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Environmental Sustainability and Climate Change

Impacts on Transportation

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Medio ambiente y cambio climático y su impacto en el transporte vial. XVI Congreso Argentino de Vialidad y Tránsito. 22 de Octubre Córdoba, Argentina.

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Overview of Global Climate Change

and the Environment

Medio ambiente y cambio climático y su impacto en el transporte vial. XVI Congreso Argentino de Vialidad y Tránsito. 22 de Octubre Córdoba, Argentina.

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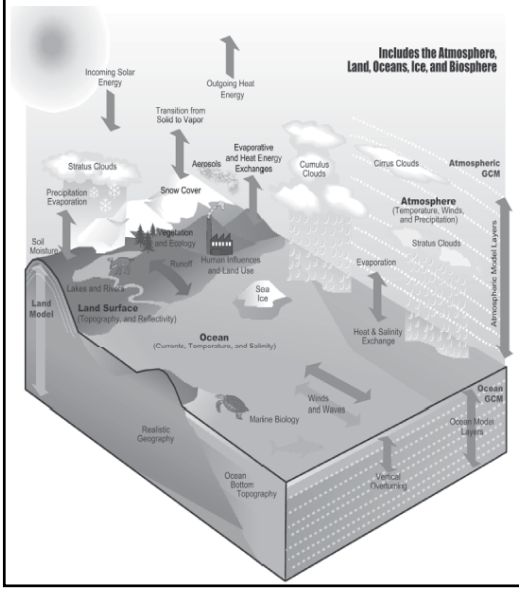
Overview of Global Climate Change and the Environment



Components of the climate system and their interactions, including the human component

(Source: Karl and Trenberth 2003, Figure 3, from Science, Vol. 302, No. 5651)

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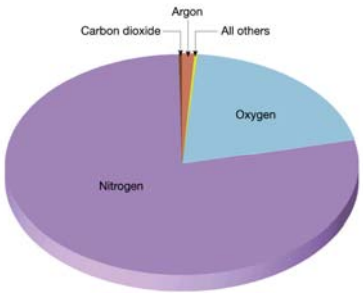
Overview of Global Climate Change and the Environment

- Natural “greenhouse” effect is real and is an essential component of the planet’s climatic processes
- A small proportion (roughly 2 %) of the atmosphere is, composed of GHGs
  - Water vapor
  - Carbon dioxide
  - Ozone
  - Methane



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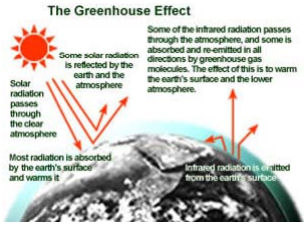
Overview of Global Climate Change and the Environment

- These gases prevent part of the heat radiated by the earth's surface from escaping to space
- The response of the global system is a climate that is warmer than it would be without the presence of these gases
- In their absence, the earth's temperature would be too low to support life
- Among the GHGs, water vapor is by far the most dominant, but other gases augment its effect through greater trapping of heat in certain portions of the electromagnetic (light) spectrum



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Overview of Global Climate Change and the Environment

- Direct atmospheric measurements made over the past 50 years have documented steady growth in the atmospheric abundance of carbon dioxide (CO_2)
- In addition to these direct, real-time measurements, ice cores have revealed the atmospheric CO_2 concentrations of the distant past
- Measurements using air bubbles trapped within layers of accumulating snow show that atmospheric CO_2 has increased by nearly 35 % over the Industrial Era (since 1750), compared with its relatively constant abundance over at least the preceding 10,000 years

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Overview of Global Climate Change and the Environment

- The predominant causes of this increase in CO_2 are the combustion of fossil fuels and deforestation
- The abundance of methane has doubled over the Industrial Era, although its increase has slowed during the past decade for reasons not clearly understood
- Increases in heat-trapping GHGs are projected to be amplified by feedback effects, such as changes in water vapor, snow cover, and sea ice

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Overview of Global Climate Change and the Environment

- Once in the atmosphere, these gases have a relatively long residence time, on the order of a century (IPCC 2001)
- Today GHGs are the largest human influence on atmospheric composition
- Climate change manifests itself primarily in a gradual but continuous increase in temperature, changes in precipitation patterns, a rise in sea levels, a reduction of the cryosphere, and shifts in the patterns of extreme events

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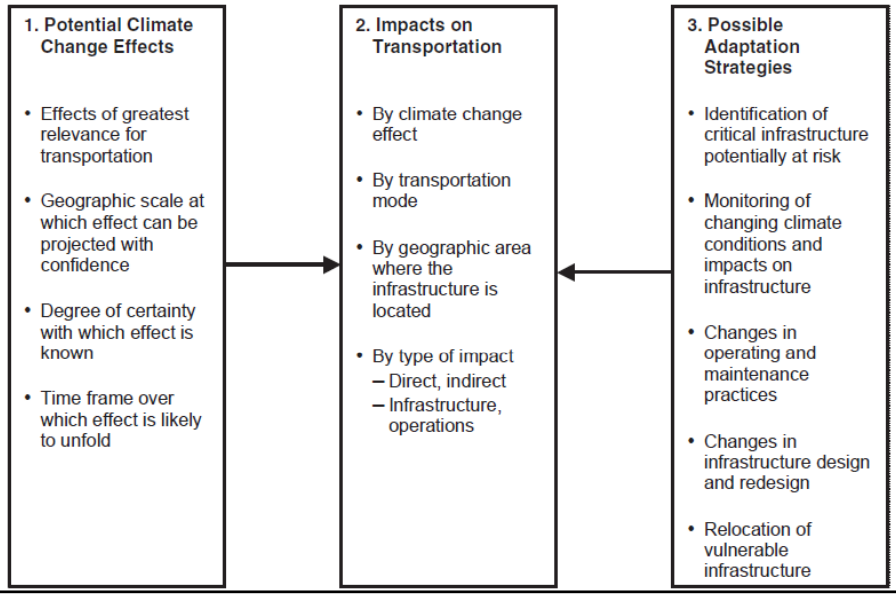
Possible Impacts of Climate Change



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Possible Impacts of Climate Change on Road Transport

- Climate variability and change impact transportation mainly through changes in weather extremes, such as very hot days, very cold days, or severe storms; changes in climate extremes, such as increases in the probability of intense precipitation events and extended droughts; and sea level rise.
- Usually, transportation systems are built for the typical weather and climate experienced locally, including a reasonable range of extremes, such as flooding events occurring as rarely as once in 100 years.

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Possible Impacts of Climate Change on Road Transport

- Moderate changes in the mean climate have little impact on transportation infrastructure or operations because the system is designed to accommodate changing weather conditions
- Changes in weather and climate *extremes* can have a considerable impact on transportation, especially if they push environmental conditions outside the range for which the system was designed.
- Weather and climate extremes of relevance to transportation have been changing over the past several decades with both negative and positive effects on the transportation system

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Possible Impacts of Climate Change

Potential Climate Change of Relevance to U.S. Transportation	Level of Uncertainty
Temperature	
Increases in very hot days and heat waves	Very likely
Decreases in very cold days	Virtually certain
Increases in Arctic temperatures	Virtually certain
Later onset of seasonal freeze and earlier onset of seasonal thaw	Virtually certain
Sea level rise	Virtually certain
Precipitation	
Increases in intense precipitation events	Very likely
Increases in drought conditions for some regions	Likely
Changes in seasonal precipitation and flooding patterns	Likely
Storms	
Increases in hurricane intensity	Likely
Increased intensity of cold-season storms, with increases in winds and in waves and storm surges	Likely

Level of Uncertainty Associated with Potential Climate Changes of Greatest Relevance to Transportation

(Source: Potential Impacts of Climate Change on U.S. Transportation, National research Council, 2008.)

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- Increases in heat-trapping GHGs are projected to be amplified by feedback effects, such as changes in water vapor, snow cover, and sea ice
- The resulting rise in surface temperature leads to less sea ice and snow cover, causing the planet to absorb more of the sun's energy, thereby raising temperatures even further
- Increases in evaporation and water vapor affect global climate in other ways besides causing rising temperatures, such as increasing rainfall and snowfall rates and accelerating drying during droughts

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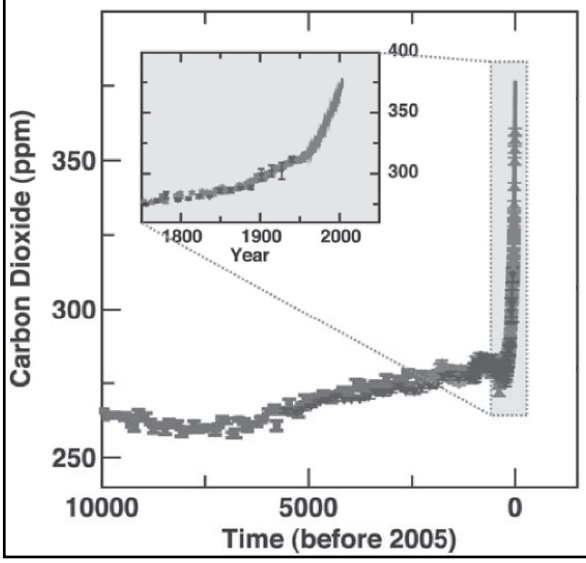

Atmospheric concentrations of carbon dioxide over the past 10,000 years (large panels) and since 1750 (inset panels)

Measurements are from a combination of ice cores (going back 10,000 years) and atmospheric samples in the 20th century.

(Source: IPCC 2007, Figure SPM-1, p. 15)

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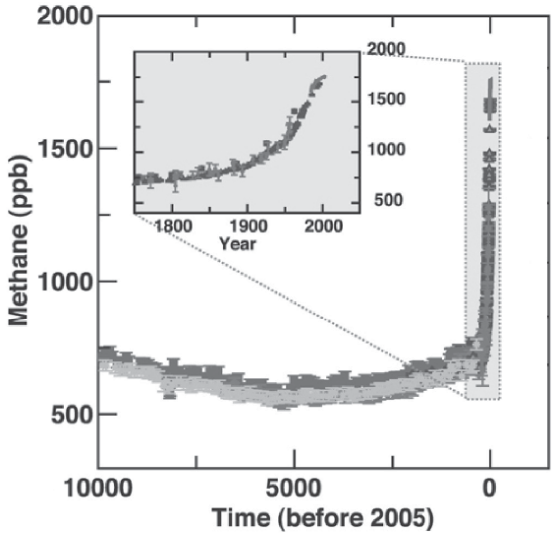
Climate Change and Transport Assessment



Atmospheric concentrations of methane over the past 10,000 years (large panels) and since 1750 (inset panels)

Measurements are from a combination of ice cores (going back 10,000 years) and atmospheric samples in the 20th century.

(Source: IPCC 2007, Figure SPM-1, p. 15)

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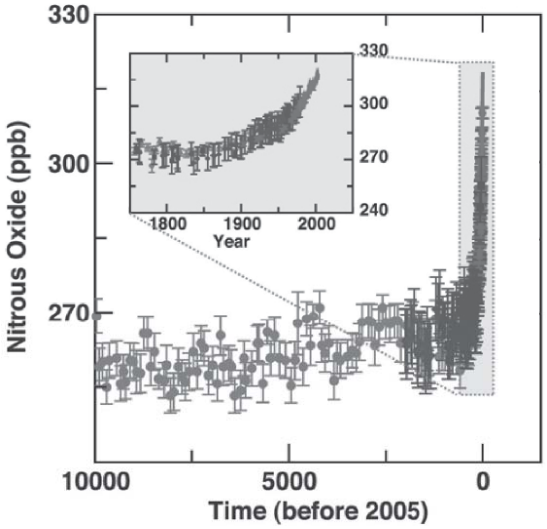

Atmospheric concentrations of nitrous oxide over the past 10,000 years (large panels) and since 1750 (inset panels)

Measurements are from a combination of ice cores (going back 10,000 years) and atmospheric samples in the 20th century.

(Source: IPCC 2007, Figure SPM-1, p. 15)

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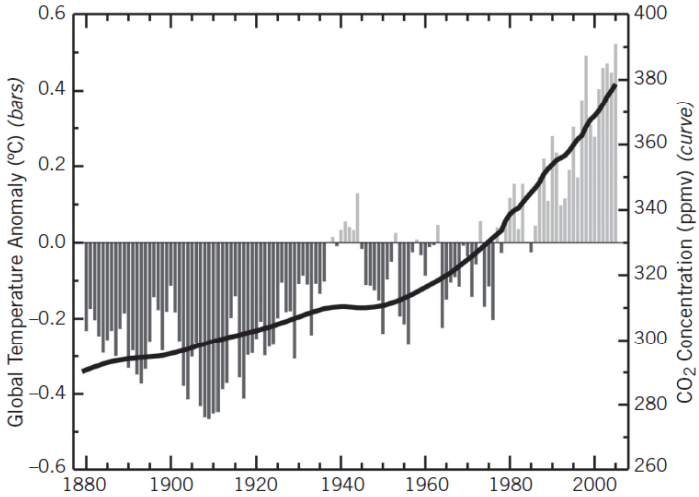

Globally averaged surface air temperature and carbon dioxide (CO2) concentration [parts per million by volume (ppmv)] since 1880

(Source: Updated from Karl and Trenberth 2003.)

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- Human activities also have a large-scale impact on the earth's land surface
- Changes in land use due to urbanization and agricultural practices are often most pronounced where people live, work, and grow food and are part of the human impact on climate
- Land use changes affect, for example, how much of the sun's energy is absorbed or reflected and how much precipitation evaporates back into the atmosphere

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- Large-scale deforestation and desertification in Amazonia and the Sahel, respectively, are two instances in which evidence suggests the likelihood of a human influence on regional climate (Andreae et al. 2004; Chagnon and Bras 2005)
- City climates differ from those in surrounding rural green areas, causing an “urban heat island” due to greater heat retention of urban surfaces, such as concrete and asphalt, as well as the waste generated from anthropogenic activities (Bornstein and Lin 2000; Changnon et al. 1981; Jones et al. 1990; Karl et al. 1988; Landsberg 1983; Peterson 2003).

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- U.S. temperatures have been rising over the past century, with more rapid increases since 1970 than earlier
- The warming has not been uniform across the continent. In general, the western portion of the contiguous United States has warmed more than the eastern portion
- Alaska has warmed the most rapidly, with temperatures in some regions increasing by more than 0.6°C (1.1°F) per decade since 1970

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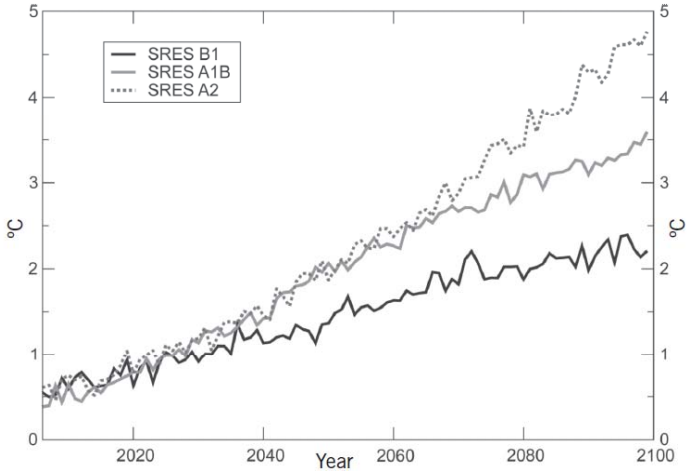

Annual surface air temperature anomaly, from the 1990–1999 average, for the eastern United States and for three different emissions scenarios

(SRES = Special Report on Emission Scenarios).

(Source: Peterson et al. 2006, Figure 5.)

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- Observed sea level changes from tide gauges and satellite altimeters indicate that the 1993–2005 rate of sea level rise was 3 mm per year (Church and White 2006)
- If this linear trend continues, sea level will rise by about 0.3 m by the end of the 21st century

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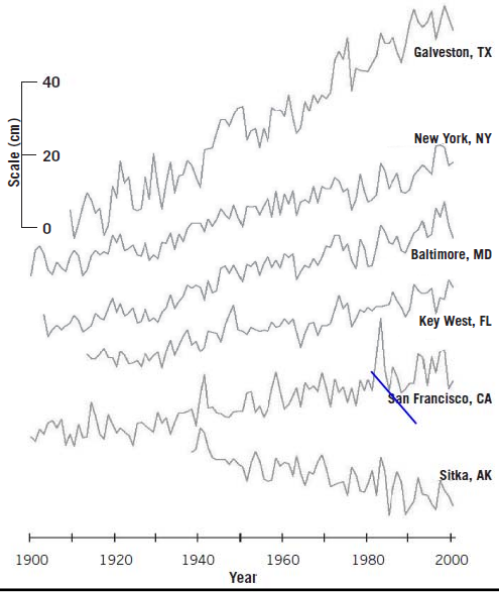

Trends in sea level from global changes in seawater volume and local changes in land surface elevation for representative locations in the United States.
(Source: NOAA 2001, p. 4.)

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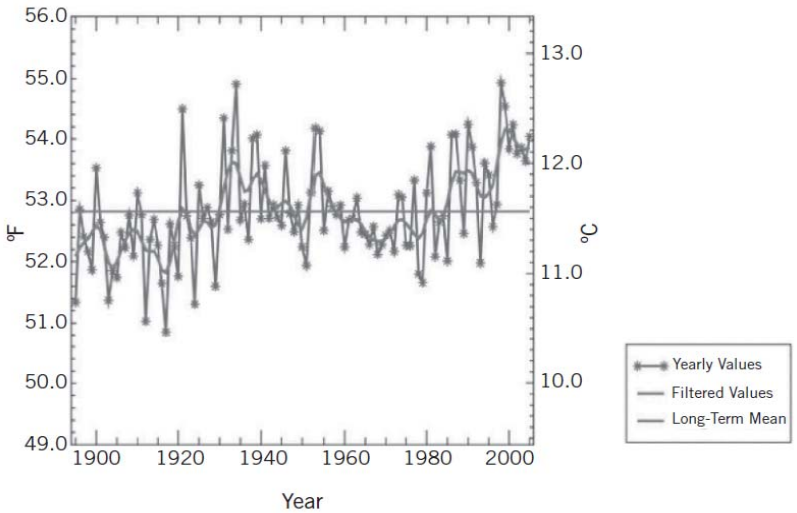

Area-averaged mean temperature time series for the contiguous United States. (Source: National Oceanic and Atmospheric Administration, National Climatic Data Center)

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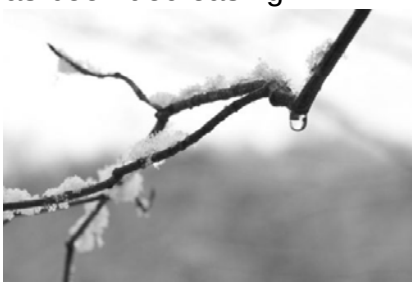
- The number of days with temperature above 32.2°C (90°F) and 37.7°C (100°F) has been increasing since 1970, but it is not quite as high today as during the early 1950s, when several areas, particularly the south-central U.S., had severe droughts
- The number of very cold days has been decreasing in the U.S. since about 1970
- This trend is also expected to continue into the future across the continent



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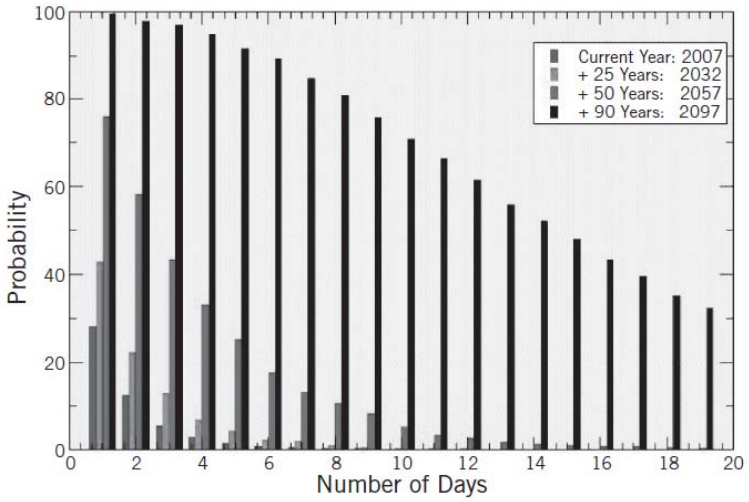

Current and future probability of having 1 to 20 days during the summer at or above 43.3C (110F) in Dallas, Texas.

(Source: Peterson et al. 2006, Figure 10b.)

