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Projected Carbon Dioxide Levels for the Year 2020 in Phoenix, Arizona

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ABSTRACT / Previous studies have demonstrated profound increases to CO_2 levels in the Phoenix, Arizona metropolitan area and this increase is linked to anthropogenic sources, including traffic volume, land-use patterns, and human population. These studies all agree that vehicular emission is the largest CO_2 source in urban areas. Our goal, therefore, is to predict CO_2 levels in the Phoenix area for the year 2020 under different fuel-efficiency-standards scenarios. In February 2002, legislation was introduced to increase Corporate Average Fuel Economy (CAFE) standards for personal vehicles by ~30%. In this study, we present three scenarios for projected CO_2 levels for the year 2020 in the Phoenix metropolitan area. In one scenario, we assume that fuel efficiency remains the same, representing no changes to CAFE standards. In the other two scenarios, we reflect possible changes to the standards: one based on the 30% increase in efficiency as proposed and the second based on a 15% increase in efficiency standards. These scenarios were created through a geographic information system model of current and future CO_2 emissions. The model was based on data from current CO_2 levels from land use, traffic, and population and projected CO_2 levels from the same sources. Results show a decrease in CO_2 emissions from soils as a result of land-use conversion from agriculture to urban. Additionally, results show an increase in the CO_2 levels for the year 2020 compared with 2000 under the 15% increase in CAFE standards and no change in CAFE standards. Under a 30% increase in CAFE standards, CO_2 emissions decreased below 2000 levels.

The global carbon budget refers to exchanges in atmospheric carbon dioxide (CO_2) through global sources and sinks of carbon. Corresponding with combustion associated with the industrial revolution ~150 years ago, changes to the global carbon budget have occurred. Many coordinated efforts have been established to understand how human activities affect the global carbon budget by examining the process by which the oceans and terrestrial biosphere store and exchange carbon with the atmosphere (IPCC 2001; Houghton and others 1990; Law and Simmonds 1996; Keeling and others 1996). Without exception, human activities—mostly concentrated in urban areas—have changed the global carbon budget due to greater population, fossil fuel combustion, land-use conversion, and cement plants.

There remains general consensus that CO_2 levels are higher in urban areas, despite differences in data collection methods, analysis techniques, and local meteorological conditions. Even though direct comparisons are difficult to make, several studies report that urban levels are higher than rural areas: urban areas in Nottingham, England are 5 ppmv higher than the surrounding rural areas (Berry and Colls 1990), 20 ppmv higher in suburban Vancouver, British Columbia (Reid and Steyn 1997), 30 ppmv higher in an urban canyon Fukuoka City, Japan (Takagi and others 1998), 90 ppmv higher in Cincinnati, Ohio, and 185 ppmv higher in Phoenix, Arizona. In Phoenix, the higher CO_2 levels have been linked to anthropogenic sources, including traffic volume, land-use patterns, and human population (Idso and others 1998a, 1998b; Koerner and Klopatek 2002; Wentz and others 2002; Day and others 2002).

Despite the interest in examining CO_2 in an urban setting, models predicting future levels of CO_2 have remained largely global in scale. The Intergovernmental Panel on Climate Change (IPCC 2001) reports three different models, each projecting different levels of CO_2. The most commonly used model reports a 1% per year compound increase of CO_2 with a doubling of CO_2 by year 2070. Models report an increase from 540 to 970 ppmv by the year 2100, which is 90–250% higher than it was in the 1700s (IPCC 2001). Current global average of CO_2 is 370 ppmv, about 95 ppmv greater

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than the preindustrial concentrations. The IPCC scenarios suggest that in the next century, there might be an increase by two to six times what we had in the last century.

Our concern is that we need local models to predict CO_2 levels in addition to the global models, which have had limited focused on oceanic and terrestrial biosphere linkages. Global models have not considered localized changes in human activities, which have occurred primarily in urban areas, and have the potential to either increase or decrease the amount of CO_2 emitted. Therefore, predicting future atmospheric CO_2 levels requires examination at scales more localized than the global models by examining the spatial distribution of activities in a local urban setting. We have the potential to understand future atmospheric CO_2 concentration trajectory resulting from current emissions in an urban setting.

