Current Issues in Global Warming and Mitigation Efforts: Focus on California

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ABSTRACT

Global warming is almost certainly the most important problem addressed by the atmospheric community today and has recently become one of the hottest on the political agenda. Because it is such a vast and complex problem, the majority of atmospheric researchers are carrying out investigations on some aspect of it. The results of these studies are assimilated in computer-intensive global circulation models to simulate the earth's climate. Despite such intensive efforts, there is still much contention over the nature and degree of global warming, over long-term climate prediction, and over the implementation of mitigating measures. In this paper, I review the scientific basis for global warming, present outstanding issues in climate modeling, and examine the reasons for the uncertainty in future predictions. Global impacts—those on California in particular—are discussed together with the measures that have been taken worldwide and at the state level to combat it.

Science Background

Even though skeptics might argue about the degree of global warming, how much of it is anthropogenically induced, and whether or not to act on it, there is no question about the scientific fact that increasing the concentration of carbon dioxide and other greenhouse gases causes warming of the earth. The laws of physics that govern this have been well established for more than a century. The earth is heated by absorption of radiation from the sun. It cools by emitting infrared radiation. Greenhouse gases (GHG) in the atmosphere absorb some of this radiation and re-radiate it—much of it back toward the surface of the earth—resulting in the so-called "trapping" of heat or "greenhouse effect." The presence of GHG in the earth's atmosphere is in fact desirable, as their very presence raises the temperature of the surface some 33°C above what it would otherwise be, allowing life as we know it to exist. The global warming problem arises because the concentration of these gases has been significantly increasing in the atmosphere since the

Industrial Revolution. Burning carbon-containing fuels in air (oxygen) to generate energy produces carbon dioxide as a by-product. In the past 150 years, we have increased the amount of CO_2 in our atmosphere by more than 30 percent, from 280 parts per million (ppm) to 379 ppm. As a consequence, the amount of "trapped" infrared radiation has increased and the earth's surface temperature has shown a concomitant warming of 0.6–0.8 °C (IPCC 2001). There is not, however, a linear or even straightforward relationship between the magnitude of the temperature increase and that of the CO_2 concentration, because of the many nonlinear feedback effects and the vast number of interconnected components in the earth system. Thus it is necessary to employ complex computer models to predict temperature increase by simulating these. Results will vary according to the number and types of components and interactions modeled, inherent assumptions employed to make the problem tractable, and the temporal and spatial scales over which the models operate. The fact that warming predictions vary from one model to the next, and vary additionally by virtue of the considerable uncertainty in our knowledge of the magnitude of future emissions of GHG and other pollutants, has led some skeptics to forestall action toward mitigation. However, the precise degree of future warming does not change the imperative to act; the only relevant question is whether our action will be sufficient, not whether it is necessary. While politicians argue about the economic and social consequences of their actions, GHG concentrations continue to rise, and scientists continue their quest to improve the sophistication and predictive capability of their models.

Climate Models

Climate models utilize the most powerful supercomputers in the world for their calculations. The relationships between the ocean, biosphere, atmosphere, and solid earth present a vast array of complex, interacting mechanisms whose incorporation into climate simulations challenge the power of even these machines. But it is the detailed understanding of these feedbacks that is key to improving our predictive capability. Some of the most important of these are the albedo, water vapor, ocean circulation, and clouds.

The albedo effect is a positive feedback, whereby warming causes the melting of ice and glaciers, thus reducing the surface reflectivity of the earth. Whereas snow reflects some 95 percent of sunlight, the water that replaces it reflects only about 5 percent—the remaining 95 percent of the sunlight is instead absorbed and causes the earth to warm.

The water vapor feedback is also positive. Water vapor is the most important greenhouse gas in that it traps more radiation in the lower atmosphere than any other gas. As the earth warms, the air's ability to hold water vapor increases, more evaporation occurs, and the water vapor concentration in the lower atmosphere increases. Thus, more infrared radiation from the earth is trapped, and the warming is furthered.