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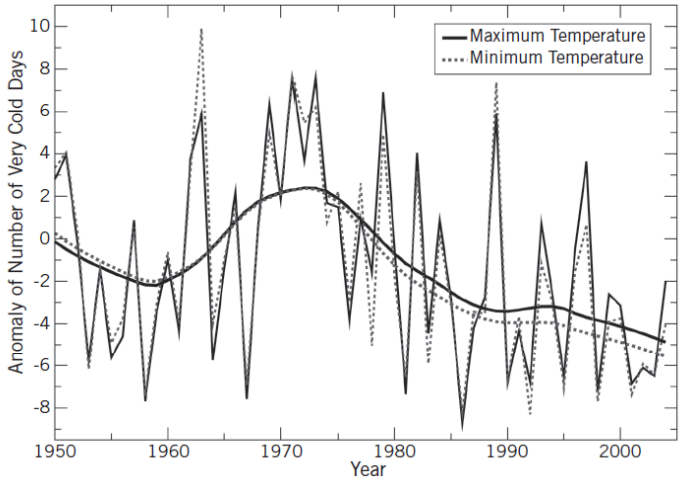

U.S. nationally averaged anomaly of the number of days at or below the coldest 10 percent of January maximum and minimum temperatures at each station (percentiles were calculated on a 1961–1990 base period).

(Source: Peterson et al. 2006, Figure 14.)

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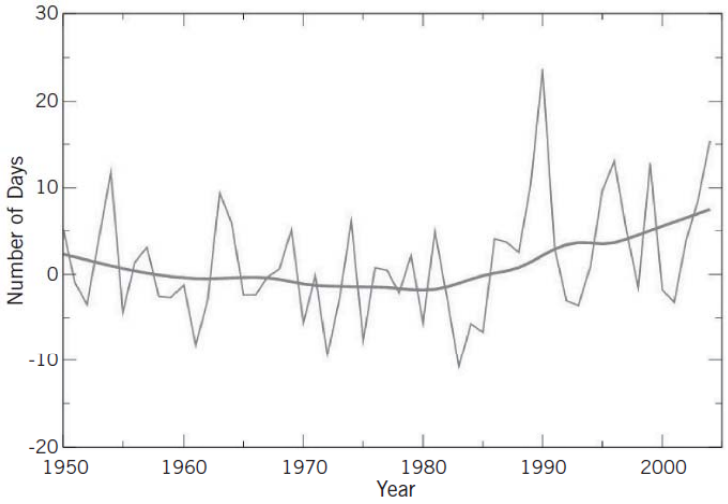

U.S. area-averaged anomaly of the length of time between the first day above 21.1C (70F) in the spring and the last day above 21.1C in the fall.

(Source: Peterson et al. 2006, Figure 19.)

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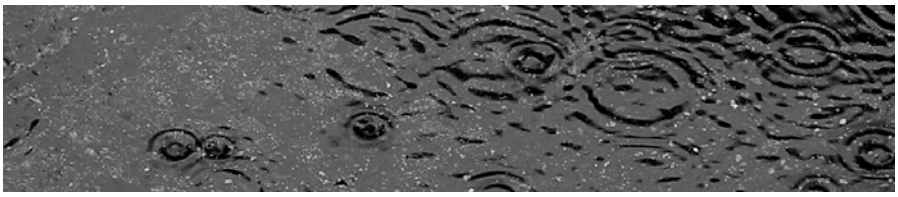
- Warmer climates, owing to increased water vapor, lead to more intense precipitation events even when total precipitation remains constant, with prospects for even stronger events when precipitation amounts increase
- In many regions of the world, increases in extreme precipitation are occurring even when total precipitation is relatively constant (Alpert et al. 2002; Groisman et al. 2003; Groisman et al. 2005)



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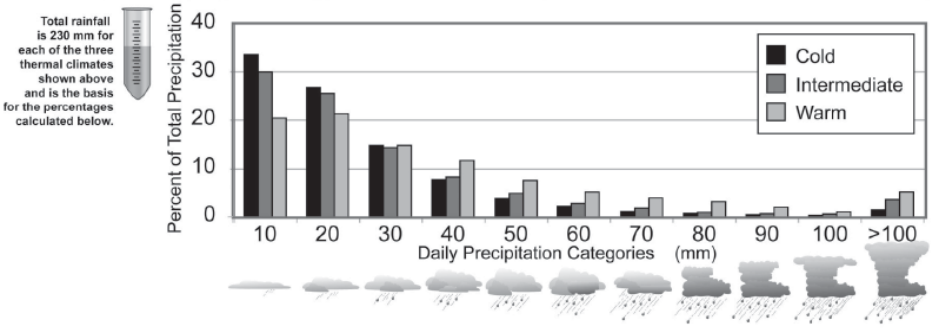

Diagram showing that warmer climates have a higher percentage of total rainfall coming from heavy and very heavy events.

The data are based on a worldwide distribution of observing stations, each with the same seasonal mean precipitation amount of 230 (±5) mm. In cool climates, there are more daily precipitation events than in warmer climates (adapted from Karl and Trenberth 2003)

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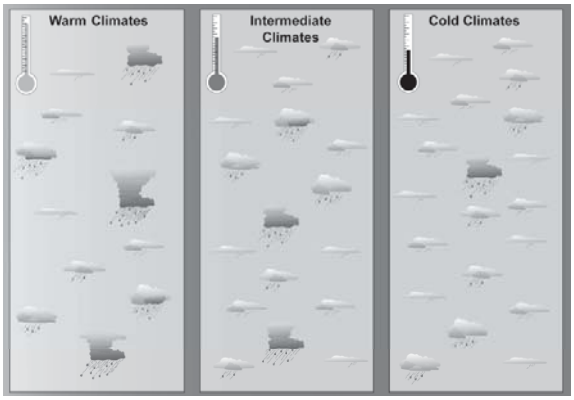

Diagram showing that warmer climates have a higher percentage of total rainfall coming from heavy and very heavy events. (Continued)

The various cloud and rain symbols reflect the different daily precipitation rates and are categorized in the top panel of the figure to reflect the approximate proportion of the different rates for cool, moderate, and warm climates across the globe.

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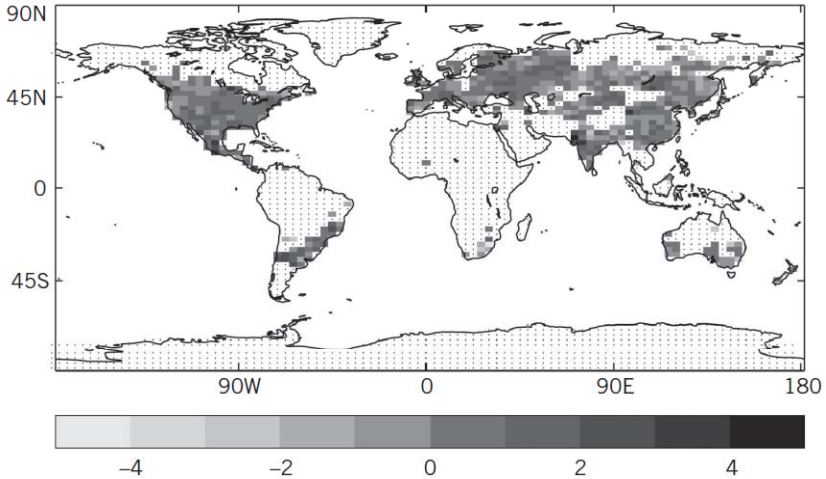

Trends in the contribution to total annual precipitation from very wet days (95th percentile) in percent per decade: regional changes, with stippled areas not reporting. Percentiles were calculated on the basis of 1961–1990 data.

(Source: Alexander et al. 2006. (Copyright 2006 by American Geophysical Union.))

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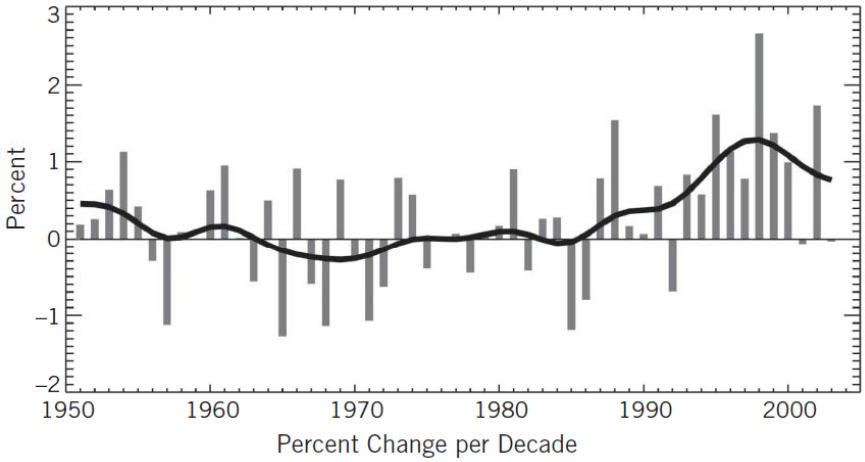

Trends in the contribution to total annual precipitation from very wet days (95th percentile) in percent per decade: worldwide changes in areas with adequate data. Percentiles were calculated on the basis of 1961–1990 data.

(Source: Alexander et al. 2006. (Copyright 2006 by American Geophysical Union.))

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- Over the past several decades, increases in the amount of precipitation occurring during the heaviest daily precipitation events have been observed in many areas of the central and eastern U.S. (Groisman et al. 2004; Groisman et al. 2005; Karl and Knight 1998)
- Over the 20th century, annual precipitation averaged across the United States increased by about 7%, but very intense precipitation events (above the 95th percentile) increased by nearly three times that rate (20%)

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- The practical implications of addressing these changes in precipitation are seen in the National Oceanic and Atmospheric Administration's (NOAA's) recent update of the Ohio River Basin's 100-year daily precipitation return period
- These data are used to help set engineering design standards related to excessive rainfall
- If there is a constant increase in intense precipitation events these design standards will need to be updated and structures, such as roadways, that were built to previous standards might not stand up to the increased precipitation.

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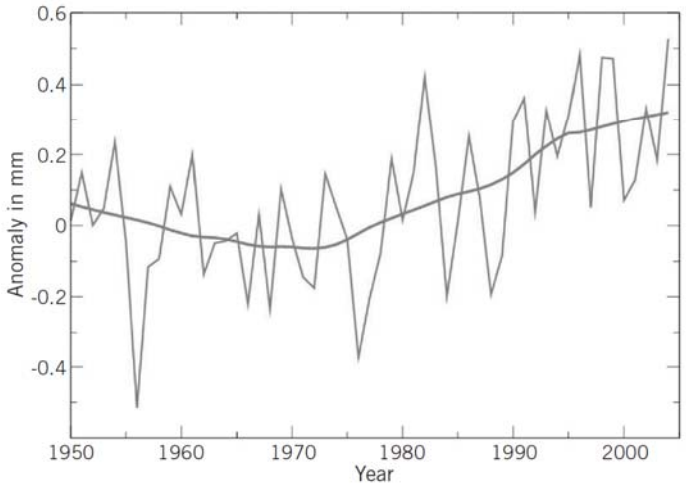

Upward trend in the Simple Daily Intensity Index (i.e., total precipitation per year divided by the number of days with precipitation) indicating that, on a U.S. area-averaged basis, when precipitation does occur, it tends to be heavier

(Source: Peterson et al. 2006, Figures 28a, 28b.)

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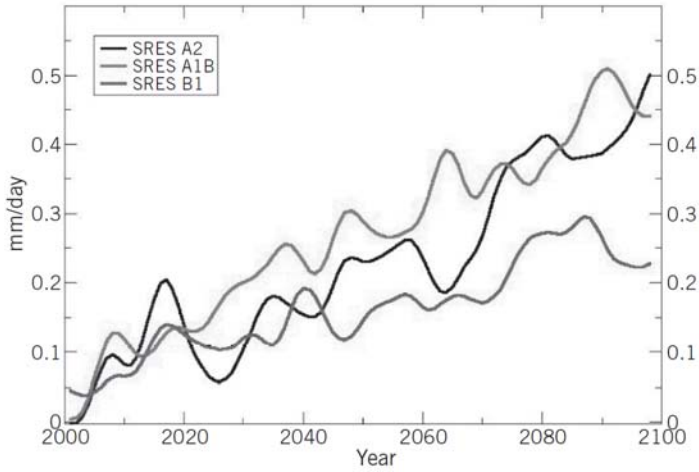

Median model-projected changes in the Simple Daily Intensity Index for the continental United States

(Source: Peterson et al. 2006, Figures 28a, 28b.)

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- U.S. droughts show pronounced multiyear to multidecadal variability, but there is no convincing evidence for systematic long-term trends toward more or fewer events.
- Drought calculations have shown that over the U.S., the increase in temperatures that may have led to increased evaporation has been compensated by a general increase in precipitation during the past few decades (Dai et al. 2004)
- With the result that there has been no general trend in drought intensity nationwide

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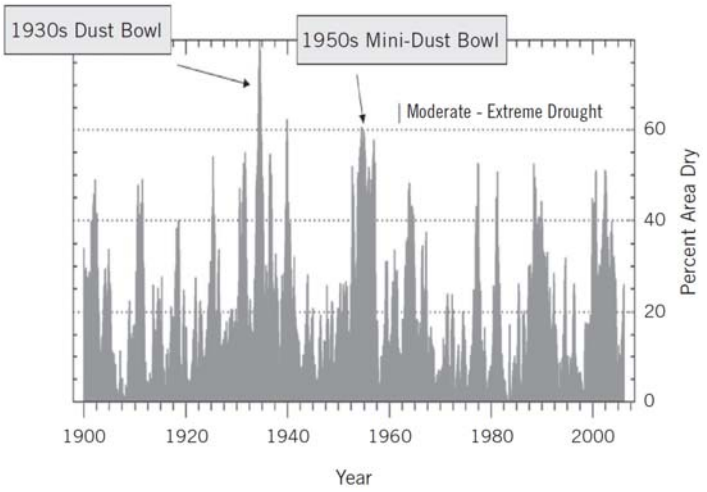

Percentage of the contiguous U.S. land area in moderate to severe drought, January 1900–March 2006, based on the Palmer Drought Index.

(Source: NOAA, National Climatic Data Center.)

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- The record-breaking hurricane season of 2005, especially the havoc created by Katrina, raised public awareness of the dangers of hurricanes to new heights
- Hurricanes respond to a number of environmental factors, including ocean temperatures, atmospheric stability, wind changes, El Niño, and others
- Since 1995, Atlantic hurricane activity has increased substantially, with more and more intense hurricanes, compared with the previous two decades

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- An important consideration with regard to hurricane intensity is the trend toward warmer sea surface temperatures, particularly in the tropical Atlantic and the Gulf of Mexico, indicating that climate change may play some role in increased hurricane intensity (Emanuel 2005; Webster et al. 2005)
- In the near term, it is expected that favorable conditions for Atlantic hurricanes will persist for the next decade or so on the basis of previously active periods

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- For the longer term, climate models project an increase in the intensity of strong hurricanes in the 21st century (Bengtsson et al. 2007;McDonald et al. 2005; Oouchi et al. 2006; Sugi et al. 2002)
- Given these conditions (stronger hurricanes and warmer tropical sea surface temperatures), climate models also predict an increase in storm rainfall rates of about 20% (T. R. Knutson, personal communication, 2006)

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- The climate changes discussed earlier may have secondary effects
- Visibility is one such effect
- For example, if the number of intense extratropical storms increases, they may be accompanied by more time with low visibility during heavy snowfall events (Rasmussen et al. 1999)
- Projections of drying in the interior of continents would imply the possibility of increases in blowing dust

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- The risk of forest wildfires in the American West is strongly associated with increased spring and summer temperatures and an earlier spring melt (Westerling et al. 2006)
- Therefore, wildfire-induced decreases in visibility are likely to become more frequent
- Transportation is significantly affected when visibility drops to less than about 400 m (0.25 mi)
- Times with such low visibility are associated primarily with fog, heavy precipitation, blowing sand or snow, or smoke from wildfires

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in South America

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Climate Change and Transport Assessment in South America

- South America has been experiencing several unprecedented weather-related events in the recent past
  - Intense rainfall in Venezuela (1999, 2005)
  - Flooding in the Argentine Pampas (2002)
  - Amazon drought (2005) in Brazil
  - Hailstorms in Bolivia (2002) and Greater Buenos Aires area (2006)
  - The devastating hurricane Katrina (2004)

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Climate Change and Transport Assessment in South America

- Studies have shown that there has been an increased rainfall in southeastern Brazil, Paraguay, Uruguay, the Argentine Pampas, and some parts of Bolivia
- Increased rainfall has had impacts on land use and crop yields, and has also increased the frequency of floods in the region
- A decreased trend in precipitation has been observed in southern Chile, southwestern Argentina, southern Peru, and western Central America

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Climate Change and Transport Assessment in South America

- Almost three-quarters of the dry land surface in Latin America are affected by degradation processes
- The combined effects of anthropogenic activities and climate change have brought a considerable decline in natural land cover; in particular, rates of deforestation of tropical forests have increased during the last five years

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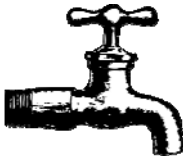
Climate Change and Transport Assessment in South America

- Climate change will pose a severe threat to the availability of water. It has been estimated that by the 2020s, the net increase in the number of people experiencing water stress due to climate change is likely to be between 70-77 million.
- This will also affect the agricultural productivity, particularly decline in rice yields.
- Livestock and dairy productivity will also decline, due to increase in temperature and reduced water availability.



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- It is likely that there will be a significant extinction of species in many areas in the tropical zone
- This will replace the tropical forests of Amazon and southern and central Mexico with savannahs.
- Further, it is anticipated that by the 2050s, 50% of the agricultural land will be subjected to desertification and salinization in some areas.

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- Coastal areas will be affected due to the rise in sea-level and frequent extreme events, particularly in low-lying areas
- This will have an impact on infrastructure, tourism, livelihood related to mangrove ecosystems, as well as on the availability of drinking water

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- Four countries in this region make the global top 30 list of highest annual CO_2 emitters, namely Brazil, Argentina, Mexico, and Venezuela (using 2008 data)
- Brazil quickly rises to the top five if emissions from deforestation are included
- The region also faces a range of climate impacts, including threats to drinking water resources due to the shrinking ice pack in the Andes mountains and potential reductions in crop yields and flooding due to sea-level rise.