One strategy to manage CO_2 is to reduce the levels of fossil fuel combustion. In February 2002, legislation was introduced to increase Corporate Average Fuel Economy (CAFE) fuel efficiency standards for personal vehicles (NCSL 2002). Under the current policy, cars must average 27.5 miles per gallon (mpg) and light trucks, SUVs and minivans must average 20.7 mpg. The new legislation would require all personal vehicles to average 36 mpg by the year 2016, an approximate 30% increase in efficiency.

Given general agreement that vehicular emission is a major CO_2 source in the urban area, our goal is to predict future CO_2 levels in metropolitan Phoenix, Arizona. We assume that population growth and land-use changes will occur with the obvious consequence of higher volumes of traffic. The only way to regulate CO_2 levels with this population growth is through emissions standards rather than land-use-change scenarios. Therefore our model examines how CO_2 levels will look under a fixed population growth and land-use-change scenario and three alternative vehicular emission standards. In one scenario, we assume that fuel efficiency remains the same representing no changes to CAFE standards. In the other two scenarios, we reflect possible changes to the standards: one based on the 30% increase in efficiency as proposed and the second based on a 15% increase in efficiency standards. These scenarios were created through a georgraphic information system (GIS)-based model of current and future CO_2 patterns. The models were based on data from current CO_2 emissions from land use, traffic, and population and projected emissions from the same data sources.

Methods

Study Area

This study was conducted in the Phoenix, Arizona metropolitan area, which is located in the upper Sonoran Desert (Brown 1982). The area is dominated by warm temperatures (26°C annual mean maximum) and low precipitation (20 cm annually). This climate influences the local vegetation, which was previously dominated by stands of creosote bush (*Larrea tridentata*) and burrsage (*Ambrosia deltoidea*). The predominate soil type is Aridisol, which are light-colored mineral soils low in organic C (Hendricks 1985). The dry climate also influences the soil C storage potential. The Phoenix area is dominated by three major patch types: desert, urban, and agriculture. The C storage potential for each of these patch types varies greatly. Desert patches have very low soil organic C levels (0.2–0.5%). The amount of soil organic C increases in agricultural and urban patches due to water subsidies allowing for greater productivity.

The city is in a mountainous area with mountains that rise ~1000 m above the urban valley. The urban valley topography promotes a closed circulation pattern whereby gases, such as CO_2, are not dispersed but are trapped in the valley among the human population. Comrie and Diem (1999) found that the dominant meteorological factor influencing CO concentrations was the nocturnal low-level temperature inversion.

The Phoenix, Arizona metropolitan area consists of the city of Phoenix and 14 other incorporated urban cities, (see Figure 1). In 2000, the metropolitan area was ranked the 14th largest urban area in the United States, with a population of 3.25 million persons. This represents a growth rate of 45.3% from 1990 to 2000 (United States Census 2001). Over the next 20 years, the resident population is projected to increase almost 70%, regional transportation is expected to rise nearly 80%, and congestion levels are expected to rise (MAG 1999).

The pattern of urban growth is characterized by low-density urban sprawl that is moving outward from the urban core into the surrounding agricultural and desert land (Jenerette and Wu 2001). Most of the urban development has taken place in the valley, but projected growth places future urban areas into the nearby mountains. One looming problem in this development of this region remains transportation; this is a city that has depended almost exclusively on automobiles as the primary mode of transportation. Highway building in the region has not kept up with the demand. As the number of jobs in the core of the city increase and