A third feedback mechanism, temperature changes resulting from possible changes in ocean circulation, occurs over longer time scales. Tropical heat is transferred through surface ocean currents via the Gulf Stream to the North Atlantic, warming the climates of the countries of Northern Europe. As this saline water chills, it sinks to the deep ocean, and through a "conveyor" system circulates deep water south beyond the tropics to the South Atlantic and ultimately to the other oceans of the world (Quadfasel 2005). This important ocean conveyor has recently received much public attention following its role in precipitating an ice age in a recent Hollywood movie. Although the scenes depicted in the movie were highly dramatized and events occurred on a highly exaggerated time scale, the ice age-inducing mechanism itself—the shutdown of this ocean conveyor—has sound scientific merit. Warming causes the melting of ice over Greenland, resulting in meltwater runoff. This dilutes the salinity (and density) of the northward-moving current and inhibits its sinking. If this is large enough in scale, it could trigger the complete shutdown of the conveyor—something believed to have occurred thousands of years ago. Such an event might cause adjacent landmasses to fall in temperature by 5°C or more. However, according to the IPCC (2001), such a complete shutdown is thought to be very unlikely, at least in this century, although climate models predict a weakening of the overturning in this system. Recent research has documented significant mass loss (57 cubic miles per year on average) from the eastern part of the Greenland ice sheet (Chen et al. 2006). As this ice melts into the North Atlantic, it could prevent the further transport of heat northward via the Norwegian Current and lead to colder temperatures in Northern Europe. Indeed, flow rate measurements by Bryden et al. (2005) have documented a reduction in this overturning since 1957. Even with a slowdown of this ocean heat transport, recent model simulations predict that the GHG warming will likely outweigh this heat loss and lead to net warming.

Clouds play opposing roles in controlling the temperature of the earth. They cool the earth by reflecting the sun's shortwave radiation, but they also serve to warm the surface of the earth in much the same way as GHG, by absorbing and emitting infrared radiation. Warming is of course their only effect at night, and during the daytime the cooling effect tends to dominate. Over a 24-hour period, the net effect of clouds depends on their type, thickness, and altitude. High clouds tend to be more transparent to sunlight and more opaque at infrared wavelengths than their lower counterparts, and thus they have a net warming effect, whereas low clouds generally reduce surface temperatures. If the areal extent of low clouds increases as a result of increased atmospheric water content, then the feedback would be negative (opposing the warming), but if the extent of cirrus clouds increases, the cloud feedback would be positive. Of concern is some observational evidence for an increase in the presence of cirrus clouds, but a complicating issue is their relationship to air traffic. The emission of water vapor and aerosol particles by aircraft directly into the (cold) upper troposphere leads to local increases in relative humidity and resulting condensation (contrails). The absence of air traffic following the events of September 11, 2001, offered scientists a brief opportunity to evaluate their effect on climate. General-circulation model simulations have suggested that contrails may contribute a warming of as much as 0.2–0.3°C per decade to temperature increases in the United States (Minnis et al. 2004), although worldwide effects are likely to be considerably less. Clouds are one of the most difficult elements of the climate system to model well and, according to the IPCC (2001), "probably the greatest uncertainty in future predictions of climate arises from clouds and their interactions with radiation."

There are many other climate effects that are poorly quantified, in particular those arising from small, suspended liquid or solid particles called aerosols. Aerosols play a direct role in affecting climate by scattering sunlight (giving polluted sky a hazy appearance in the day and red sunsets at night) or absorbing it, and thereby serve to reduce the amount of sunlight reaching the earth's surface (Charlson et al. 1992). In addition to their direct effect, aerosols have an indirect effect on the radiation budget, through their role as cloud condensation nuclei. Pollution has increased the quantity of aerosols, and when water vapor condenses on them in clouds, a larger number of smaller cloud droplets form, resulting in brighter, or more highly reflecting, clouds. Through both the direct and indirect effects, aerosols currently mask the true degree of greenhouse gas warming by a potentially significant amount (Andreae et al. 2005). The pursuit of a cleaner atmosphere and the short lifetimes of aerosols are likely to diminish the magnitude of this masking effect in the future and may lead to even greater warming than that already predicted by climate models.