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Climate Change and Transport Assessment in South America

- Downscaling experiments on climate change scenarios in South America have shown a reduction of rainfall in Amazonia as well as an small increase in rainfall in various regions of South America during 2071-2100 for the SRES A2 and B2 scenarios (Marengo and Ambrizzi 2006, Marengo et al 2007, Nuñez at al. 2006, Solman and Nunez 2007)
- Studies by Marengo et al. (2008) have shown an increase in the frequency of dry spells in tropical South America East of the Andes, warm nights in all South America and increases in rainfall extremes in Southeastern South America by the end of the 21st Century

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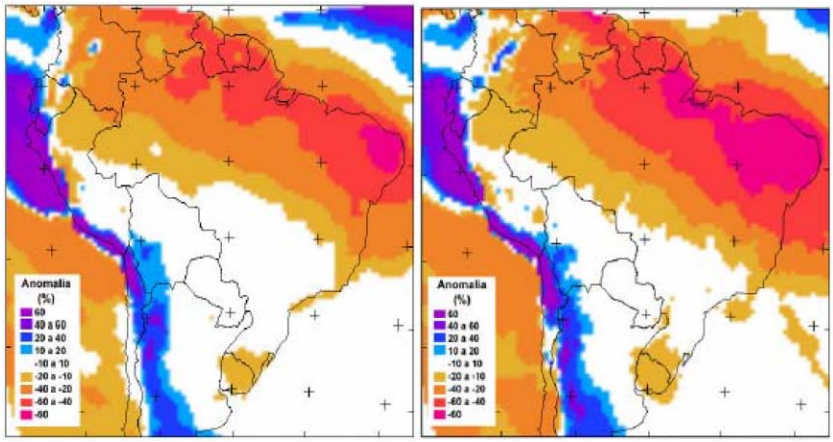
Climate Change and Transport Assessment in South America



Projections of annual rainfall (mm/day) anomalies for both A2 and B2 scenarios for 2071-2100 relative to 1961-90

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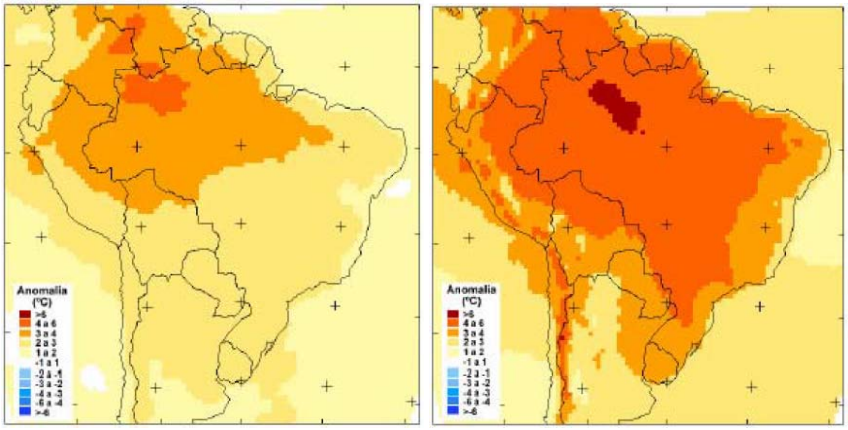
Climate Change and Transport Assessment in South America



Projections of annual air temperature anomalies (ºC) for both A2 and B2 scenarios for 2071-2100 relative to 1961-90

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Climate Change and Transport Assessment in South America

- Glaciers in Latin America have receded dramatically in the past decades, and many of them have disappeared completely (Williams and Ferrigno, 1998)
- In 18 glaciers in the Peruvian Andes, mass balances since 1968 and satellite images show a reduction of more than 20% of the glacial surface, corresponding to 11,300 million m^3 of ice (Morales-Arnao, 1969a,b; INAGGA-CONAM, 1999)
- Significant reductions also have occurred in southern Chile and Argentina (e.g., glacier Sarmiento) (Basso, 1997)

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Climate Change and Transport Assessment in South America

- In northwestern Mexico, there is a tendency for more winter precipitation, which has resulted in positive trends in river water levels
- However, along with more intense winter precipitation, interannual climate variability has increased (Magaña and Conde, 2000)
- For Nicaragua, rainfall analysis for 1961–1995 showed negative trends in the north and northwest parts of the country

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Climate Change and Transport Assessment in South America

- A systematic increment was detected on the Caribbean coast, and almost no variation was found along the central and the Pacific coastal regions (MARENA, 2000)
- For central Colombia, rainy seasons have been occurring earlier in recent years than 25 years ago (Mesa *et al.,* 1997)

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Climate Change and Transport Assessment in South America

- For northwestern South America, monthly mean air temperature records show a warming of 0.5–0.8°C for the last decade of the 20th century (Pabón, 1995a; Pabón *et al*., 1999; Quintana-Gomez, 1999)
- Colombia also presents increasing trends in the time series for the daily series of daily mean and minimum temperature for the past 30–40 years

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- In several cities in southern and southeastern Brazil, studies on long-term tendencies for air temperature, from the beginning of the 20th century, have indicated warming tendencies (Sansigolo *et al*., 1992)
- This could be attributable to urbanization effects or to systematic warming observed in the south Atlantic since the beginning of the 1950s (Venegas *et al.,* 1996, 1998)
- In the Amazon region, Victoria *et al*. (1998) have detected a significant warming trend of +0.63°C per 100 years

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- Using tree-ring and glacial evidence, summer temperatures in northern Patagonia show distinct periods of higher and lower temperatures during the past 1,000 years (Villalba, 1994; Villalba *et al*., 1997).
- For instance, there was a cold interval from AD 900 to 1070, followed by a warm period from AD 1080 to 1250 (coincident with the Medieval warm period).

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- Warm climatic episodes similar to that observed during the 1980s may have occurred in the recent past under preindustrial CO_2 levels in northern Patagonia (Chile and Argentina) (Villalba *et al*., 1997)
- Data for the eastern Pacific region indicate that the number of strong hurricanes in the region has been increasing since 1973 (Whitney and Hobgood, 1997)
- In the Mexican Altiplano, dry atmospheric conditions result in radiative cooling and frosts even during the summer (Morales and Magaña, 1998)

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- The World Bank (1997) analyzed the 1982–1983 El Niño event and, with a great degree of certainty, considered it to be the most intense in the 20th century
- Losses from droughts, floods, and hurricanes were estimated at US$14 billion
- Of these, US$2 billion were lost in the western coast of South America, half in Peru—mainly losses from fishing revenue and destruction of infrastructure.
- Reconstruction and development of related activities in Peru depleted resources and resulted in losses of 6% in GNP

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Climate Change and Transport Assessment in South America

- Damages in Peru in 1997–1998 were on the order of US$1 billion
  - 55% was transportation infrastructure
  - 15% agriculture
  - 14% energy
  - 9% education
- More than 400 relief projects had to be implemented, requiring emergency attention in 14 of the 24 departments of Peru

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- The Gulf of Fonseca—which supplies important fishing, firewood, and transport to the rural communities of El Salvador, Honduras, and Nicaragua—could be affected by sea level rise (Quesada and Jiménez, 1988)
- After Hurricane Mitch, some countries in Central America regressed decades in health services and transport infrastructure, thereby making it more difficult to assist the affected population (OPS, 1999)

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Climate Change and Transport Assessment in South America

Region	Temperature	Precipitation
Mexico	increase	decrease
Costa Rica		
– Pacific sector	+3°C	-25%
– Southeast Caribbean sector		small increase
Nicaragua		
– Pacific sector	+3.7°C	-36.6%
– Caribbean sector	+3.3°C	-35.7%
Brazil		
– Central and south central sector	+4°C	+10 to +15% for autumn reductions for summer
Central Argentina	summer: +1.57°C (+1.08–2.21°C) winter: +1.33°C (+1.12–1.57°C)	summer: -12% winter: -5%

Source: Climate Change 2001, Impacts, Adaptation, and Vulnerability, 2001

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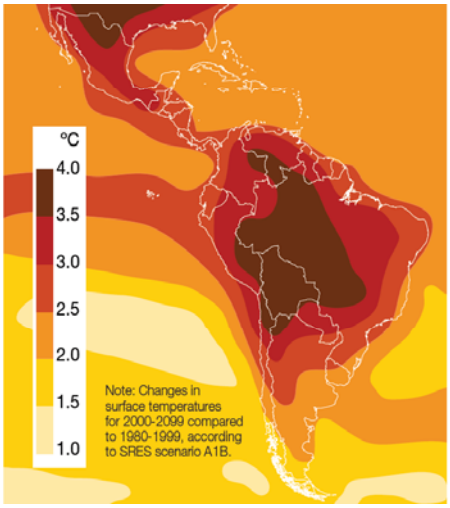
Climate Change and Transport Assessment in South America



Warming of earth's surface
(Source: IPCC: Climate Change 2007 Synthesis Report. Contributions of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 2007.)

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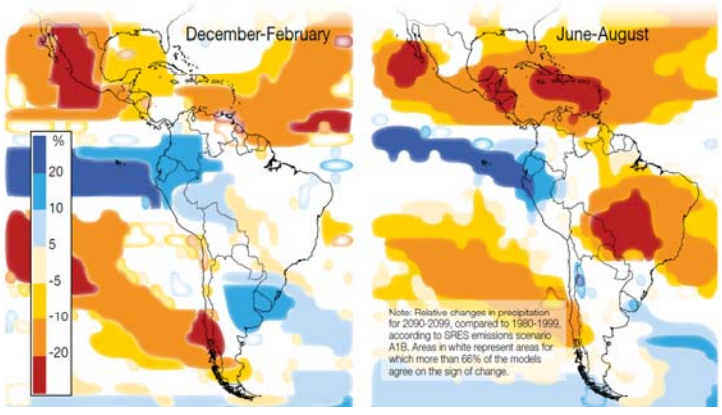

Relative changes in precipitation (Source: IPCC: Climate Change 2007 Synthesis Report. Contributions of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 2007.)

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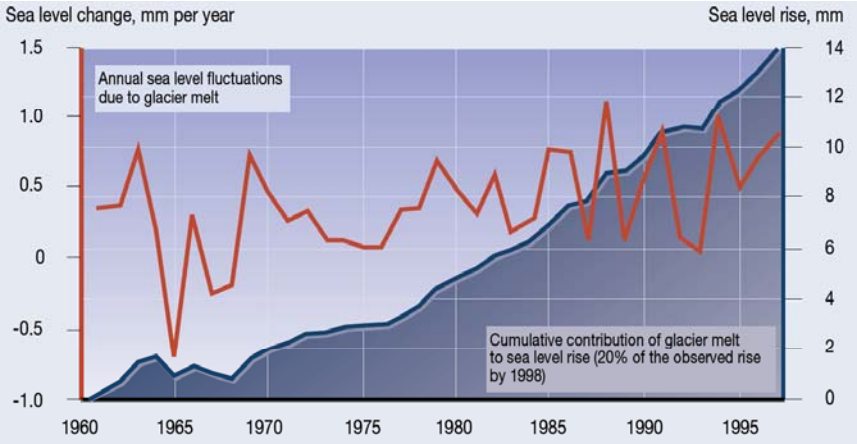

Sea level rise caused by the melting of mountain and subpolar glaciers

(Source: Institute of Arctic and Alpine Research; Church and Geography, 2001; Dyugerov, 2002; Ringot, 2003.)

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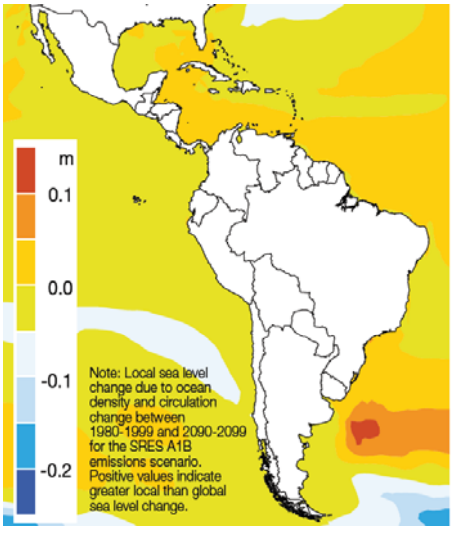

Change in sea level as a result of changes in ocean density and circulation

(Source: Meehl, G.A. et al., Global Climate Projections, IPCC, 2007)

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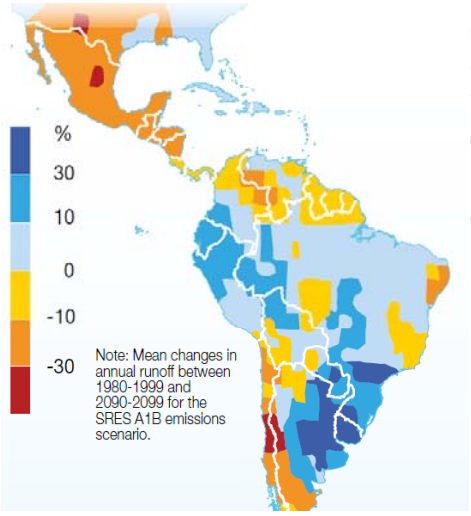

Mean changes in runoff

(Source: Parry, M.L. et al. : Technical Summary. Climate Change 2007: Impacts, Adaptation and Vulnerability, Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 2007.)

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Climate Change and Transport Assessment in South America

- The retreat of the glaciers is another manifestation of climate change affecting the region
- The Bolivarian Republic of Venezuela, Colombia, Ecuador and Chile show evidence of reductions in the size of their glaciers
- In Peru and the Plurinational State of Bolivia, the shrinkage of the glaciers, compared to 1970 and 1975, is even more striking
- In Peru, since 1970, there has been a substantial reduction in the surface area of the smaller glaciers, along with a significant loss in water reserves during the last 50 years (NC-Peru, 2001)

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- Since the mid-1990s, the Chacaltaya glacier in the Plurinational State of Bolivia has lost half of its surface area and two thirds of its volume, endangering its long-term sustainability (Francou *et al*., 2003)
- Likewise, the San Quintín glacier in North Patagonia, in addition to rapidly decreasing in size, has also been exhibiting cracks and fractures in recent years
- In Colombia, between 1959 and 1996, the snowcapped volcano of Santa Isabel showed a 44% decrease in its ice-covered peak

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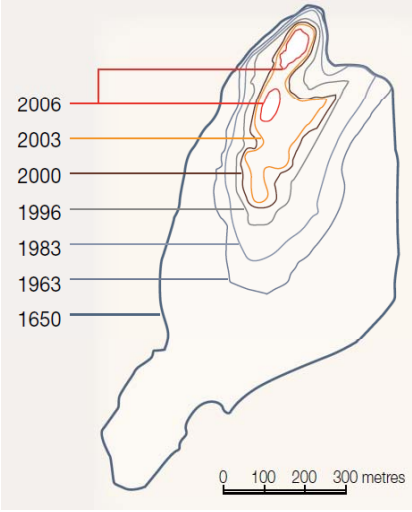

Chacaltaya glacier

(Source: CAN, UNEP and Spanish Agency for International Cooperation ¿El fin de las cumbres nevadas? Glaciares y Cambio Climático en la Comunidad Andina, 2007.)

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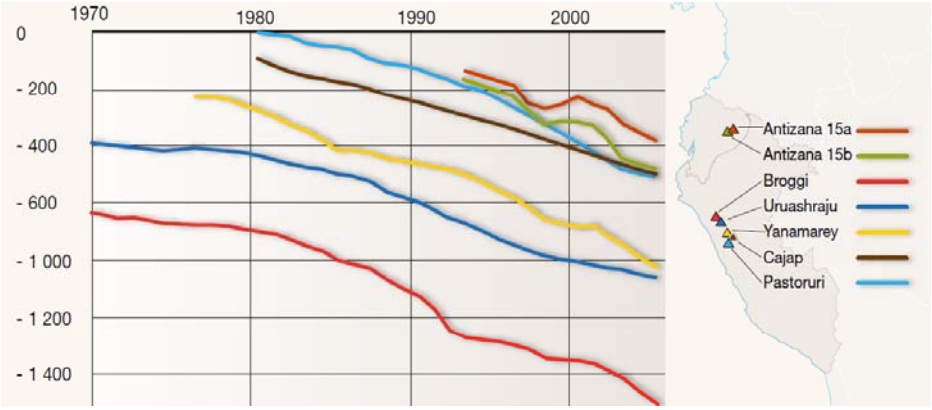

Retreat of Andean glaciers, cumulative evolution of length in meters

(Source: CAN, UNEP and Spanish Agency for International Cooperation, ¿El fin de las cumbres nevadas? Glaciares y Cambio Climático en la Comunidad Andina, 2007.)

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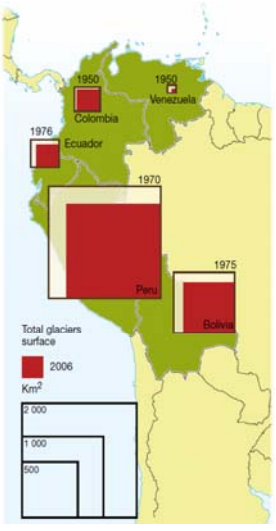

Retreat of tropical glaciers

(Source: CAN, UNEP and Spanish Agency for International Cooperation, ¿El fin de las cumbres nevadas? Glaciares y Cambio Climático en la Comunidad Andina, 2007.)

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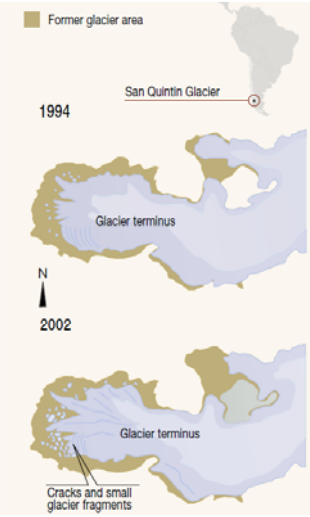

Rapid decline of the San Quintin glacier, Northern Patagonia

(Sources: NASA, 2003; Rignot, 2003.)

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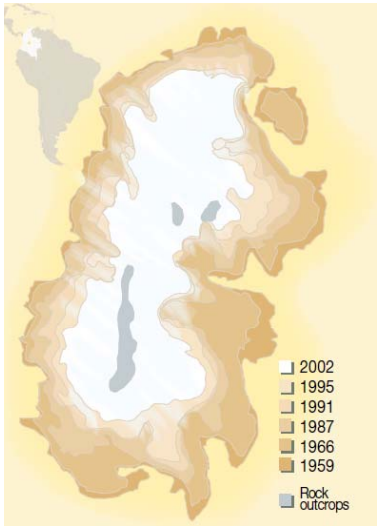

Retreat of the snowcapped volcano of Santa Isabel, Colombia

(Source: Ceballo, J. L., et al., Fast shrinkage of tropical glaciers in Colombia, 2006.)

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Climate Change and Transport Assessment in South America

- Latin America and the Caribbean, in particular, has seen a recent increase in extreme climatic events, and with it a rise in the number of people affected
- The number of storms between 2000 and 2009 increased by 12 compared to the period between 1970 and 1979
- In this same time period, floods quadrupled
- The number of people affected by extreme temperatures, forest fires, droughts, storms and floods grew from 5 million in the 1970s to more than 40 million in the most recent decade

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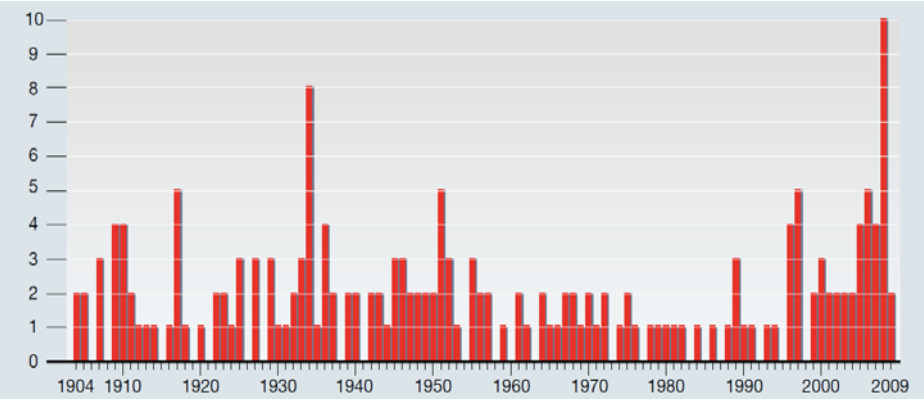

Hurricanes in Mesoamerica and the Caribbean, 1904-2009, annual total number
(Source: National Hurricane Center, NOAA, online database, accessed October 2010.)

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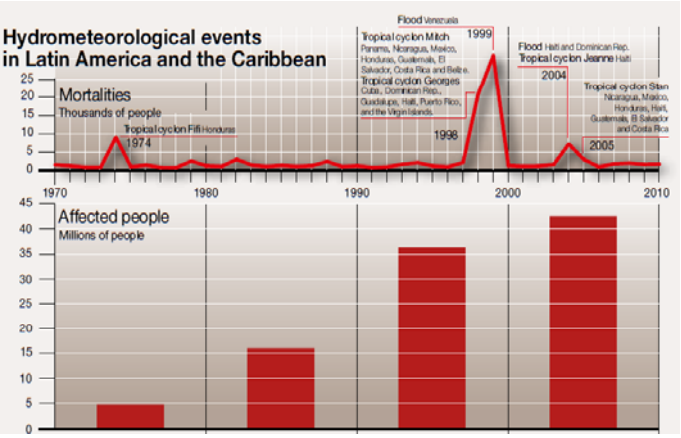

Hydrometeorological events in Latin America and the Caribbean
(Source: The International Disasters Database, accessed in August 2010.)

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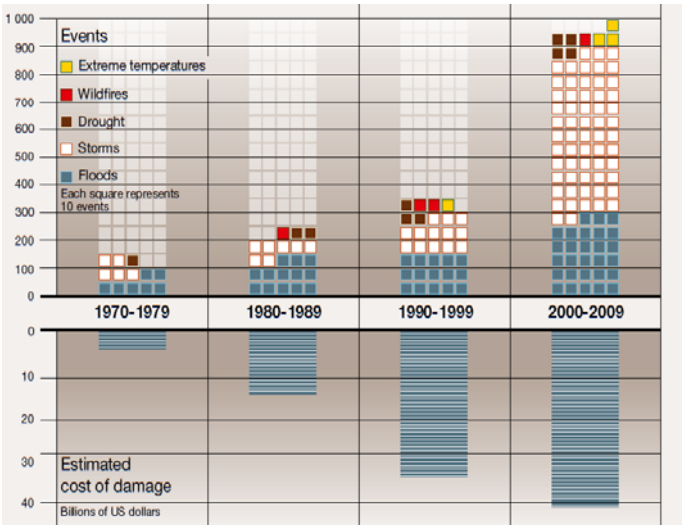

Hydrometeorological events in Latin America and the Caribbean (continued)
(Source: The International Disasters Database, accessed in August 2010.)