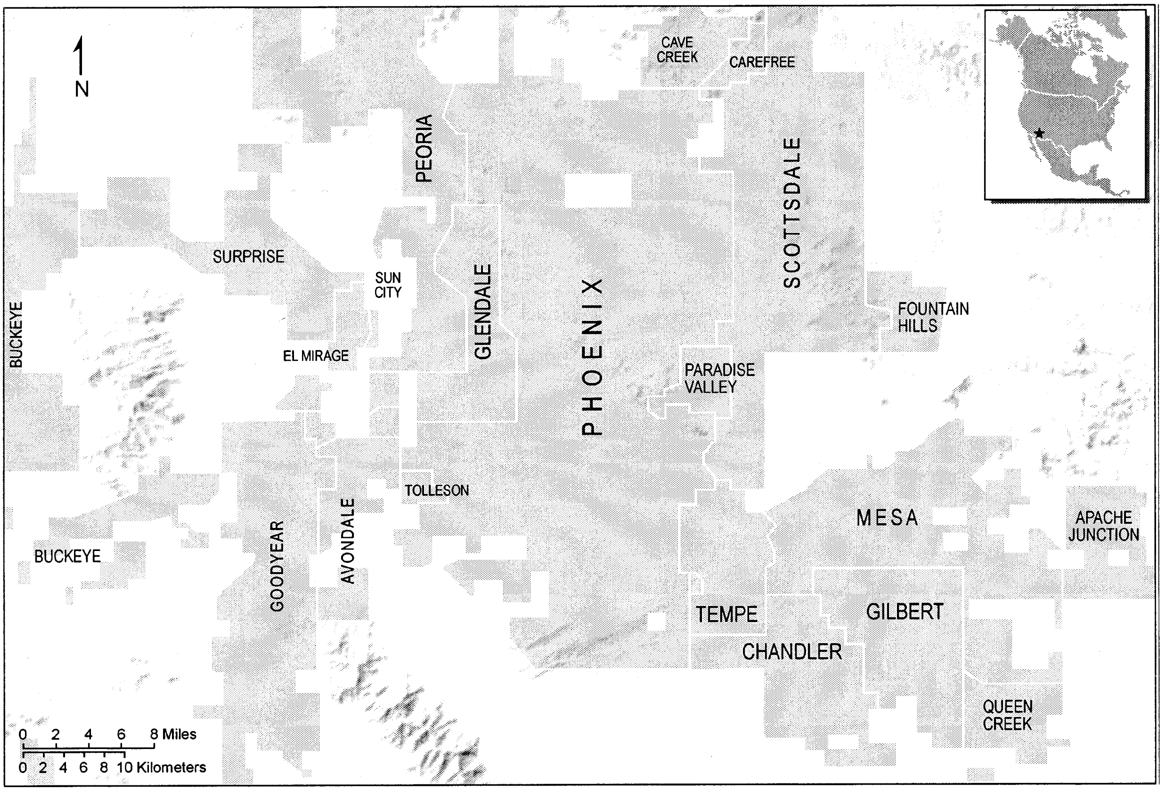

Figure 1. Map of the Phoenix, Arizona metropolitan area including 14 other incorporated cities. The gray areas represent the incorporated urban areas.

residential areas continue to move outward, the problem will only worsen.

Data Sources and Analysis

The structure of current CO_2 levels have been linked to natural and anthropogenic sources. Koerner and Klopatek (2002) showed that the major sources of CO_2 for the Phoenix metropolitan area are soils (dependent on land use), vehicle use, human respiration, power-plant emissions, landfills, and airplane emissions in descending order. For this study, we anticipate changes in CO_2 emissions from soils as a result of land-use change, human population growth, and increased traffic volumes. CO_2 emissions for power plants, landfills, and airplanes are held constant. Power-plant and landfill emissions can be held constant because no new power plants or landfills are scheduled for construction during the projected time period. We do anticipate changes in airplane usage, but airplane emissions levels are low when compared to other sources that we deem any changes will be insignificant when compared with other sources.

Land-use-change data for 2000 and 2020 were obtained from Jenerette and Wu (2001), and these data were used to predict changes in soil CO_2 emissions from 2000 to 2020. These land-use-change data were classified as desert, agriculture, or rural land uses. Annual soil respiration rates were applied to each land-use type. The soil respiration rates for agriculture and desert were determined as in Koerner and Klopatek (2002). An urban soil respiration rate was determined from an area-weighted mean of all urban land-use types identified in Koerner and Klopatek (2002). The soil respiration rates for desert, agriculture and urban were 6, 82, and 14 Mg/ha/year, respectively.

