reporte Anual Maestria en Ingenieria Ambiental, Universidad Nacional Autonoma de Mexico.

Fast, J.D. and S. Zhong: 1999, Meteorological factors associated with inhomogeneous ozone concentrations within Mexico City basin,*Journal of Geographical Research*, Vol. **103**, No. D15, pp. 18927-18946.

Garcia R. A., T. Schoenemyer, A. Jazcilevich D., G. Ruiz-Suarez, V. Fuentes-Gea: 2000, *Implementation of the Multiscale Climate Chemistry Model (MCCM) for Cental Mexico*, Air Pollution VII, ISBN 1-85312-822-8, Editors: J.W.S Longhurst, C.A. Brebbia, H. Power, WIT Press, pp. 71-78

Grell G.A., J. Dudhia and D. R. Stauffer: 1994, A description of the fifth-generation Penn State/NCAR Mesoscale Model(MM5), NCAR Tehcnical Note TN-398+SRT.

Grell G.A., S. Emeis, W. R. Stockwell, T. Schoenemeyer, R. Forkel, J. Michalakes, R. Knoche and W. Seidl: 2000, Application of a multiscale, coupled MM5/Chemistry model to the complex terrain of the VOLTAP valley campaign, *Atmospheric Environment* **34**, pp. 1435-1453.

INEGI: 1999, Sistema de Cuentas Nacionales de Mexico:1993-1997, PIB por entidad federativa.

Jazcilevich D. A., A. Garcia, L. Gerardo Ruiz-Suarez: 2003,A study of air flow patterns affecting pollutant concentrations in the Central Region of Mexico, *Atmospheric Environment*, **37**, pp. 183/193.

Jazcilevich D. A., A. Garcia, Caetano, E.: 2005,Locally induced surface air confluence by complex terrain and its effects on air pollution in the Valley of Mexico, *Atmospheric Environment*, submitted for publication.

Stockwell W. R., R. P. Middleton, J. S. Chang and X. Tang: 1990, The second generation regional acid deposition model chemical mechanism for regional air quality modeling, *J. Geophys. Res.* **95**, pp. 16343-16367.

Skidmore, E.L. and J. Tatarko (eds). 1999. Wind Erosion - An International Symposium/Workshop. Proc. USDA-ARS Wind Erosion Research Unit. 3-5 June 97 KSU, Manhattan, KS, USA CD and http://www.weru.ksu.edu/index.htm.

USDA-ARS-WERU. 2001. The Wind Erosion Prediction System: WEPS 1.0 user manual draft. J. Tatarko (Ed.). USDA-ARS-Wind Erosion Research Unit. Manhattan, KS USA. 175pp. Available at: http://www.weru.ksu.edu/weps

Vega, Elizabeth: 2004, Monitoreo y analisis de particulas, Seminario Sobre Contaminacion Atmosferica, Imstituto Nacional de Ecologia, February, 2004.

Willmott C.J.: 1981, On the validation of models, *Physical Geography* **2** pp. 184-194.