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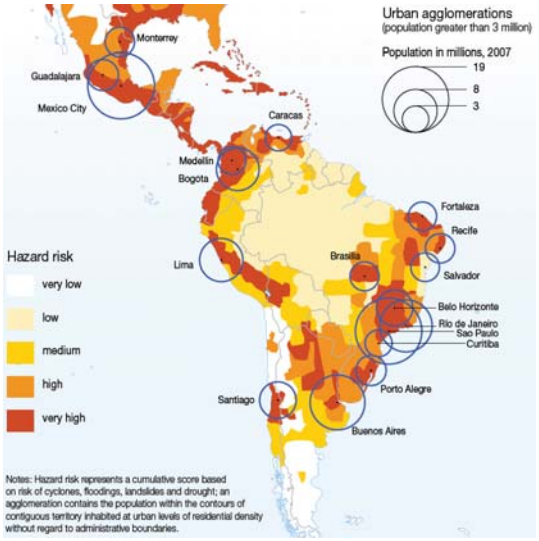

Vulnerability of large cities to climate hazards

(Sources: A. de Sherbinin et al, The vulnerability of global cities to climate hazards, 2007; UN DESA, World Urbanization Prospects, the 2007 Revision, 2008.)

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Roles of Major Modes of Transportation

in Mitigating Climate Change Impacts

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Roles of Major Modes of Transportation in Mitigating Climate Change Impacts

- Together, cars, trucks and aircraft account for a large portion of travel in the U.S.
- 97% of passenger travel
- 48% of freight travel

- Cars, trucks, and aircraft also account for about 95% of all transportation fuel use
- How can we use policy to mitigate the greenhouse gas (GHG) emissions from these modes specifically?

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Roles of Major Modes of Transportation in Mitigating Climate Change Impacts

- The transportation sector accounts for 13% of all greenhouse gas emissions in the world and 28% in the U.S.
- The transportation sector as a whole accounts for 2/3 of the liquid petroleum used annually in the U.S.
- In Latin America, transport accounts for 66% of all oil consumption (IEA, 2009)

- Petroleum accounts for 97% of the energy used in transportation
  - CO_2 emissions from petroleum use are a major greenhouse gas contributor
  - The transportation sector has the fastest-growing share of carbon monoxide emissions in the U.S.

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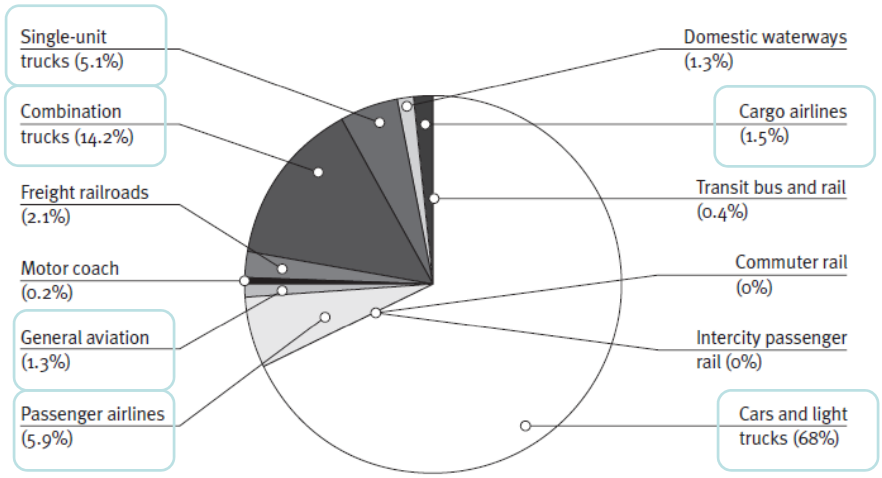
Roles of Major Modes of Transportation in Mitigating Climate Change Impacts



1. Transportation Research Board, Policy Options for Reducing Energy Use and Greenhouse Gas Emissions from U.S. Transportation. TRB Special Report 307, national Research Council, Washington D.C. (2011)

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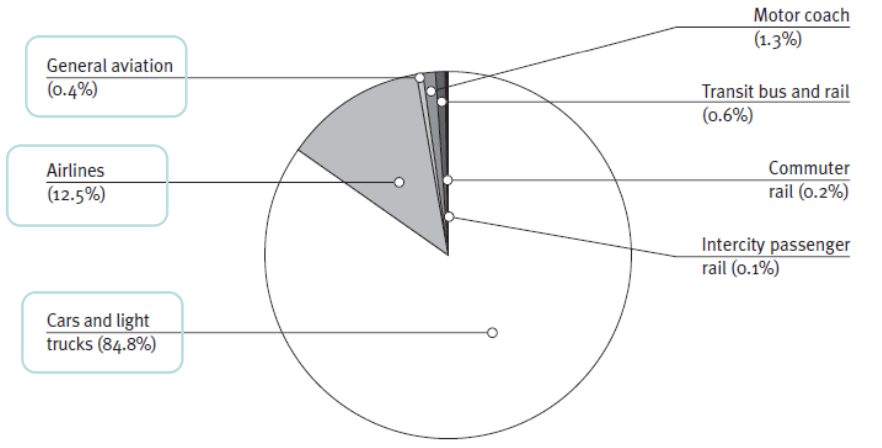
Roles of Major Modes of Transportation in Mitigating Climate Change Impacts



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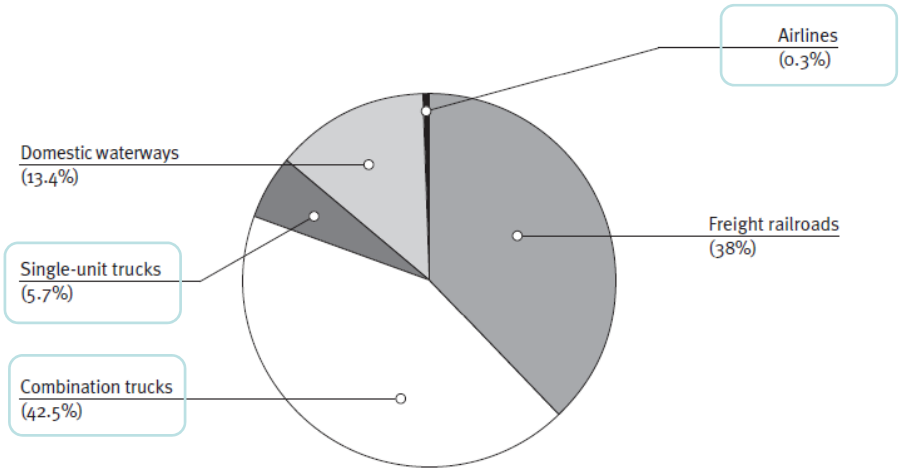

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Roles of Major Modes of Transportation in Mitigating Climate Change Impacts

- The growing population and economy will apply upward pressure on travel demand
- However, more strict U.S. national standards on fuel economy are expected to greatly decrease these effects
- The total energy used by light duty vehicles is expected to grow only 10% between 2010 and 2035

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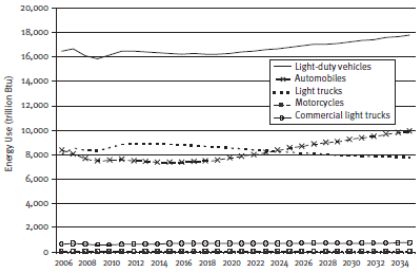
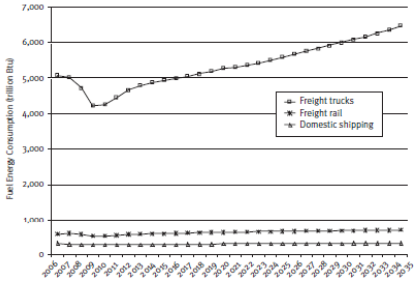
Roles of Major Modes of Transportation in Mitigating Climate Change Impacts

Light Duty Vehicles



Heavy Duty Vehicles



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Roles of Major Modes of Transportation in Mitigating Climate Change Impacts

- The U.S. *Annual Energy Outlook* assumes that petroleum will remain the predominate transportation fuel through 2035 and predicts the following trends:

Staying the Same

- Consumption of motor gasoline
- The transportation sector's share of total U.S. energy consumption

Increasing

- Consumption of ethanol diesel fuels
- Price of transportation fuels

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Roles of Major Modes of Transportation in Mitigating Climate Change Impacts

- Transportation vehicles have little room for energy storage, requiring them to be refueled often
- Vehicles have significant range and power requirements that demand fuels with high energy density and handling ease

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Roles of Major Modes of Transportation in Mitigating Climate Change Impacts

- Huge expense and time would be required to:
  - Transition the large and diverse vehicle fleet to alternative fuels
  - Make changes in the vast physical infrastructure that is used and served by transportation
- The speed at which fuel consumption declines will depend largely on the incentive for and ability of travelers to adjust their vehicles, mobility demands, and travel patterns

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Roles of Major Modes of Transportation in Mitigating Climate Change Impacts

- Light duty vehicles alone account for 68% of the transportation sector's petroleum usage
- Though vehicle fuel efficiency is greatly improving, the total fuel usage from light-duty vehicles continues to increase

Attribute: Light-Duty Vehicle	1970	2007	Increase
Num. vehicle registrations (millions)	103.5	237.4	129%
Avg. miles traveled per vehicle	10,081	11,720	16%
Fuel consumed (million gal)	90,192	136,170	70%
Avg. fuel consumed per vehicle (gal)	775	574	-26%
Avg. fuel economy (miles per gallon)	13	20.4	57%
Average passenger per vehicle	1.9	1.64	-14%
Average passenger-miles per gallon of fuel consumed	24.7	33.5	36%

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Roles of Major Modes of Transportation in Mitigating Climate Change Impacts

- Freight truck – combined single-unit and combination trucks – account for about 50% of freight transport in the U.S.
- As opposed to light-duty vehicles, average fuel usage for freight trucks is increasing with increased freight demand

Attribute: Heavy-Duty Vehicle	1980	2006	Increase
Fuel consumed (million gal)	19,960	37,918	90%
Avg. fuel consumed per vehicle (gal)	3,447	4,300	25%
Avg. fuel economy (miles per gallon)	5.4	5.9	9%
Num. registered trucks (million)	5.79	9.92	71%
Avg. miles traveled per vehicle	18,736	25,290	35%
Freight Ton-miles (million)	629,675	1,294,492	106%
Vehicle-miles of travel (million)	108,491	223,037	106%

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Roles of Major Modes of Transportation in Mitigating Climate Change Impacts

- As jets become larger, they tend to become more fuel efficient per passenger carried
- The amount of fuel, or energy, used per passenger mile has declined because of large gains in the airline industry's economic efficiency

Attribute: Airline Carriers	1970	2006	Increase
Revenue passenger enplanements (thousand)	153,662	675,212	339%
Revenue ton-mile of freight (thousand)	2,708,900	15,859,729	485%
Num. aircraft available for service	2,690	6,758	151%
Seats per aircraft	103	114	11%
Fuel consumed (million gal)	7,857	13,458	71%
Fuel per seat mile (gal)	27	55	104%
Energy intensity (Btu / passenger mi.)	10,185	3,070	-70%

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Data Needs and Availability for Decision Making

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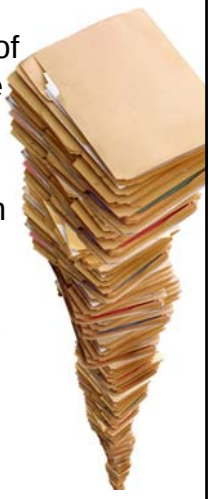
Data Needs and Availability for Decision Making

- Transportation decision makers note that one of the most difficult aspects of addressing climate change is obtaining the relevant information in the form they need for planning and design
- This difficulty is not limited to the transportation sector
- A recent National Research Council report (NRC Summing Up 195 2007) found that while the scientific understanding of climate change has made great progress, the use of that knowledge to support decision making and formulate mitigation and adaptation strategies is much less well developed



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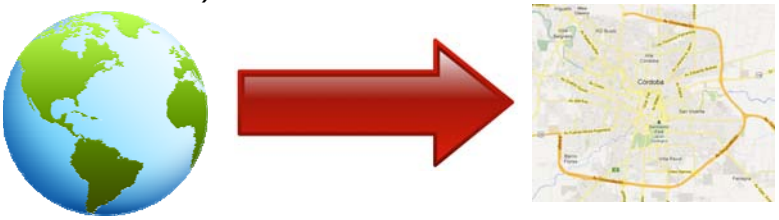
Data Needs and Availability for Decision Making

- Climate change is understood with greatest confidence as a global or continental phenomenon, while transportation planners as well as other decision makers need local and regional climate projections
- They also need a better understanding of how projected climate changes, such as changes in temperature and precipitation, will affect the environment (e.g., soil moisture, runoff) in which the infrastructure is situated



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Data Needs and Availability for Decision Making

- Climate projections themselves are presented by climate scientists as a portfolio of plausible scenarios and outcomes, which are continually refined and revised as new knowledge accumulates
- Transportation planners need to have a better understanding of which scenarios are most plausible for their regions and most significant for their operations and plans
- Transportation professionals should be encouraged to define with greater precision the climate data needed to improve transportation decisions

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Data Needs and Availability for Decision Making

- These would include things such as temperature and precipitation thresholds at finer-grained geographic scales or climate conditions that would create unacceptable performance outcomes
- Climate scientists would be challenged to elaborate on the possibilities and limitations of projecting impacts of climate change at the levels of geographic specificity that are most useful for transportation planners
- Hydrologists and others would be challenged to consider how the environment would influence these effects and their impacts on transportation infrastructure

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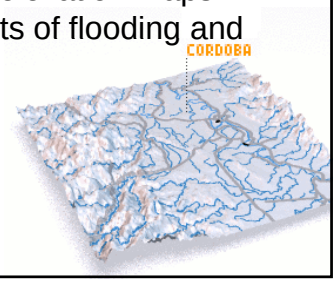
Data Needs and Availability for Decision Making

- One promising approach might be for the government to support a number of pilot projects in which other government agencies would work closely with local transportation planners to include the full range of relevant climate information that could affect a specific project
- Needed tools include accurate digital elevation maps in coastal areas for forecasting the effects of flooding and storm surge heights



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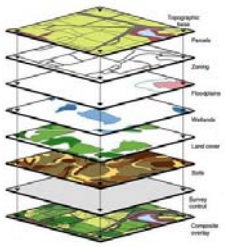
Data Needs and Availability for Decision Making

- GIS that can be used to map the locations of critical infrastructure, overlaid with information on climate change effects (e.g., sea level rise, permafrost melt)
- Greater use of scenarios that include climate change in the development of long-range regional transportation plans to pinpoint likely vulnerabilities (e.g., areas susceptible to sea level rise, aggravated by storm surge) and ways to address them



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Data Needs and Availability for Decision Making

- Better transportation network models for examining the system-wide effects of the loss of critical transportation infrastructure links

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Data Needs and Availability for Decision Making

- Current passenger data is driven by the National Household Travel Survey (NHTS)
  - The program often lacks funding
  - State, regional, and local governments often pay for supplemental NHTS data
  - NHTS suffers from low response rates, like other surveys of its type
- The Commodity Flow Survey (CFS) is the major source of freight travel data in the U.S.
  - The survey is conducted infrequently and is underfunded
  - It does not include information on freight routes

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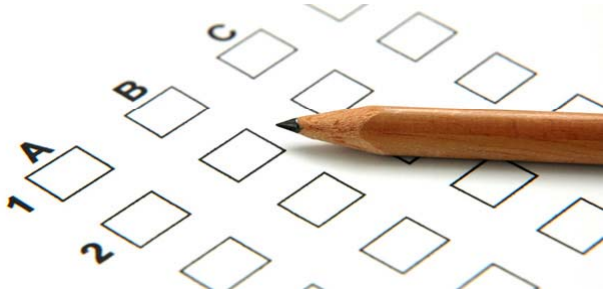
Data Needs and Availability for Decision Making

- An estimated $300 million is spent annually on data collection for transportation improvements (Burbank, 2009)
- More reliable data is needed to build sophisticated transportation planning models



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Vulnerability Assessment

for Different Modes of Transportation

Medio ambiente y cambio climático y su impacto en el transporte vial. XVI Congreso Argentino de Vialidad y Tránsito. 22 de Octubre Córdoba, Argentina.

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Vulnerability Assessment for Different Modes of Transportation

- 53% of the U.S. population lives in counties with coastal areas, although such areas make up only 17% of the nation's contiguous land area (Crossett et al. 2004; U.S. Census Bureau 2005, 28)
- Population density in coastal counties is significantly higher than the national average—300 versus 98 persons per square mile—reflecting the limited land area involved (Crossett et al. 2004)
- This population swells in the summer months, as beaches are the top tourist destination (Douglass et al. 2005)

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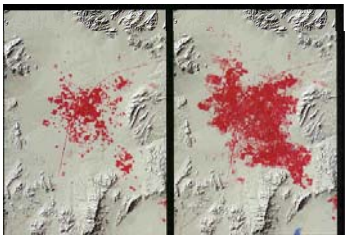
Vulnerability Assessment for Different Modes of Transportation

- Many of the most populous coastal counties located in California, south Florida, and Texas (Harris County), which already experience the effects of hurricanes and other tropical storms, are expected to grow rapidly in the coming decades (Crossett et al. 2004)
- This growth will generate demand for more transportation infrastructure and increase the difficulty of evacuation in an emergency



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Vulnerability Assessment for Different Modes of Transportation

- Sea level rise, in combination with expected population growth, will aggravate the situation, making housing and infrastructure in low-lying coastal areas even more vulnerable to extensive flooding and higher storm surges
- An estimated 60,000 miles of coastal highways is already exposed to periodic coastal storm flooding and wave action (Douglass et al. 2005)
- Those highways that currently serve as evacuation routes during hurricanes and other coastal storms could be compromised in the future

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Vulnerability Assessment for Different Modes of Transportation

- Coastal areas are also major centers of economic activity
- Six of the nation's top 10 U.S. freight gateways (by value of shipments) (BTS 2007) will be at risk from sea level rise
- Seven of the 10 largest ports (by tons of traffic) (BTS 2007, 30) are located in the Gulf Coast, whose vulnerability was amply demonstrated during the 2005 tropical storm season

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Vulnerability Assessment for Different Modes of Transportation

- Several thousand off-shore drilling platforms, dozens of refineries, and thousands of miles of pipelines are vulnerable to disruption and damage from storm surge and high winds of tropical storms, as was recently demonstrated by Hurricanes Katrina and Rita
- Those hurricanes halted all oil and gas production from the Gulf, disrupted nearly 20 percent of the nation's refinery capacity, and closed oil and gas pipelines (CBO 2006)

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Vulnerability Assessment for Different Modes of Transportation

- Inland areas are also likely to experience the effects of climate change
- Increased intense precipitation could increase the severity of such events as the great flood of 1993
- That event caused catastrophic flooding along 500 miles of the Mississippi and Missouri River system, paralyzing surface transportation systems, including rail, truck, and marine traffic

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Vulnerability Assessment for Different Modes of Transportation

- Major east–west traffic was halted for roughly 6 weeks in an area stretching from St. Louis west to Kansas City and north to Chicago
- This affected one-quarter of all U.S. freight that either originated or terminated in the flood-affected region (Changnon 1996)

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Vulnerability Assessment for Different Modes of Transportation

- Drier conditions are likely to prevail in the summer in midcontinental regions, such as the Saint Lawrence Seaway
- Weather and vessel incidents cause most of the lock downtime on the seaway, but in 2000 and 2001, water levels were at their lowest point in 35 years, reducing vessel carrying capacity to about 90 percent of normal (BTS 2005, 140)
- If low water levels become more common, freight movements could be seriously impaired, and extensive dredging could be required to keep shipping channels open (Great Lakes Regional Assessment Team 2000; Quinn 2002)

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Vulnerability Assessment for Different Modes of Transportation

- The vulnerability of transportation infrastructure to climate change is in part a function of its robustness and degree of protection from exposure to climate change effects (as is the case, for example, with seawalls and levees)
- It also depends on the amount of redundancy in the system
- System redundancy proved critical to the rapid restoration of partial rail service during both Hurricane Katrina and the 1993 Mississippi River flood

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Vulnerability Assessment for Different Modes of Transportation

- Yet the predominant trend has been for the railroads (as well as other owners of infrastructure) to shed uneconomical unused capacity by consolidating operations and abandoning underused lines
- Likewise, major businesses, both manufacturing and retail, have reduced operating costs through just-in-time delivery strategies, but with the effect of increasing their vulnerability to disruptions or failures of the transportation system from either natural or human causes

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Vulnerability Assessment for Different Modes of Transportation

- The impacts of climate change on transportation infrastructure will differ depending on the particular mode of transportation, its geographic location, and its condition
- Increased precipitation levels in some regions will affect moisture levels in the soil and hydrostatic buildup behind retaining walls and abutments and the stability of pavement subgrades
- Runoff from increased precipitation levels will also affect stream flow and sediment delivery in some locations, with potentially adverse effects on bridge foundations.