Population data were obtained from the Maricopa Association of Governments (MAG). The population data were based on the 1995 Special Census and were spatially arranged in traffic analysis zones. These data configurations were used because they were the only data projected for the year 2020. United States Census data for 2000 were not used for the 2000 calculations in order to maintain consistency between data sources and spatial configurations. The population data based on the 1995 Special Census was ~10% lower than 2000 U.S. Census figures. A human respiration rate of 31.5 mol CO_2/person/day was applied to the population data. This human respiration rate is based on the fol-

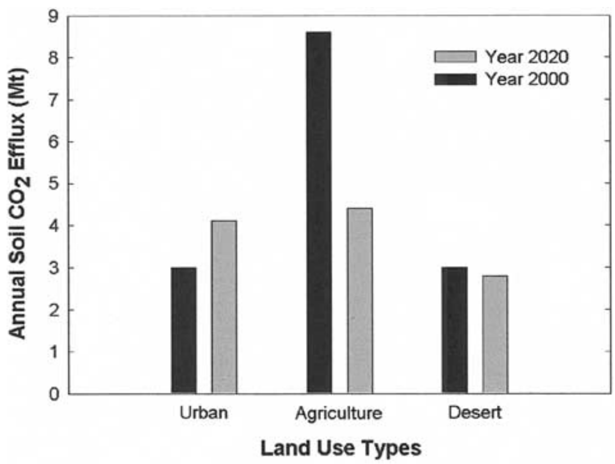

Figure 2. Annual soil CO_2 emissions for the Phoenix, Arizona metropolitan area for the years 2000 and 2020.

lowing assumptions: An average person weighs 70 kg, has a metabolic rate twice the resting rate, and the only metabolic fuel is a carbohydrate.

On-road motor vehicle CO_2 emissions for the entire study area were determined using average weekday traffic volumes modeled for the years 2000 and 2020 by MAG. Vehicle CO_2 emissions for 1999 were obtained from the Arizona Department of Environmental Quality, and the mean for all vehicles tested that year was 0.23 g CO_2/m. This rate was applied to both 2000 and 2020 traffic volume data under the assumption that vehicle emissions would remain constant under current fuel-efficiency standards. A rate of 0.16 g CO_2/m was applied to 2020 traffic volume data assuming a 30% increase in fuel-efficiency standards, and a rate of 0.20 g CO_2/m was applied to 2020 traffic volume data assuming a 15% increase in fuel efficiency standards.

The land-cover data from Jenerette and Wu (2001) for 2000 and 2020 were provided in a gridded format with a spatial resolution of 250 m. The traffic analysis zones with 2000 and 2020 predicted populations and the 2000 and 2020 average weekday traffic volume data were provided by MAG in vector data format and were converted to a 250-m grid format. Emissions for each data type and prediction scenario were then calculated to obtain an annual CO_2 emission from each source.

Results

More urban land uses are predicted by 2020, which results in a 37% increase in soil CO_2 efflux for urban land uses from 3.0 Mt CO_2 in 2000 to 4.2 Mt CO_2 in 2020 (Figure 2). Agricultural land use decreases result in a 50% decrease in soil CO_2 efflux from 8.5 Mt CO_2 in 2000 to 4.3 Mt CO_2 in 2020 is predicted. Desert land area is also predicted to decrease, which results in a 7% decrease in annual soil CO_2 efflux from 3.0 Mt CO_2 in 2000 to 2.8 Mt CO_2 in 2020. The large decrease in agricultural land use results in a total decrease in soil CO_2 efflux from 2000 to 2020 (Table 1).

The annual CO_2 emissions for vehicles increase 62% from 10.1 Mt CO_2 in 2000 to 16.4 Mt CO_2 in 2020 under current fuel-efficiency standards (Figure 3). Under a scenario of a 15% increase in fuel-efficiency standards compared to current standards, the annual CO_2 emissions for vehicles increase 38% from 10.1 Mt CO_2 in 2000 to 13.9 Mt CO_2 in 2020. Under a scenario of a 30% increase in fuel-efficiency standards compared to current standards, the annual CO_2 emissions from vehicles still increase 14% from 10.1 Mt CO_2 in 2000 to 11.5 Mt CO_2 in 2020. Even with a 30% increase in fuel-efficiency standards, the predicted increase in traffic volume overrides the increased fuel efficiency.

The CO_2 emissions from human respiration increase 50% from 1.5 Mt CO_2 in 2000 to 2.25 Mt CO_2 in 2020. The increase in human respiration can be attributed directly to an increase in population. When evaluating all of the major emissions sources, a total of 28.5 Mt of CO_2 was emitted into the atmosphere in 2000 (Table 1). CO_2 emissions increase to 32.2 Mt CO_2 by 2020 under the current fuel-efficiency standards, and to 29.7 Mt CO_2 under a 15% increase in fuel efficiency standards. Under a 30% increase in fuel-efficiency standards, total CO_2 emissions for the entire Phoenix metropolitan area decrease to 27.3 Mt CO_2, 4% below 2000 levels.

Discussion

Urbanization is increasing throughout the world, and the impact of urbanization on global change can be seen through five main impacts: land-use/cover change, altered biogeochemical cycles, altered hydrology, decreased biodiversity, and climate change. Climate-change impacts occur both on a global and a local scale. Understanding impacts of land-use change and CO_2 emissions at a local scale is necessary to evaluate the broader influence of these factors at a global scale. Currently, we are able to monitor land-use/cover change in urban ecosystems (Stefanov and others 2001), but we need to monitor other variables such as CO_2, which may have a global impact. Previous studies have shown that Phoenix has a pronounced heat island as well as elevated CO_2 levels (Balling and Brazel 1987, 1988; Idso and others 1998a; Wentz and others 2002). Each of these effects alters local climate as well as influencing global climate. In order to understand how

Table 1. CO_2 emissions from the six largest sources in the Phoenix, AZ metropolitan area for the years 2000 and 2020

	2000	2020 (0% increase)	2020 (15% increase)	2020 (30% increase)
Soil respiration (Mt)	14.6	11.3	11.3	11.3
Vehicle emissions (Mt)	10.1	16.4	13.9	11.5
Human respiration (Mt)	1.5	2.2	2.2	2.2
Power plants (Mt)	1.8	1.8	1.8	1.8
Landfills (Mt)	0.4	0.4	0.4	0.4
Airplanes (Mt)	0.1	0.1	0.1	0.1
Total (Mt)	28.5	32.2	29.7	27.3

Note: The three different projections for the year 2020 represent no increase, a 15% increase and a 30% increase in fuel efficiency standards.

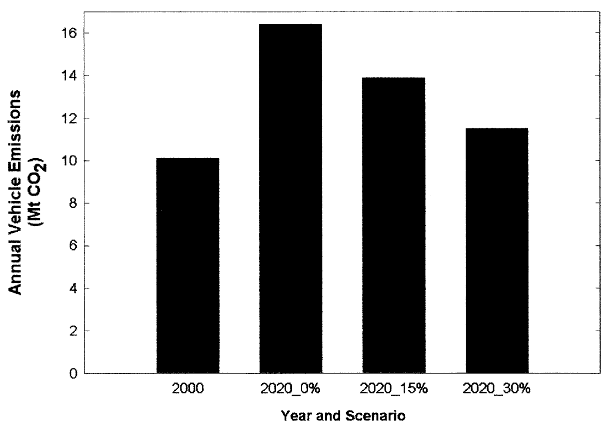

Figure 3. Annual CO_2 emissions from vehicles in Phoenix, Arizona for the years 2000 and 2020. Three scenarios are present for the year 2020. No change in Corporate Fuel Economy (CAFE) standards is shown by 2020_0%. A 15% increase in CAFE standards is represented by 2020_15%, and a 30% increase in CAFE standards is represented by 2020_30%.

future urbanization and policy decisions may alter global climate, local predictions are necessary.

Future urbanization in this arid region will reduce soil CO_2 emissions because most urban land conversion will be from agricultural land uses over the next 20 years. This reduces CO_2 soil efflux because soil moisture is the largest contributing factor to soil CO_2 efflux in arid regions such as Phoenix and because urban landscapes are irrigated far less than agricultural land uses. This study does not account for the loss of a vegetative C sink in the agricultural to urban land-use conversion. Vegetation plays an important role in the pattern of elevated CO_2 levels, especially during the day (Wentz and others 2002). We also did not account for aboveground vegetative respiration because we assumed vegetation to be a net C sink (Schlesinger 1991).