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Vulnerability Assessment for Different Modes of Transportation

- Permafrost decline will affect Arctic land forms and hydrology, with potentially adverse effects on the stability of road- and rail beds.
- Sea level rise will affect coastal land forms, exposing many coastal areas to storm surge as barrier islands and other natural barriers disappear

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Vulnerability Assessment for Different Modes of Transportation

- There are also likely to be many indirect effects of potential climate changes on transportation
- For example, possible climate-caused shifts in demographics or in the distribution of agricultural production, forests, and fisheries would have implications for road usage and other transport patterns between emerging economic centers and urban areas.
- Transportation patterns could also shift as the tourism industry responds to changes in ecologically or recreationally interesting destinations

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Vulnerability Assessment for Different Modes of Transportation

- Land transportation modes comprise
  - Highways (including bridges and tunnels)
  - Rail (including private rail lines and public transportation)
  - The vehicles that use these facilities
    - Passenger cars
    - Trucks
    - Buses
    - Rail and rail transit cars
  - Pipelines (recognizing that the latter are buried underground in many areas)




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Vulnerability Assessment for Different Modes of Transportation

- Projected warming temperatures and more heat extremes will affect all of these modes
- The effects of temperature warming are already being experienced in Alaska in the form of continued retreat of permafrost regions, creating land subsidence issues for some sections of the road and rail systems and for some of the elevated supports for aboveground sections of the Trans-Alaska pipeline
- Warming winter temperatures have also shortened the season for ice roads that provide vital access to communities and industrial activities in remote areas

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Vulnerability Assessment for Different Modes of Transportation

- Expected increases in temperature extremes, will lead to more freeze–thaw conditions, creating frost heaves and potholes on road and bridge surfaces and resulting in load restrictions on certain roads to minimize the damage
- Periods of excessive summer heat are likely to increase wildfires, threatening communities and infrastructure directly and bringing about road and rail closures in affected areas

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Vulnerability Assessment for Different Modes of Transportation

- Longer periods of extreme heat may
  - Compromise pavement integrity (e.g., softening asphalt and increasing rutting from traffic)
  - Cause deformation of rail lines and derailments or, at a minimum, speed restrictions (Rossetti 2002)
  - Cause thermal expansion of bridge joints, adversely affecting bridge operation and increasing maintenance costs

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Vulnerability Assessment for Different Modes of Transportation

- Projected increases in intense precipitation events will necessitate updating design specifications to provide for greater capacity and shorter recurrence intervals, increasing system costs
- The most immediate impact of more intense precipitation will be increased flooding of coastal roads and rail lines
- Expected sea level rise will aggravate the flooding because storm surges will build on a higher base, reaching farther inland (Titus 2002)

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Vulnerability Assessment for Different Modes of Transportation

- Several studies of sea level rise project that transportation infrastructure in some coastal areas will be permanently inundated sometime in the next century (Dingerson 2005; Gornitz and Couch 2000; Leatherman et al 2000; Titus 2002)
- Low-lying bridge and tunnel entrances for roads, rail, and rail transit will also be more susceptible to flooding, and thousands of culverts could be undersized for flows

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Vulnerability Assessment for Different Modes of Transportation

- Engineers must be prepared to deal with the resulting erosion and subsidence of road bases and rail beds, as well as erosion and scouring of bridge supports
- Interruption of road and rail traffic is likely to become more common with more frequent flooding

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Vulnerability Assessment for Different Modes of Transportation

- The impact of sea level rise is limited to coastal areas, but the effect of intense precipitation on land transportation infrastructure and operations is not
- For example, a record-breaking 24-hour rainstorm in July 1996 resulted in flash flooding in Chicago and its suburbs, with major impacts on the urban area
- Extensive travel delays occurred on metropolitan highways and railroads, and streets and bridges were damaged
- Commuters were unable to reach Chicago for up to 3 days, and more than 300 freight trains were delayed or rerouted (Changnon 1999)

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Vulnerability Assessment for Different Modes of Transportation

- Marine transportation infrastructure include
  - Ports
  - Harbors
  - Supporting intermodal terminals
  - Ships and barges that use these facilities



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Vulnerability Assessment for Different Modes of Transportation

- For the next several decades, warming temperatures and melting sea ice are likely to result in increased variability in year-to-year shipping conditions and higher costs due to requirements for stronger ships and support systems (e.g., ice-capable ship designs, icebreaker escorts, search and rescue support) (ACIA 2004)
- In addition, improved access to remote areas may increase the risk of environmental degradation to fragile ecosystems

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Vulnerability Assessment for Different Modes of Transportation

- With lower lake levels, ships will be unable to carry as much cargo, and hence shipping costs will increase, although some of the adverse economic impacts could be offset by a longer shipping season
- A recent study of the economic impact of climate change on Canadian commercial navigation on the Great Lakes, for example, found that predicted lowering of Great Lakes water levels would result in an estimated increase in shipping costs for Canadian commercial navigation of between 13 and 29 percent by 2050, all else remaining equal (Millard 2005)

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Vulnerability Assessment for Different Modes of Transportation

- Lower water levels could also create periodic problems for river traffic, reminiscent of the stranded barges on the Mississippi River during the drought of 1988 (du Vair et al. 2002)
- In the longer run, less efficient waterborne commodity movement would likely result in shifts to other transportation modes, such as truck and rail

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Vulnerability Assessment for Different Modes of Transportation

- Landside facilities will be particularly vulnerable to flooding from an increase in intense precipitation events and to the impacts of higher tides and storm surges from rising seas
- The navigability of shipping channels is also likely to change. Some channels may be more accessible to shipping farther inland because of sea level rise
- The navigability of others, however, could be adversely affected by changes in sedimentation rates and the location of shoals
- In other areas, a combination of sea level rise and storm surge could eliminate waterway systems entirely

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Vulnerability Assessment for Different Modes of Transportation

- Air transportation comprises
  - Airports
  - ground facilities
  - Passenger airplanes
  - Freight airplanes
  - The air traffic control system

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Vulnerability Assessment for Different Modes of Transportation

- Warming temperatures and possible increases in temperature extremes will affect airport ground facilities—runways in particular—in much the same way that they will affect roads
- More heat extremes, however, are likely to be problematic, causing heat buckling of runways
- Extreme heat can also affect aircraft lift; hotter air is less dense, reducing mass flowing over the wing to create lift
- The problem is exacerbated at high-altitude airports

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Vulnerability Assessment for Different Modes of Transportation

- If runways are not sufficiently long for large aircraft to build up enough speed to generate lift, aircraft weight must be reduced or some flights canceled altogether
- Increases in extreme heat are likely to result in payload restrictions, flight cancellations, and service disruptions at affected airports, and could require some airports to extend runway lengths, if feasible

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Vulnerability Assessment for Different Modes of Transportation

- An analysis for the Denver and Phoenix airports estimated summer cargo loss (June through August) for a single Boeing 747 of about 17 and 9 percent, respectively, by 2030 because of the effects of increased temperature and water vapor (T.R. Karl and D.M. Anderson, Emerging Issues in Abrupt Climate Change, briefing, March 12, 2007)

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Vulnerability Assessment for Different Modes of Transportation

- Several of the nation's largest airports lie in coastal zones, built along tidal waters, sometimes on fill (Titus 2002)
- Their runways are particularly vulnerable to flooding and erosion from increased intense precipitation and, in the longer term, from sea level rise
- At a minimum, increased intense precipitation is likely to cause more disruptions and delays in air service and periodic airport closures

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Vulnerability Assessment for Different Modes of Transportation

- A special case study of the transportation sector's response to and recovery from Hurricanes Katrina and Rita
- One of the primary objectives of this study was to examine the vulnerability of the transportation system to a major disruption, with a particular focus on the impact of an interruption on national-level movement of freight
- The Gulf Coast is one of the key economic and population centers of the U.S., home to more than 15 million Americans located in five states (Texas, Louisiana, Mississippi, Alabama, and Florida) and three major metropolitan areas

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Vulnerability Assessment for Different Modes of Transportation

- Several of the nation's most heavily used ports are located along the Gulf Coast
- Hurricane Katrina was the most destructive and costliest natural disaster in U.S. history, claiming more than 1,800 lives and causing an estimated $75 billion in damage
- Hurricane Rita, exceeding Katrina in both intensity and maximum wind speed, claimed 120 lives and caused approximately $10 billion in damage

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Vulnerability Assessment for Different Modes of Transportation

- The unusually large losses of life and physical destruction of Hurricane Katrina resulted from a levee failure and the inability of the floodwaters to recede because so much of New Orleans lies below sea level
- A failed evacuation plan for the car-less exacerbated the human toll

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Vulnerability Assessment for Different Modes of Transportation

- Both storms seriously disrupted transportation systems
- Key highway and railroad bridges were heavily damaged or destroyed, necessitating rerouting of traffic and placing increased strain on other routes, particularly other rail lines

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Vulnerability Assessment for Different Modes of Transportation

- The pipeline network was shut down, producing shortages of natural gas and petroleum products
- Despite predictions of long-lasting transportation stoppages, however, the majority of the Gulf Coast highways, rail lines, pipelines, ports, and airports were back in service within weeks to a month
- The worst-damaged bridges took 3 to 6 months to repair.
- Three bridges that carry highway US-90 along the edge of the Gulf Coast failed to reopen until mid- to late 2007, approximately 2 years after they were destroyed.

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Vulnerability Assessment for Different Modes of Transportation

- The fact that Hurricanes Katrina and Rita had only a modest impact on national-level freight flows can be attributed primarily to redundancies in the transportation system, the timing of the storms, and the track of Hurricane Rita
- Reported costs of individual projects from Hurricane Katrina alone total more than $1.1 billion

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Vulnerability Assessment for Different Modes of Transportation

- Lessons learned about the vulnerability of the transportation system from the experience with these two hurricanes:
  - The physical redundancies of a mature transportation system provided sufficient alternative routes to keep freight flows moving without major disruption
  - Where the infrastructure was privately owned (e.g., CSX Railroad), arrangements with other carriers enabled operations to continue

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Vulnerability Assessment for Different Modes of Transportation

- Restoration of transportation services depended heavily on the availability of electrical power and manpower
- Electricity is critical for
  - Highway system to operate traffic lights and signs
  - Railroads to operate signal systems and crossing gates
  - Ports to operate cranes and elevators
  - Airports to power air traffic control facilities and operate nighttime runway lights
  - Pipelines to power pumping stations

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Vulnerability Assessment for Different Modes of Transportation

- Thus, redundancy of power and communications systems is also necessary for the rapid restoration and functioning of freight transportation networks
- Adequate manpower is critical to timely efforts to restore transportation services and staff restoration projects
- New Orleans itself was closed for more than a month. Thus, major transportation companies such as CSX were forced to bring in workers from other locations to staff reconstruction projects

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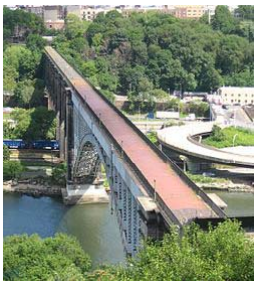
Vulnerability Assessment for Different Modes of Transportation

- Almost all of the major river and bay bridges destroyed by the hurricane's surge waters will be rebuilt at higher elevations, above the maximum forecast surge levels



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Vulnerability Assessment for Different Modes of Transportation

- All modes of transportation are vulnerable to climate change
- Just as infrastructure is local and regional, however, so, too, are the impacts of climate change
- They will vary depending on the location, mode, and condition of the transportation infrastructure
- Transportation infrastructure will experience impacts unique to each mode but many impacts, such as flooding and erosion, will be common across all modes

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Vulnerability Assessment for Different Modes of Transportation

- The condition of the infrastructure itself will affect the impacts experienced
- The impacts of climate change on U.S. transportation will be widespread and costly
- Projected climate extremes are likely to have a particularly severe impact on transportation infrastructure because transportation systems are usually built to typical weather conditions at the time and local weather and climate experienced

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Vulnerability Assessment for Different Modes of Transportation

- Expected changes in climate extremes, such as more extreme temperatures, more intense precipitation, and more intense storms, could push environmental conditions outside the range for which the system was designed
- This in turn could necessitate changes in design, materials, construction, and operating and maintenance practices

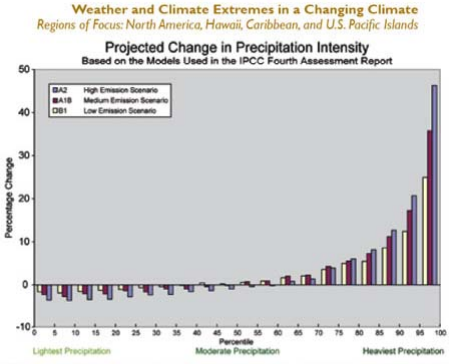

Figure ES.5 Projected changes in the intensity of precipitation, displayed in 5% increments, based on a suite of models and three emission scenarios. As shown here, the lightest precipitation is projected to decrease, while the heaviest will increase, continuing the observed trend. The higher emission scenarios yield larger changes. Figure courtesy of Michael Wehner.

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Vulnerability Assessment for Different Modes of Transportation

- In all cases, transportation professionals will have to confront and adapt to climate change without knowing the full magnitude of expected changes
- The greatest challenge is the uncertainty as to exactly what changes to expect and when
- Transportation decision makers will need to adopt a more probabilistic risk management approach to infrastructure planning, design, and operations to accommodate uncertainties about the nature and timing of expected climate changes

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Decision Frameworks and Models

to Address Climate Change

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Decision Frameworks and Models to Address Climate Change

- How should transportation planners and engineers proceed in view of the challenges just outlined?
- A decision-making framework is needed that more adequately accommodates uncertainty and incorporates more probabilistic approaches to assessing risk and making investment choices
- The basic concepts in such a probabilistic assessment include hazards, assets, and consequences, each of which is subject to uncertainties

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Decision Frameworks and Models to Address Climate Change

- In the context of climate change, the hazards represent the potential threats from changing climate conditions, such as more extreme temperatures or more intense tropical storms
- The assets represent the infrastructure and its value—both its economic value to the performance of the transportation system and its physical replacement value
- The consequences represent the susceptibility of the infrastructure to damage from the hazards, which in turn depends on the infrastructure's design and state of repair, among other factors

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Decision Frameworks and Models to Address Climate Change

- Estimating future risk involves solving for the probability of occurrence of the hazards times the probable consequences if the hazards occurred, summed over all the transportation assets in a region

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Decision Frameworks and Models to Address Climate Change

- The objective is to minimize future risks
- Transportation professionals already take risk into account, particularly in designing facilities, and in recent years more probabilistic approaches have been incorporated (Meyer 2006)

- Engineers often size the drainage capacity of a transportation facility to handle a storm so severe that it occurs, on average, just once in 100 years

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Decision Frameworks and Models to Address Climate Change

- Adapting risk-based approaches to account for climate change poses new challenges
  - Historical experience will not be a reliable predictor of future climate conditions
  - The hazards themselves are likely to change over time, but in ways that are not currently understood with any precision
  - Attempting to hedge by simply designing to a more robust standard—say, a higher wind speed tolerance or a 500-year storm—will produce much more costly designs, likely to be unacceptable given limited budgets

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Decision Frameworks and Models to Address Climate Change

- A more strategic and selective risk-based approach that explicitly trades off the costs of designing for greater resilience against the costs associated with failure could help in setting realistic design standards and investment priorities

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Decision Frameworks and Models to Address Climate Change

- California's seismic retrofit program for bridges is an example of one way to proceed
- Following the Loma Prieta earthquake in 1989, the state was faced with the daunting task of how best to retrofit its stock of some 25,000 bridges

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Decision Frameworks and Models to Address Climate Change

- Earthquakes are a recurring problem, but there is considerable uncertainty about when or where a seismic event will occur
- The resources needed to retrofit every bridge to the highest standard or to conduct a physical inventory of all structures to determine which need to be retrofit are not available

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Decision Frameworks and Models to Address Climate Change

- The California Department of Transportation decided to proceed in the following manner
- First, departmental engineers determined an acceptable performance standard or level of risk, reducing one of the uncertainties
- For most bridges, that standard was “no collapse” under a maximum seismic event, consistent with the geographic location of the bridge
- The objective was to avoid loss of life; some damage to the structure was acceptable as long as the structure itself remained intact

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Decision Frameworks and Models to Address Climate Change

- The exceptions were 750 structures on state highways and 11 major toll bridges, which were held to a higher standard both to protect the substantial investment in these major structures and to ensure that these vital transportation lifelines would remain in service following a major seismic event to provide access for emergency responders
- The experts devised a layered screening system to rate the structures most in need of retrofit; an in-depth physical inventory was conducted only for those bridges that did not meet the performance standard

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Decision Frameworks and Models to Address Climate Change

- Elected officials were brought on board, and a combination of funds was employed to implement a long-term investment program that continues to this day
- State and local transportation officials could adopt a similar approach to assess how climate change may affect transportation assets and develop appropriate adaptation responses and investment strategies

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Decision Frameworks and Models to Address Climate Change

- To begin, they might ask the following questions:
  - Which projected climate changes are most relevant for their region?
  - How are climate change hazards likely to be manifested (e.g., flooding, storm surge coupled with sea level rise)?
  - Which transportation assets may be affected?
  - How severe must a hazard be before it becomes relevant and action is required? Can thresholds be identified?
  - How likely is it that a projected hazard will exceed the threshold, when, and where?
  - How much risk can be tolerated, or in other words, what infrastructure performance level is tolerable?

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Decision Frameworks and Models to Address Climate Change

- To begin, they might ask the following questions:
  - What level of investment (capital and operating) is needed to maintain different levels of service? Can acceptable performance standards for all modes of transportation be established?
  - Are there critical levels of service needed to protect health and safety?
  - Who is empowered to make these judgments and decisions?
  - What are the risks of adverse impacts or consequences if no action is taken?
  - If action is necessary, how will investment priorities be determined?
  - Who will make the necessary investments, and how will they be funded?

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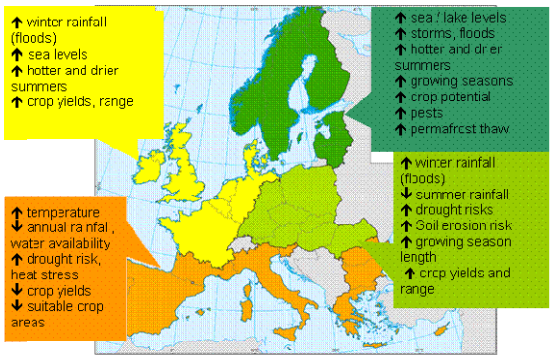
Decision Frameworks and Models to Address Climate Change

- Decision Framework to Address Impacts of Climate Change on Transportation Infrastructure

1. Assess how climate changes are likely to affect various regions and modes of transportation (assess hazards).



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Decision Frameworks and Models to Address Climate Change

2. Inventory transportation infrastructure essential to maintaining network performance in light of climate change projections to determine whether, when, and where the impacts of projected changes could be consequential (assess the vulnerability of assets and the system's resilience to loss of assets).
3. Analyze adaptation options to assess the trade-offs between making the infrastructure more robust and the costs involved. Consider monitoring as an option.

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Decision Frameworks and Models to Address Climate Change

4. Determine investment priorities, taking into consideration the criticality of the infrastructure component as well as opportunities for multiple benefits (e.g., congestion relief, removal of evacuation route bottlenecks).
5. Develop and implement a program of adaptation strategies for the near and long terms.
6. Periodically assess the effectiveness of adaptation strategies, and repeat Steps 1 through 5.