In addition to the land-use/cover change associated with urbanization, increases in population will affect CO_2 emissions. Increasing populations in urban ecosystems results in increased respiration predominately associated with imported C into the ecosystem. As the population increases and agricultural land is converted to urban land uses, the Phoenix metropolitan area will increase reliance on imported food sources, which may further accelerate land-use change elsewhere to support the growing urban population. Luck and others (2001) have shown that the agricultural land area required to support urban ecosystems can be quite extensive.

Increasing population in urban areas is also associated with increasing traffic volumes. Along with the air quality issues involved with fossil fuel combustion in personal vehicles (Tiao and others 1989), increasing vehicle usage leads to increased urban CO_2 levels. Changing policies regarding fuel efficiency can reduce CO_2 emissions from vehicles. As shown in this study, traffic volumes are expected to increase in the future (MAG 1999), but the effect of increased vehicle usage on local CO_2 levels can be controlled by increasing the fuel efficiency of personal vehicles. Even with a 30% increase in fuel efficiency, CO_2 emissions from vehicles will still increase by 2020, but the increase is small when compared to the other scenarios. The scenarios presented here provide a useful tool to evaluate the impact of government policies on a local scale.

The emissions source approach used here is useful for monitoring how future policy decisions may affect CO_2 emissions on a local scale. By modeling future CO_2 emissions in urban areas, we can evaluate how different policy decisions can affect both local and global environments. Current models often evaluate changes at the global scale, but local-scale events collectively impact the global environment. In addition, urban environments are changing rapidly. By modeling the changes that may occur in urban environments, we can better understand the wider impacts at a global level.

Conclusions

Most projections agree that urbanization will most likely increase in the future. Most of the world's population increase will be absorbed by urban areas through either population growth or rural to urban migration (United Nations Population Division 2002). This will result in the number of million-plus cities to increase, especially in the less developed regions such as Latin America, Africa, and South Asia (Berry 1990). As developing nations become more industrialized, the CO_2 emitted into the atmosphere will increase because developed countries produce four times more CO_2 than developing nations (Boyden and Dovers 1992). Most of the production of CO_2 in urban areas is a result of fossil fuel combustion in vehicles as well as power plants (Koerner and Klopatek 2002). As urban areas expand outward, energy requirements will increase, therefore increasing the amount of CO_2 emitted into the atmosphere.

Because of predicted urban expansion worldwide, we have presented three different scenarios under which CO_2 emissions may occur in the year 2020 for the Phoenix metropolitan area. These scenarios are based on differing levels of CAFE standards. Altering fuel efficiency appears to be the way in which CO_2 emissions may be most affected within the next 20 years, as legislation to increase CAFE standards has already been proposed. We have used these scenarios to develop a GIS model of CO_2 emissions and have determined that increases in CAFE standards have the capacity to offset CO_2 increases associated with increasing urbanization, indicating that policy decisions on the national level have the capacity to reduce CO_2 emissions on the local level.

Governments in both developing and developed nations have the opportunity to examine how policy changes may affect urban-scale CO_2 emissions, such as strategies to limit CO_2 emissions during fossil fuel combustion. The example we examined in this article was how changes to the CAFE fuel-efficiency standards for personal vehicles would change CO_2 emissions for the Phoenix area. Further studies are needed that explore the relationship between policy changes and CO_2 in urban areas. Most models that forecast CO_2 are globally based and attempt to provide a link between sources and sinks in the oceanic and terrestrial biospheres. In contrast, this research has contributed to a better understanding of how human activities have the potential to either increase or decrease the amount of CO_2 emitted at a local scale. Through a better understanding of localized sources, including human population, land-use/cover change, and traffic, we can better project urban atmospheric CO_2 concentrations using current emission levels and human activities as the basis for projected levels. Future research would ideally attempt to link this knowledge with globalscale research on carbon sources and sinks. In addition, future research would also attempt to account for changes in irrigation patterns resulting from possible climatic changes as well as further reductions in CO_2 emission due to increased hybrid vehicle usage.

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