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Decision Frameworks and Models to Address Climate Change

- This approach provides guidance on how to proceed in addressing many of the technical questions previously posed
- However, it does not cover relevant organizational and political issues
- Transportation officials must communicate the results of their technical analyses to senior management and elected officials, who make the policy decisions that guide funding choices

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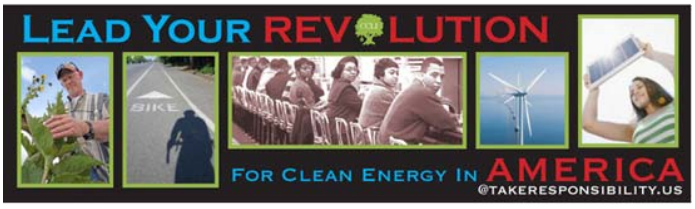
Decision Frameworks and Models to Address Climate Change

- Communicating the need for early attention to the impacts of climate change requires leadership, supported by compelling analyses, on the part of the transportation community



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Multimodal Planning and Policy Options to Mitigate Climate Change Impacts

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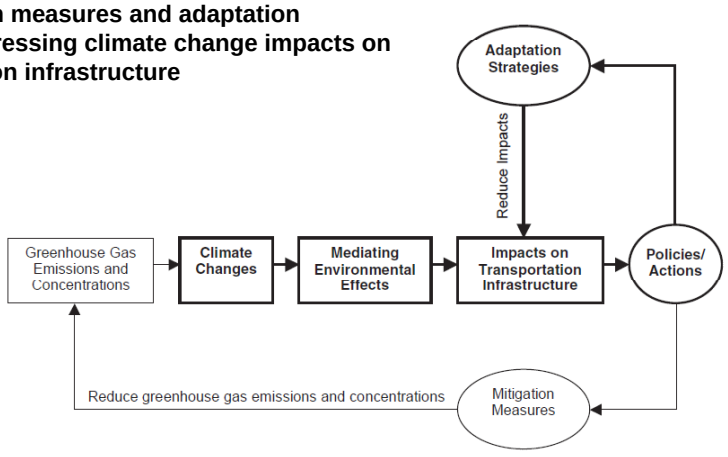
Multimodal Planning and Policy Options to Mitigate Climate Change Impacts

Role of mitigation measures and adaptation strategies in addressing climate change impacts on U.S. transportation infrastructure



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Multimodal Planning and Policy Options to Mitigate Climate Change Impacts

- The transportation sector in the United States:
  - The fastest-growing share of carbon monoxide emissions in the country
  - Depends on petroleum for 97% of its fuel
  - Accounts for 28% of all green-house gas (GHG) emissions
  - Consumes twice as much petroleum as the country produces each year
- Transportation carbon dioxide emissions (the main GHG emissions from transportation) are growing faster than is the U.S. economy as a whole

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Multimodal Planning and Policy Options to Mitigate Climate Change Impacts

- Most current federal transportation policies and programs that attempt to reduce emissions focus on vehicles and fuels
  - Land-use and multimodal planning policies are left to local, regional, and state governments

Adaptation policies refer to actions taken to alleviate, reduce, or eliminate the impacts of changes in climate

Mitigation policies (the focus of this section) influence the use of vehicles through strategies that

a. Raise the cost of using higher energy-consuming and GHG-emitting types (automobiles, trucks, and aircraft)
b. Encourage shifts to more energy-efficient modes (transit, rail, and water)

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Multimodal Planning and Policy Options to Mitigate Climate Change Impacts

Current U.S. Fuel Efficiency Policies: The Federal Level

- Fuel Economy Standards:
  - Corporate Average Fuel Economy (CAFÉ) standards are set to reach 35 miles/gal by 2020 and new vehicle models must advertise their fuel economy as well as GHG emissions performance ratings
- Energy Efficiency Standards:
  - For heavy-duty vehicles, voluntary energy conservation programs encourage fuel efficiency. These programs may become mandatory in the near future.

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Multimodal Planning and Policy Options to Mitigate Climate Change Impacts

Current U.S. Fuel Efficiency Policies: The Federal Level

- Alternative Fuel and Vehicle Tax Incentives:
  - Tax credits are available for households that purchase energy-efficient vehicles, manufacturers building energy-efficient vehicles, and gas stations that supply alternative fuels
- Renewable Fuels Mandate:
  - Federal government requires a certain percentage of gasoline consist of fuel from renewable resources (8% in 2010). This percentage has increased over the past several years

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Multimodal Planning and Policy Options to Mitigate Climate Change Impacts

Current U.S. Fuel Efficiency Policies: The Federal Level

- Support for Research and Development:
  - Federal governments supports a number of research projects aimed at technologies that would improve energy efficiency. Federal agencies themselves also conduct fuel efficiency research projects
- Federal Fuel Tax:
  - The tax placed on the purchase of gasoline raises its retail value by about 25%, providing an incentive to buy (and therefore use) less fuel. Funds that come from these taxes go back to the individual states for traffic mitigation, air quality improvement, etc.

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Multimodal Planning and Policy Options to Mitigate Climate Change Impacts

Current U.S. Fuel Efficiency Policies: The State Level

- State and Local Fuel Tax:
  - About half the U.S. states impose lower taxes on alternative fuels. In addition, fuel taxes can help discourage the use of large quantities of fuel
- State Performance Standards:
  - California is granted the option to develop its own emissions performance standards, which other states may adopt. In 2002, California enacted a law to improve vehicle fuel efficiency to 35 miles/gal by 2016 (2 years sooner than the federal standard)

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Multimodal Planning and Policy Options to Mitigate Climate Change Impacts

Current U.S. Mitigation Policies: The Local Level

- Local governments, who have authority over infrastructure like parking lanes, transit modes, bicycle laws, etc. play an important role in mitigating GHG
- Local governments have enacted a variety of policies for reducing GHG emissions, such as:
  - Ordinances governing truck and bus idling
  - Providing excellent walking and biking facilities
  - Incorporating land-use and zoning plans to mitigate fuel usage
- Metropolitan planning organizations are often responsible for GHG mitigation policies in local government

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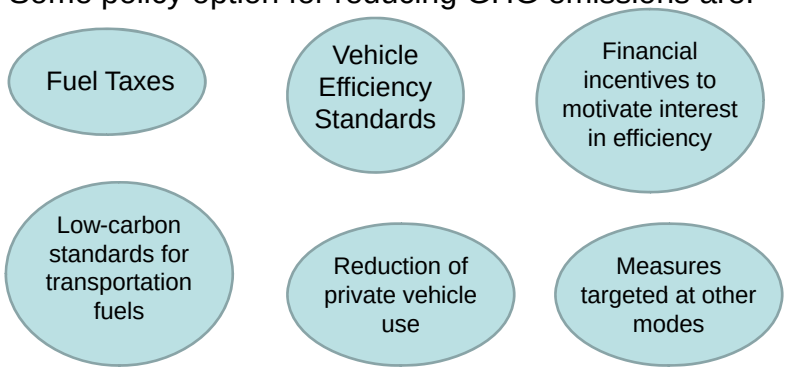
Multimodal Planning and Policy Options to Mitigate Climate Change Impacts

- Some policy option for reducing GHG emissions are:



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- An increase in fuel tax would lead to an increase in the cost of fuel
  - Disincentive to use “gas guzzler” vehicles
  - Neither state governments nor the federal government have been able to pass an increased fuel tax since the early 1990’s

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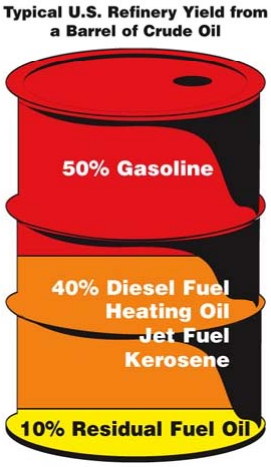
Multimodal Planning and Policy Options to Mitigate Climate Change Impacts

- A 2010 study showed that taxes on refined oil as a whole – rather than just gasoline – has greater potential to reduce oil use and GHG emissions
- Another 2010 study shows an increased response when gas taxes were combined with national carbon pricing, though this option is admittedly aggressive



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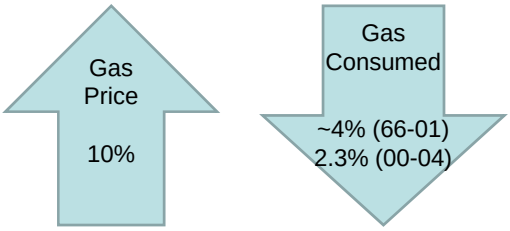
Multimodal Planning and Policy Options to Mitigate Climate Change Impacts

- A considerable body of literature exists that shows motorists are relatively inelastic to increases in gas price
  - 10% increase in fuel price in the U.S. led to a short-run 0.4% and long run 2.3% decrease in gas consumption (2000 – 2004)
  - This is compared to a 4 – 5% decrease in fuel consumption from a 10% price increase between 1966 and 2001 (Small and Van Dender, 007)



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Multimodal Planning and Policy Options to Mitigate Climate Change Impacts

- As average income increases, the reduction in VMT as a result of gas price increase declines
  - Increased income → Greater transportation fuel budget
- Consumers are still reluctant to invest in fuel efficient vehicles, due to their higher up-front cost

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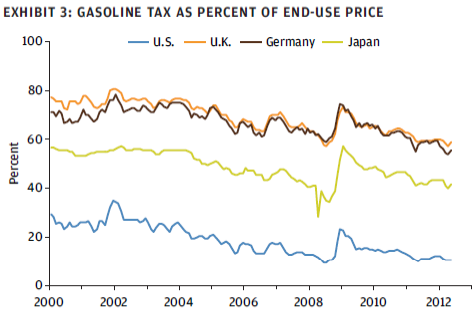
Multimodal Planning and Policy Options to Mitigate Climate Change Impacts

- A variable tax on gasoline would reduce price volatility, setting a minimum gas price
  - Variability in the gas price makes it risky to invest in alternative fuels
  - A tax that changes inversely with the price of oil would create a more stable gasoline market



Source: International Energy Administration (IEA). Data as of 7.4.12.

[5] Sarah Mongourdin-Denoix and Felix Wolf, *Wage indexation in the European Union*, Eurofound background paper, 2010.

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Multimodal Planning and Policy Options to Mitigate Climate Change Impacts

- This type of tax would not be a viable option for funding highway projects, since revenue could not be guaranteed
- The most significant challenge to this tax scheme would be consumer resistance to rising taxes

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Multimodal Planning and Policy Options to Mitigate Climate Change Impacts

- Fuel efficiency standards have been around for decades
- Some current efficiency standards from around the world are shown here:

Country or Region	Model Year Effective	Standard Type	Unadjusted Fleet Target or Measure	Structure	Targeted Fleet
United States	2016	Fuel economy, GHG	34.1 mpg (14.5 km/L) or 250 g of CO_2/mile (155 g of CO_2/km)	Footprint-based corporate average	Cars, light trucks
Canada (proposal)	2016	GHG	155 g of CO_2/km	Footprint-based corporate average	Cars, light trucks
European Union	2015	GHG	130 g of CO_2/km	Weight-based corporate average	Cars, light trucks
Australia	2010	GHG	222 g of CO_2/km	Single average	Cars, light trucks
Japan	2015	Fuel economy	16.8 km/L	Weight-based corporate average	Cars
China (proposal)	2015	Fuel economy	14.2 km/L	Weight-based per vehicle and corporate average	Cars, light trucks
South Korea (proposal)	2015	Fuel economy, GHG	17 km/L or 140 g of CO_2/km	Weight-based corporate average	Cars, light trucks

Source: German and Lutsey 2010.

1. Transportation Research Board, Policy Options for Reducing Energy Use and Greenhouse Gas Emissions from U.S. Transportation. TRB Special Report 307, national Research Council, Washington D.C. (2011)

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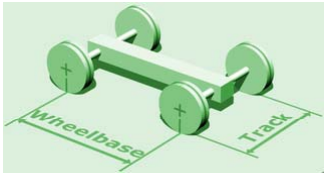
Multimodal Planning and Policy Options to Mitigate Climate Change Impacts

- Fuel efficiency standards for light duty vehicles are usually for weight-based or footprint-based average
  - Footprint refers to the actual projected area of the vehicle on the roadway: track width times wheelbase
- Critics claim that these standards lead to auto manufacturers choosing smaller vehicle designs that compromise occupant safety



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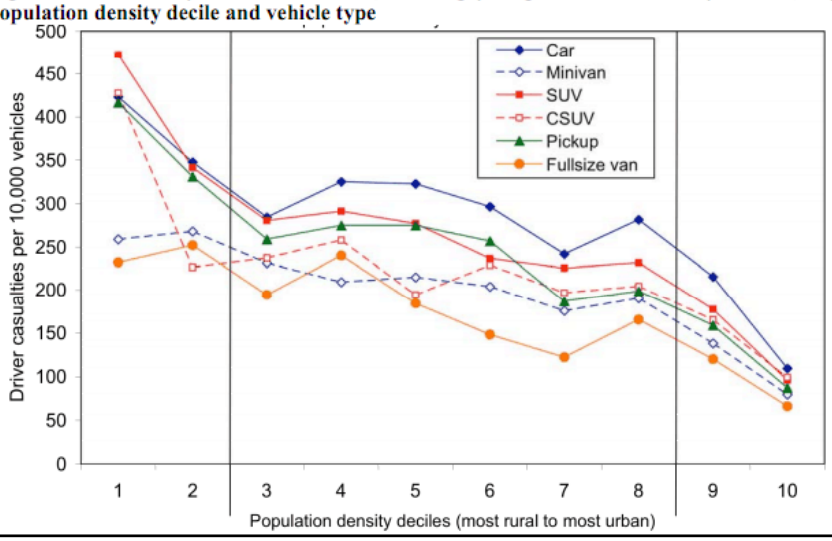
Multimodal Planning and Policy Options to Mitigate Climate Change Impacts

Figure 4-2. Casualty risk for drivers (excluding young males and elderly drivers), by population density decile and vehicle type



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Multimodal Planning and Policy Options to Mitigate Climate Change Impacts

- Taxes, tax credits, and rebates can be used to encourage acceptance of fuel efficient vehicles
- Many countries currently place a tax on “gas-guzzler” vehicles
- A “Feebate” is a proposed government program that would provide both financial incentive for fuel efficiency and disincentive for fuel inefficiency
  - All new vehicles would be tested to determine their emissions performance with respect to some standard
  - Consumers would be charged a graduated fee or rebate based on by how much the vehicle falls below or exceeds the threshold, respectively

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Multimodal Planning and Policy Options to Mitigate Climate Change Impacts

	France	Ireland	Germany	United States	Canada
Type of program	Feebate	Fee (tax only)	Fee (tax only)	Fee (tax only)	Noncontinuous Feebate
Fleet affected	Light-duty vehicles between 96 and 25 mpg	Light-duty vehicles between 49 and 28 mpg	All light-duty vehicles	Cars less than 22.5 mpg	Light-duty vehicles, varied mpg coverage
Pivot point	About 42 mpg	N/A	N/A	N/A	~ 24 mpg for cars, 22 mpg for others
Deviations from a true feebate system	Incomplete coverage; Not continuous	Fees only; Incomplete coverage; Not continuous	Fees only; Annual only; Some fees based on engine size	Fees only; Does not cover majority of the fleet; Not continuous	Differing feebate by vehicle type: Does not cover majority of fleet; Not continuous

1. Transportation Research Board, Policy Options for Reducing Energy Use and Greenhouse Gas Emissions from U.S. Transportation. TRB Special Report 307, national Research Council, Washington D.C. (2011)

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Multimodal Planning and Policy Options to Mitigate Climate Change Impacts

- A renewable fuel standard (like the one adopted in the U.S.) replaces a certain percentage of petroleum fuel with a volume of renewable fuel

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Multimodal Planning and Policy Options to Mitigate Climate Change Impacts

- A low-carbon fuel standard (LCFS) requires fuel suppliers to reduce the level of GHG emissions released by their fuels (like the one adopted by California)
  - In the California program, this includes the emissions released during the manufacture of the fuel
- LCFS programs are more likely to be effective if they cover a larger region than simply a single U.S. state
  - The “leakage” problem refers to the disincentive for regional suppliers to alter their fuel composition for just one relatively small area

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Multimodal Planning and Policy Options to Mitigate Climate Change Impacts

- The greatest potential for reducing private-vehicle travel through planning lies in the metropolitan regions
  - More likely to have available transit options
  - Can facilitate walking and biking for short distance trips
- Strategies for decreasing the mode share of personal automobiles include
  - Moderating growth in city driving
  - Pricing road usage
- Most of these policy strategies fall under the umbrella of multimodal development and land-use planning

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Multimodal Planning and Policy Options to Mitigate Climate Change Impacts

- Pricing strategies, while controversial, could reduce total automobile travel by causing some trips to be forgone and by encouraging mode shift
- Pricing strategies include:
  - Congestion pricing
  - Area-wide pricing
  - Parking
  - Tolling
  - Charging for mileage traveled

- Congestion pricing is concerned with a time-of-day shift while the others are concerned with a mode shift

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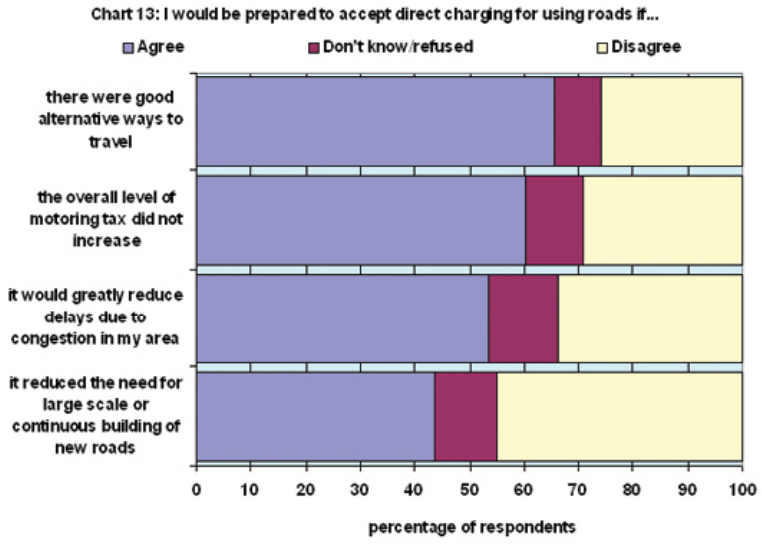
Multimodal Planning and Policy Options to Mitigate Climate Change Impacts



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Multimodal Planning and Policy Options to Mitigate Climate Change Impacts

- Studies have shown that pricing can reduce VMT, but little research has been completed surrounding:
  - Equity
  - Public acceptability
  - Environmental impact
  - Management needs
- The concept of road pricing through tolling is not a new concept
- Nearly 100 variable-tolling facilities are in use or in development around the world

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Multimodal Planning and Policy Options to Mitigate Climate Change Impacts

- The state of Oregon collects weight-distance taxes from motor carriers in lieu of diesel taxes
- Germany charges truck tolls based on mileage, emissions, and number of axles
  - On-board GPS and wireless communication devices are used to calculate charges

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Multimodal Planning and Policy Options to Mitigate Climate Change Impacts

- Pay-as-you-drive insurance policies
  - Insurance is charged based on miles driven
  - System alerts drivers to the increased probability of having an accident for each increased mile driven

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Multimodal Planning and Policy Options to Mitigate Climate Change Impacts

- In the U.S., the availability of off-street parking in many urban centers drives the market price of parking to zero
- Shoup (1997, 2006, and 2007) has studied the cost of parking extensively and recommends parking pricing as a means of reducing personal automobile travel
  - Charging market-clearing prices for on and off-street parking
  - Eliminating or re-evaluating mandates on how much parking developers must provide
  - Providing workers with cash or transit credits in exchange for not using company parking spaces

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Multimodal Planning and Policy Options to Mitigate Climate Change Impacts

- Compact land development effectively brings trip origins and destinations closer together
  - Allows the transit mode to be more competitive
  - Encourages non-motorized transport modes like walking
- The effects of land-use policies on total VMT are difficult to measure
  - Time scales and the presence of outside factors (like socio-economic differences)
- These policies can be difficult to implement due in part to the variability in types of developers

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Multimodal Planning and Policy Options to Mitigate Climate Change Impacts

- In the U.S., many areas have successfully increased the mode share of bicycling by adding
  - Dedicated bike lanes
  - Bike sharing programs
- The utility of biking and walking increases when attractions are located closer together in mixed-use

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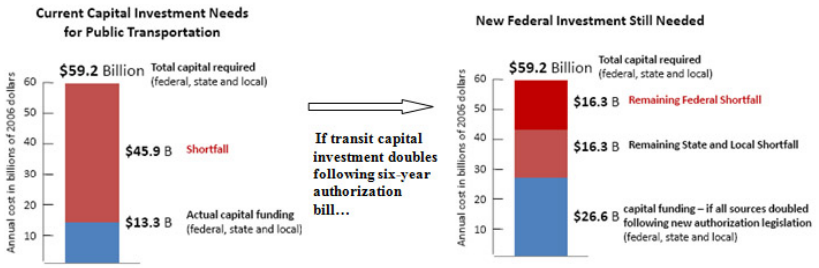
Multimodal Planning and Policy Options to Mitigate Climate Change Impacts

- Investment in public transit in the U.S. accounts for 20% of surface transport expenditures, but only about 3% of all metropolitan trips



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Multimodal Planning and Policy Options to Mitigate Climate Change Impacts

- Policies that reduce transit fares and wait times have been most successful in increasing ridership (Taylor, Miller, et al. 2009)
- Other steps to help boost transit ridership include
  - Increasing safety monitoring of riders
  - Providing real-time traveler information

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Multimodal Planning and Policy Options to Mitigate Climate Change Impacts

- Trucking and airlines are the transportation sector's 2nd and 3rd largest contributors to GHG emissions, respectively

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Multimodal Planning and Policy Options to Mitigate Climate Change Impacts

- Many of the efficiency standards suggested for light-duty vehicles can be applied to heavy-duty trucks and airlines
- One major challenge is the lack of technology for hybrid engines that meet the weight and distance requirements of these modes

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Multimodal Planning and Policy Options to Mitigate Climate Change Impacts

- Federal regulations on truck weight limits can lead to less fuel efficiency
  - Trucks must not exceed a certain weight limit for safety and roadway maintenance reasons
  - This may prompt freight companies to make 2 trips to haul the amount of goods that could fit into a single tractor trailer
- Recent addition of GHG emissions to the standards under the U.S. Clean Air Act could lead to airline and freight efficiency enhancements

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Multimodal Planning and Policy Options to Mitigate Climate Change Impacts

- Policies can be implemented on government owned and operated roadways that reduce fuel emissions for freight vehicles
  - The European Union limits truck speeds to about 56 mph (90 km/h) to meet optimal fuel efficiency
  - Dedicated truck lanes would allow lower speeds and less stop-and-go traffic for freight vehicles
  - Intelligent transportation systems (ITS) such as automated toll collection, real time congestion updates, etc. can aid in fuel efficiency
- Similar policies can be implemented in government-controlled air space for airline travel

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Multimodal Planning and Policy Options to Mitigate Climate Change Impacts

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Multimodal Planning and Policy Options to Mitigate Climate Change Impacts

Summary of policy options:

- Fuel taxes not only increase the cost of gas, but also stabilize it
  - Research needed to understand consumer response to increased fuel cost and price elasticity
- More strict fuel efficiency standards
  - Policies should be implemented in such a way that vehicle performance and occupant safety is not compromised
- Financial incentives such as the “feebate”
- Low-carbon fuel standards that encompass large regions or entire countries

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Multimodal Planning and Policy Options to Mitigate Climate Change Impacts

- Reducing the mode share of private vehicles, especially in metropolitan areas
  - Congestion pricing to shift trip times of day
  - Mileage pricing to reduce total miles traveled or encourage a mode shift
  - Parking pricing to discourage use of the personal automobile
  - High-density land development policies can make transit modes more practical
  - High-density and mixed-use land use policies can encourage walking and bicycling
  - Programs to reduce fares and wait times, enhance traveler safety, and provide traveler information can increase the mode share of transit

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Multimodal Planning and Policy Options to Mitigate Climate Change Impacts

- Leveraging the government ownership of roadways and airspace to enact freight and airline fuel efficiency
- Harnessing ITS research to reduce roadway congestion
  - This would lead to greater efficiency for all vehicles, but especially for heavy-duty trucks

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Multimodal Planning and Policy Options to Mitigate Climate Change Impacts

- Federal, state, and local policy makers need informed guidance about the effectiveness, costs, feasibility, and acceptability of transportation mitigation strategies
- Effective research in the area should be guided by the following:
  - The topics investigated should be directly relevant to the needs of federal, state, and local transportation policy makers
  - Funding should be awarded on the basis of open competition and merit review of proposals by peers
  - Results should be evaluated by expert and practitioner stakeholders

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Sustainable Land Development

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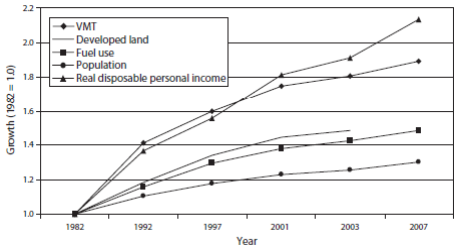
Sustainable Land Development

- Low density land use development has been the trend for generations
- Low density areas lead to increased VMT
  - Origins and destinations are farther apart, making non-motorized modes of travel impossible to use



U.S. Growth Trends

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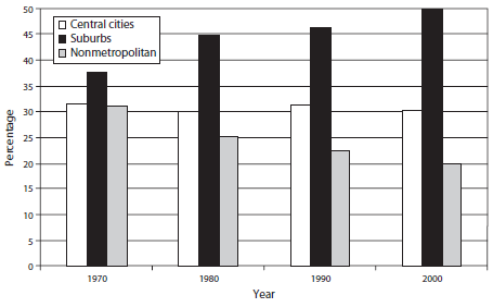
Sustainable Land Development

- Between 1982 and 2003, an estimated 35 million acres of land (55,000 miles^2) was developed in the United States (National Resources Inventory)



- The share of the population living in suburbs has greatly increased from 1970 to 2000

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Sustainable Land Development

- Since the 1980's, cities have tended to orient themselves toward having central cities and less dense land use (NRC 1999)
- *Urban sprawl* characterizes low density, dispersed, single-use, automobile-dependent land development

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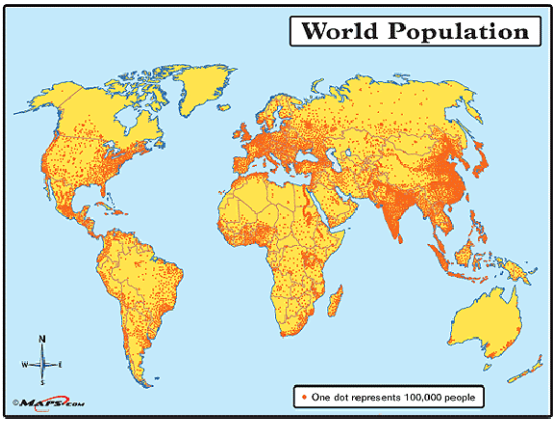
Sustainable Land Development

- Cities that were established before the invention of the automobile in the U.S. tend to have greater density than the newer cities
  - Highest density cities are in the Northeast (New York @ about 20 people per urbanized acre)
  - Lowest densities are in the Southwest (Phoenix @ about 7.2 people per urbanized acre)



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Sustainable Land Development

- Transportation networks complement and interact with land development patterns
- Characteristics that measure interaction between networks and development patterns
  - Grid style transportation networks tend to provide greater accessibility for encouraging alternative modes
  - This is as opposed to hierarchical branching networks

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Sustainable Land Development

- Larger residential lot sizes are at least partly responsible for the rapid decline in density
  - From 1987 to 1997, the density of the average urban acre declined from 1.86 dwelling units (DUs) per acre to 1.66 DUs per acre
- Current models of land development predict constantly decreasing density the farthest from
- *Centrality* indicates the extent to which land development in a region spreads out from a single senter
- *Density gradient* measures the average population density at increasing intervals from the point of concentration

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Sustainable Land Development

- Land development patterns can be characterized by the "five D's":
  - Density (population and employment)
  - Diversity of lane use types
  - Design, especially concerning the availability of facilities for non-motorized modes of travel
  - Destination accessibility – the ease of accessing attractions from other areas
  - Distance to transit

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Sustainable Land Development

- Strategies for increasing land-use density go by many names
  - Transit-oriented development
  - Neotraditional design
  - Smart growth

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Sustainable Land Development

- The effect of higher densities on VMT is not entirely straightforward
  - If desired destinations are closer, trip frequencies might increase
  - Trip length itself is a measure comprised of trip length, frequency, and mode choice (Ewing and Cervero, 2001)
- Increased density alone cannot decrease fuel consumption, but must be combined with mixed-mode development

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Sustainable Land Development

- The direct link between sustainable development and VMT is uncertain
  - Questions still arise concerning the degree of the connection and the direction of causality (Handy, 2005)
  - Socio-economic characteristics, employment density, and automobile ownership each play important roles

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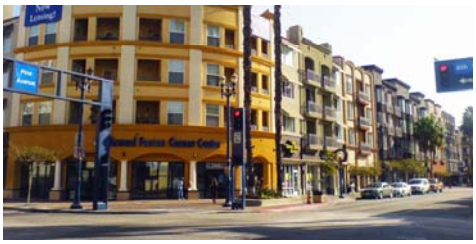
Sustainable Land Development

- Increasing density alone may not be sufficient to lower VMT by a significant amount
  - A diversity of land uses that results in locating desired destinations
  - Networks that provide good connectivity between locations and accommodate nonvehicular travel
  - Demand management policies that complement eff orts to lower VMT



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Sustainable Land Development

- Research into the relationship between VMT and land use is made more complex by a lack of standard metrics
  - Simply measuring the built environment in terms of density overlooks the effects of the other “5 D’s”
  - Many typical measurements for vehicle usage exist in literature, but there is not a standard one used in land-use studies
  - The change in VMT as a result of land-use patterns is highly dependent on geographic scale

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Sustainable Land Development

TABLE 3-1 **Elasticity Estimates of Changes in VMT Relative to Changes in the Built Environment from Selected Studies and Surveys of the Literature**

Authorship	Built Environment Feature	Scale	Geographic Location	Percentage Increase in Built Environment Feature	Percentage Reduction in VMT
Ewing and Cervero (2001, 111)[a]	Density	Neighborhood	Multiple locations	100	5
	Diversity (land use mix)	Neighborhood		100	5
	Design	Neighborhood		100	3
	Density, diversity, and design	Neighborhood		100	13
	Accessibility	Regional		100	20
Bento et al. (2005, 475–477)[b]	City shape, jobs–housing balance, road density, rail supply (for rail cities)—each variable alone	Regional	114 U.S. MSAs	100	≤7
	Population centrality alone	Regional	114 U.S. MSAs (without New York)	100	15
	All built environment variables	Regional	Atlanta, GA; Boston, MA	Various	25
Brownstone and Golob (2009)[c]	Density	Regional	California	100	12

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Sustainable Land Development

- Transit-Oriented Development (TOD): travelers tend to use transit 2-5 times more than other users
- Must keep in mind that a primary reason for higher TOD transit use is self-selection
  - Many residents locate in TODs precisely because they want to use transit
- The demographic profile of TOD residents is often different from the profile of residents in surrounding communities
  - Typically smaller households without children

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Sustainable Land Development

- Greater density and therefore shorter trips can increase trip frequencies, but empirical evidence suggests that the increase is not enough to off set the reduction in VMT that comes from reduced trip lengths alone

Area	Transit Mode Share (percent)	Walking Mode Share (percent)	Automobile Mode Share (percent)	VMT per Capita	Automobile Ownership per Household
Neighborhoods with mixed use and good transit	11.5	27.0	58.1	9.80	0.93
Neighborhoods with good transit only	7.9	15.2	74.4	13.28	1.50
Remainder of Multnomah County	3.5	9.7	81.5	17.34	1.74
Remainder of the region	1.2	6.1	87.3	21.79	1.93

Source: 1994 Metro Travel Behavior Survey for all trip types.

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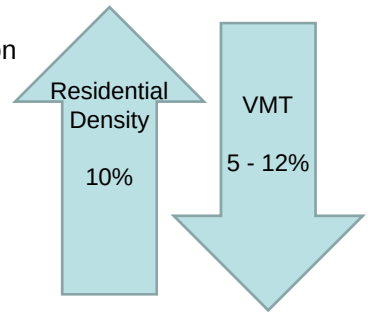
Sustainable Land Development

- Literature suggests doubling residential density might lower VMT by 5 – 12%
- Even greater VMT reduction could be met by implementing:
  - Higher employment concentration
  - Public transit improvements
  - Mixed land use



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Understanding the Role of Travel Behaviour

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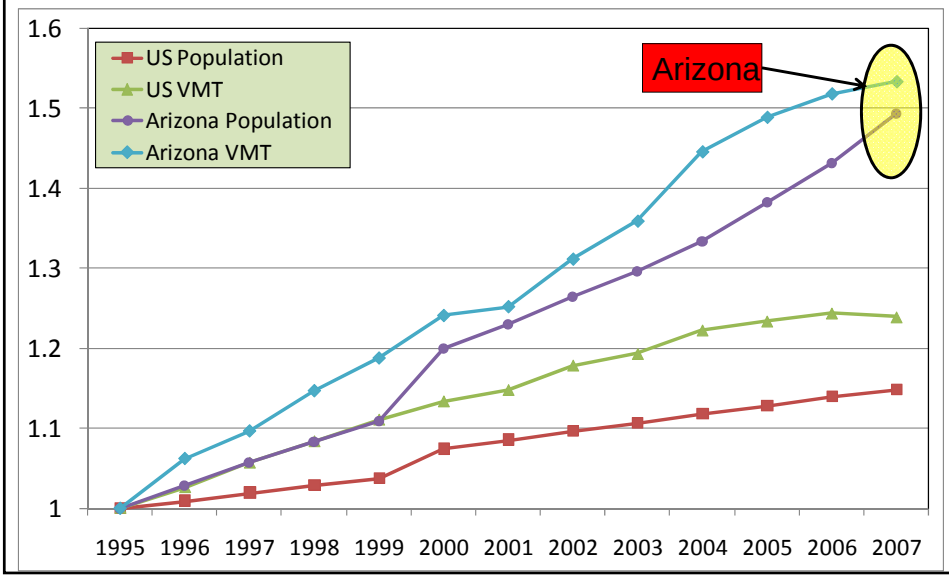
Understanding the Problem



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Mode Choice: Journey to Work

Mode	Greater Phoenix	Portland, OR
SOV	76%	66%
HOV	14%	11%
Motorcycle	1%	0%
Public Transit	2%	9%
Non-motorized	2%	7%
Other	1%	1%
Work from home	5%	6%
Total	***100%***	***100%***

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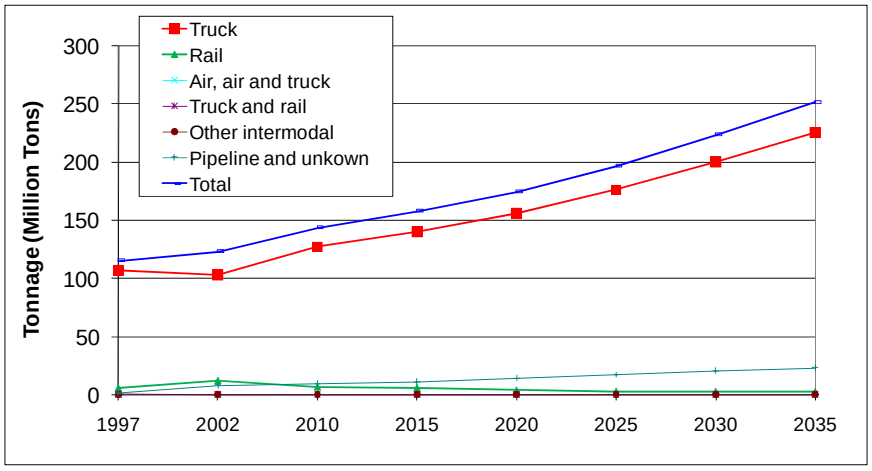
Freight Tonnage by Mode



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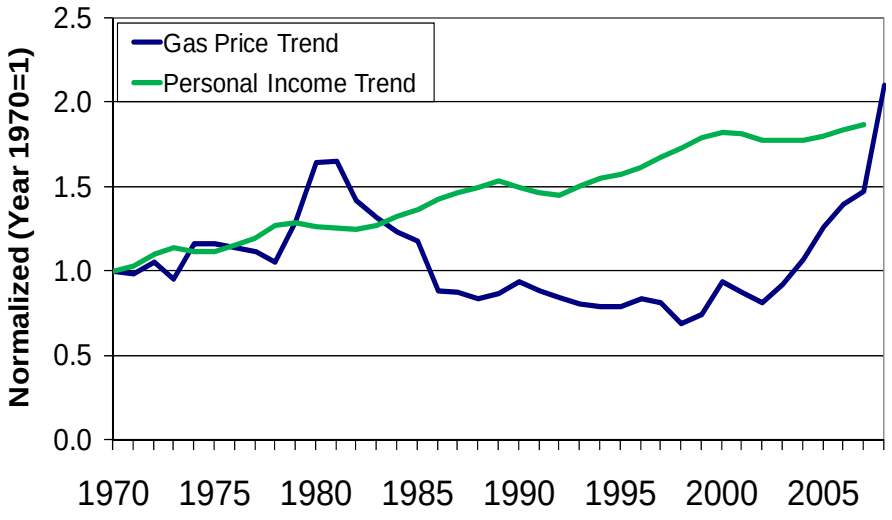
Gas Prices vs Personal Income



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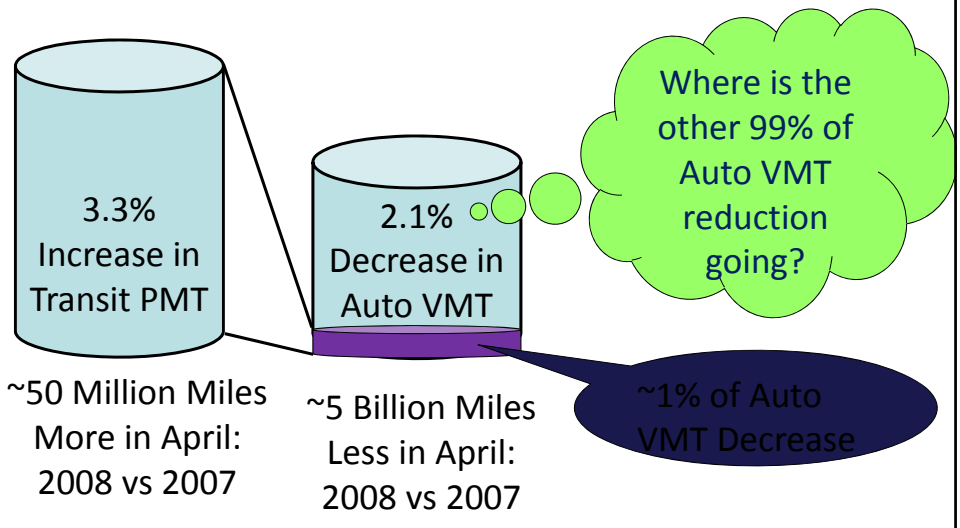
Understanding Scale: The Insensitivity of Travel



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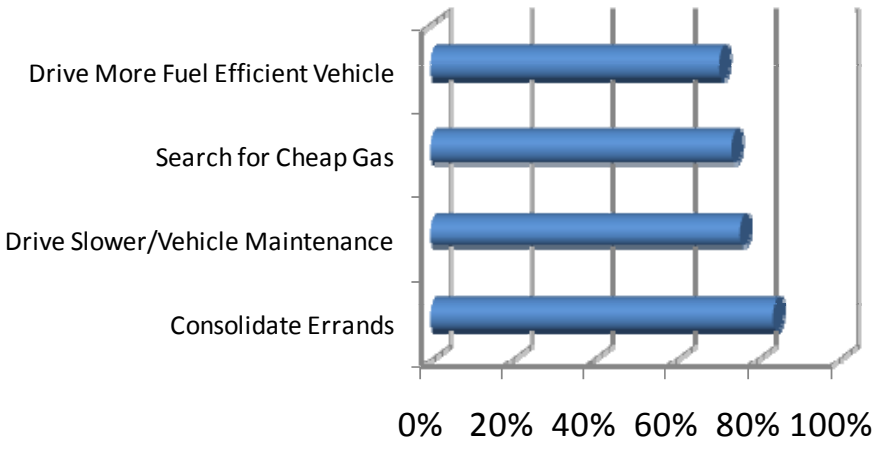
How Do People Adapt?



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Modal Speeds

Mode	MPH
Car	31.0
Van	31.7
SUV	33.0
Pickup truck	33.7
Other truck	42.4
RV	45.1
Motorcycle	32.2
Local public transit bus	**7.9**
Commuter bus	**17.1**

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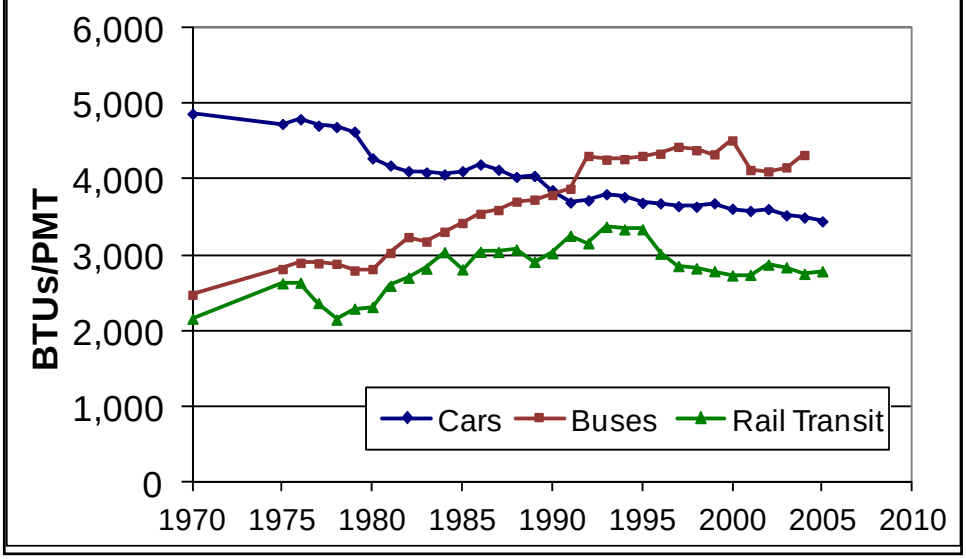
Modal Energy Efficiency



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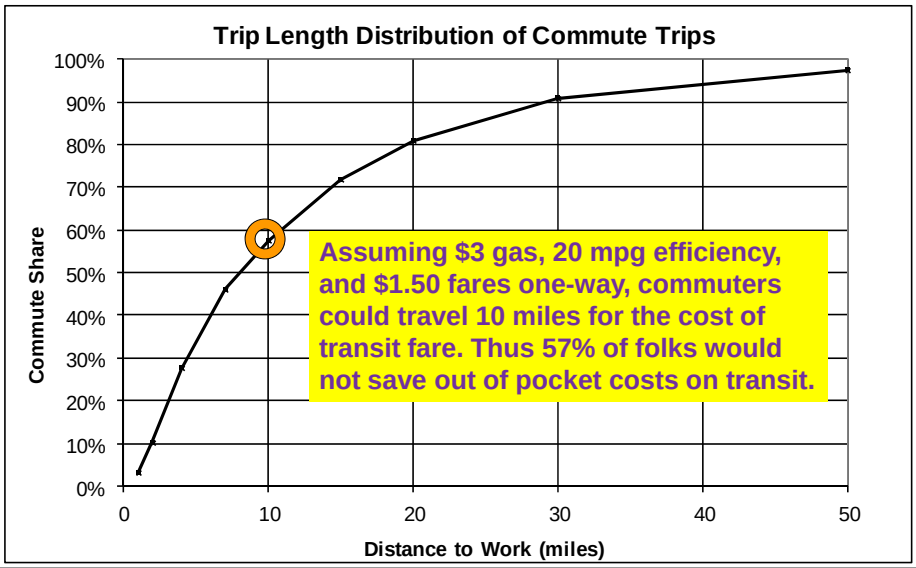
Modal Cost



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Drivers of Travel Demand

Time

Growth in

- Income
- Knowledge

Specialization in

- Employment
- Consumption
- Social relationships
- Time use

Growth in

- Person Travel
- Commerce
- Communication

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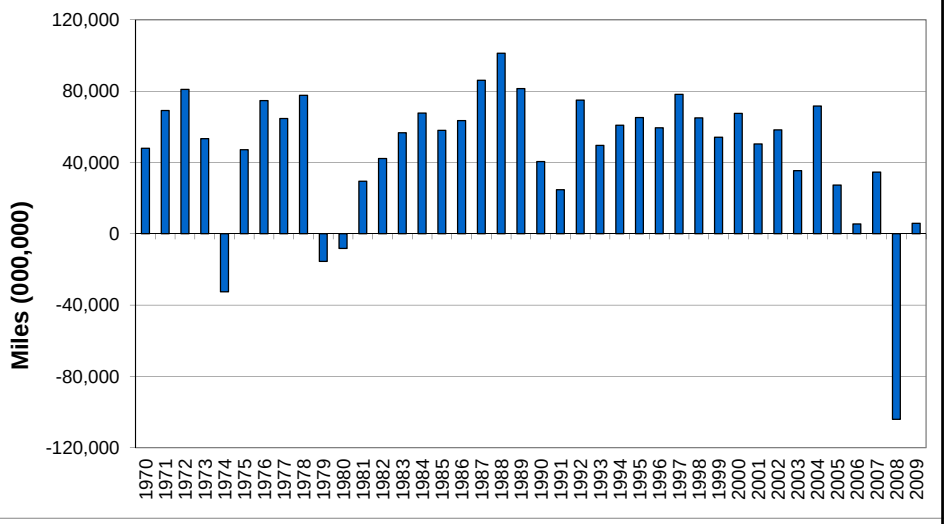
Annual Change in Vehicle Miles of Travel (VMT)



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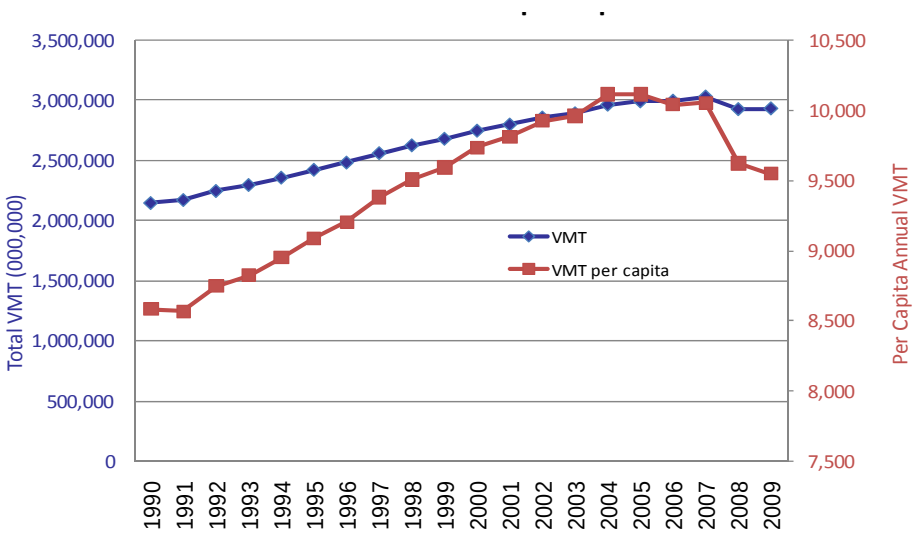
Vehicle Miles of Travel per Person



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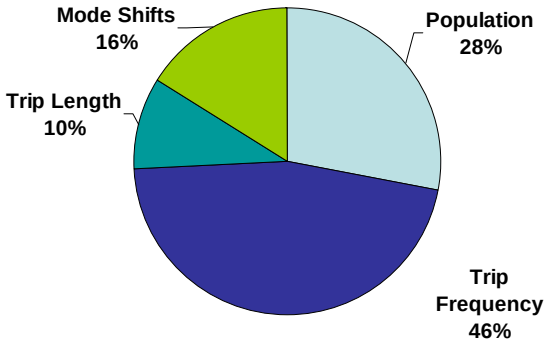
Factors Contributing to US VMT Growth (1977-2008)



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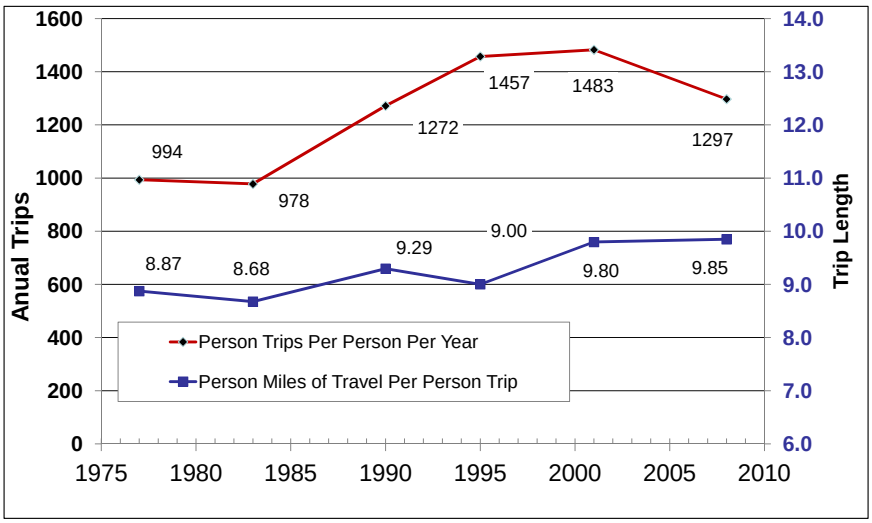
Trip Rate and Trip Length



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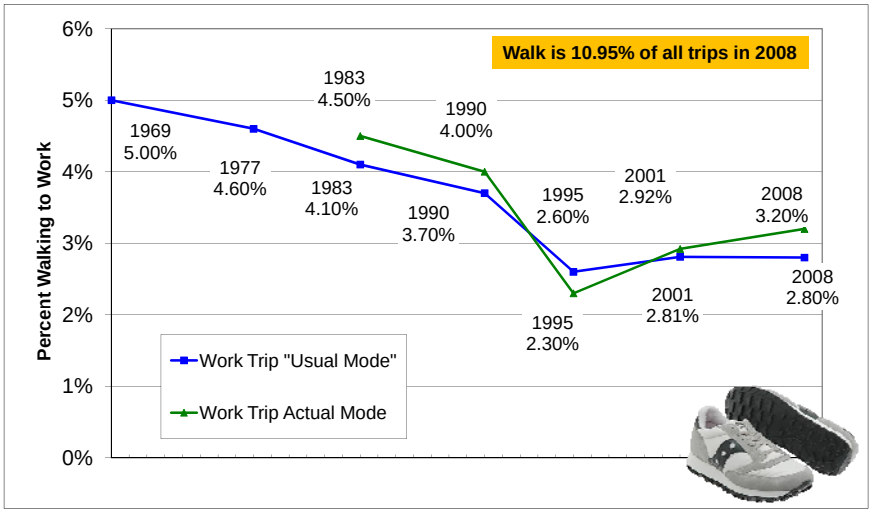
Walk Mode Shares



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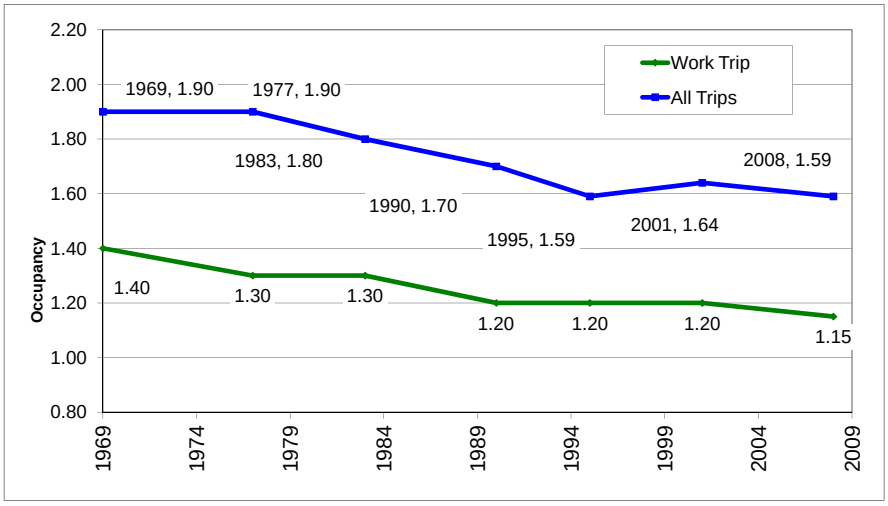
Vehicle Occupancies



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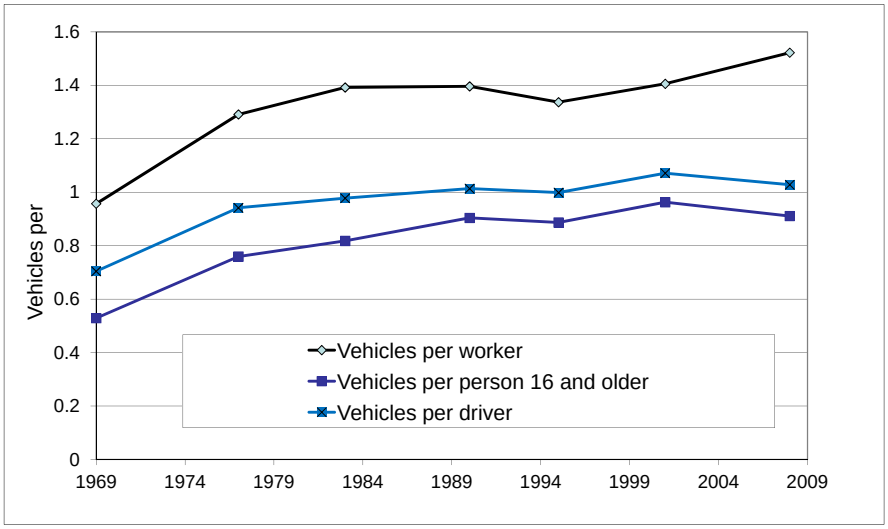
Vehicle Availability



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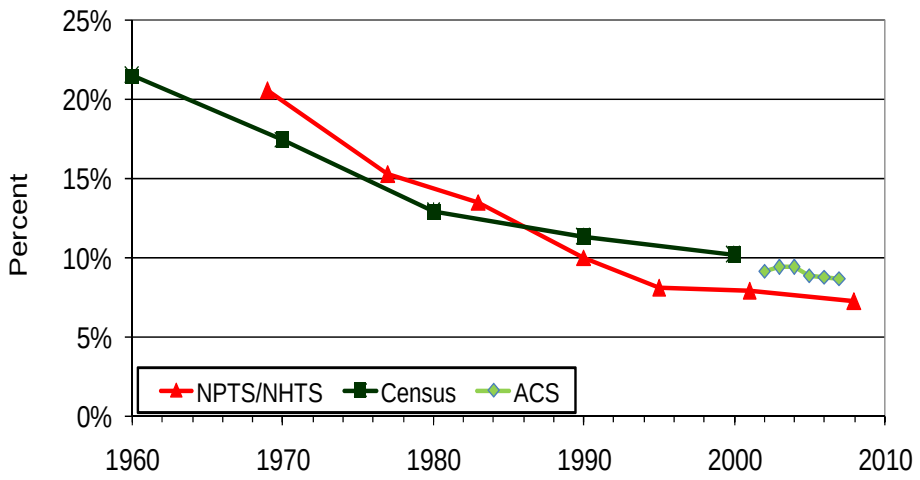
Declining Zero-Vehicle Households



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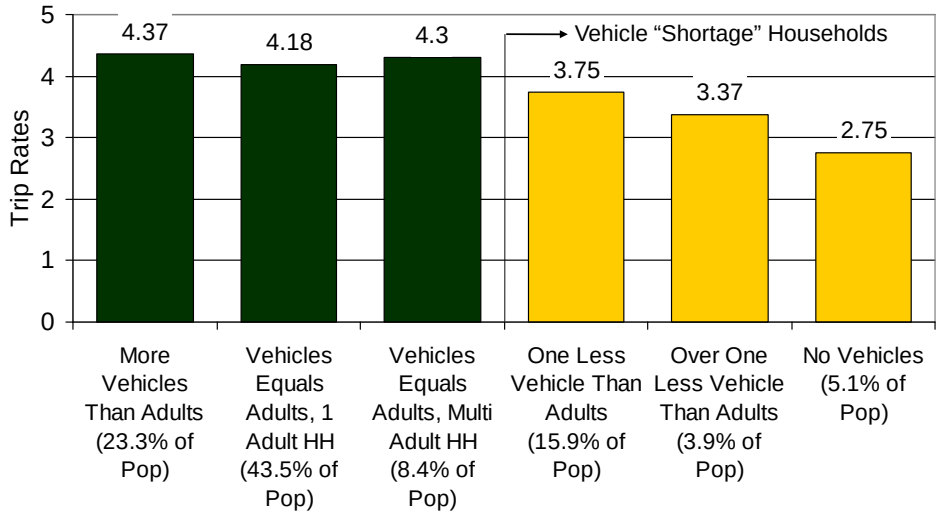
Vehicle Availability Makes a Difference



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What is the Future of Travel Demand?

Travel Desire
- Population
- Real Income
- Wealth
- Value of Time

System Supply
- Modes
- Speeds
- Costs

Land Use
- Density
- Mix

Energy Costs/ Other Costs

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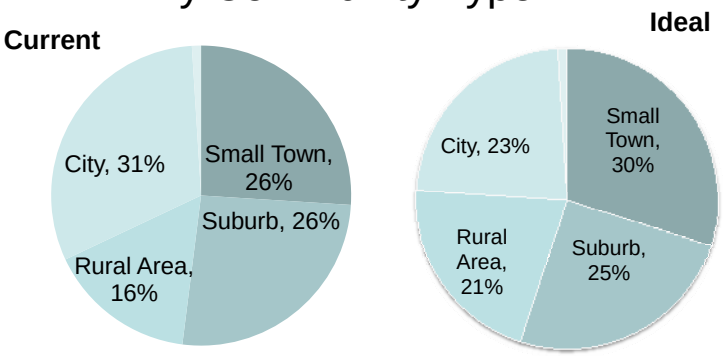
Residential Location Preference

By Community Type



Note: "Don't know/Refused" responses are not reported

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Much Research in Progress

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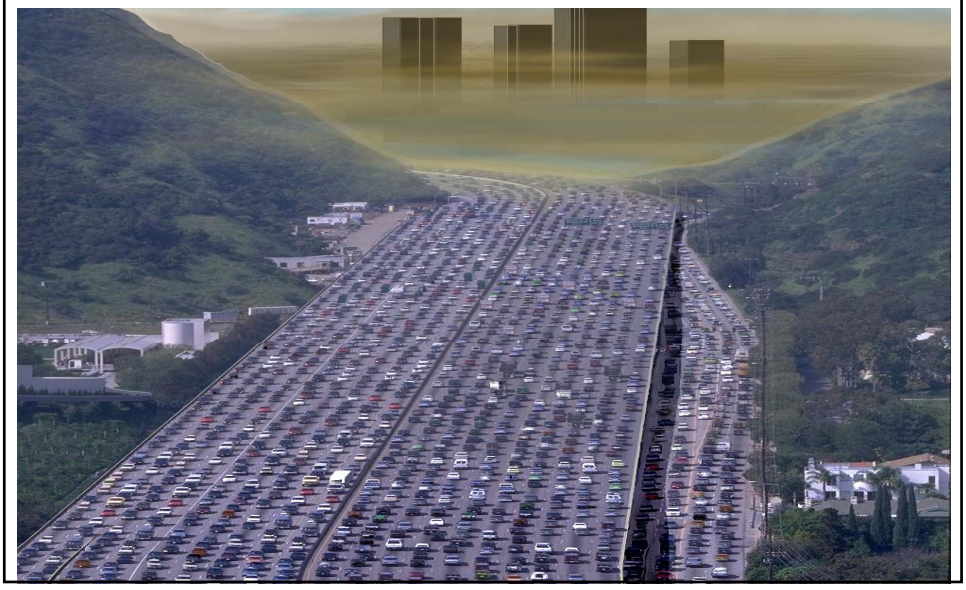
What Does the Future Hold?



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What Does the Future Hold?

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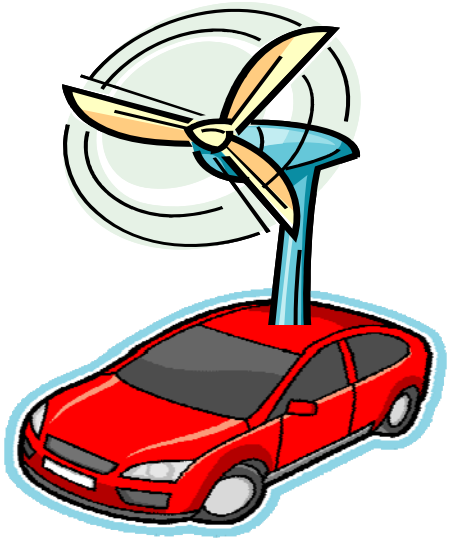
What Does the Future Hold?



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Planning Methods, Tools, and Data Needs

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Sustainable Land Development