Aerosols also play an important role in stratospheric ozone depletion, acting as precursors for the chemical depletion process. As warming of the earth's surface and troposphere occur, the stratosphere will cool. This leads to growth of stratospheric aerosols (Steele and Hamill 1981) and an increase in the likelihood of polar stratospheric clouds upon which the chemical reactions leading to ozone depletion take place. A reduction in ozone will have the effect of cooling, but also, importantly, leads to an increase in damaging surface ultraviolet radiation.

Global Consequences

Although the average surface temperature of the earth has increased by less than 1°C over the past 150 years (IPCC 2001), it has warmed at an unprecedented rate of 0.2°C per decade for the past 30 years, and the temperature is now at its warmest in the current interglacial period, which began about 12,000 years ago. It is also within about 1°C of its highest in the past million years (Hansen et al. 2006). The consequences of this warming are already apparent. An additional warming of 1.5–4°C, as predicted, could have disastrous effects.

One effect of global warming is the shrinkage of the world's ice sheets and glaciers, the complete disappearance of which would raise sea level by 73 m. Even if the melting were much less extreme than this, the consequences of losing ice are potentially devastating. They include an accelerating rate of warming via the albedo feedback, a loss of much of the world's storage of freshwater, and large-scale changes to ocean circulation. In its 2001 report, the IPCC predicted continuing mass loss in the Greenland ice sheet, but believed the Antarctic ice sheet to be stable and perhaps even subject to growth during this century. The West Antarctic Ice Sheet, which is less stable because it is grounded below sea level, was also predicted to survive. However, there has been a continuing and dramatic retreat and disintegration of Antarctic ice over the past 10 years. A breakup of the Larsen A ice shelf occurred in 1995. The Larsen B ice shelf on the Antarctic Peninsula, which had been retreating steadily since 1995, shattered and separated from the continent in early 2002, causing the release of 2,300 km^2 of ice (Rack and Rott 2004). Thousands of icebergs were set afloat in the Weddell

Sea. Although the breakup of the Peninsula ice shelves has little effect on global sea levels, the shelves are significant in that they act as buttresses for glaciers on the continent. Once the ice shelves disappear, the glaciers tend to accelerate toward the ocean and lose more volume as they melt in the ocean than they accumulate in snow. Indeed, there is evidence that since the breakup of Larsen B, the Antarctic Peninsula glaciers have suffered associated mass loss, thinning by tens of meters per year (Rignot et al. 2004). If a larger ice shelf such as Ross were to disintegrate, the effect on the glaciers behind it could be devastating. Over the past 61 years, 87 percent of the glaciers on the Antarctic Peninsula have retreated (Cook et al. 2005). The West Antarctic Ice Sheet alone contains 3.8 million km^3 of ice, and if it were to disappear, it would take more than 10,000 years to grow back (Oppenheimer et al. 1998).

The overall volume of Greenland's ice sheet was roughly constant during the 1990s (Luthcke et al. 2006), but estimates for ice loss rate this century are between 100 and 240 Gt per year. Alarmingly, recent satellite data has shown a 250 percent increase in the rate of ice loss in the past 2 years, relative to just 4 years ago (Velicogna and Wahr 2006). Arctic sea ice is also declining. In October 2006, the National Snow and Ice Data Center (NSIDC) expressed concern that sharp declines in Arctic sea ice were already a response to global warming. In summer, the rate of sea ice decline is now more than 8 percent per decade, and at this rate, it will have disappeared completely by 2060 (NSIDC 2006). Satellite images from August 2006 showed, for the first time, a sea passage to the North Pole as dramatic openings in the Arctic's perennial sea ice pack appeared, prompting the European Space Agency to remark that it was "unlike anything observed in previous record low ice seasons" (ESA 2006). Such loss of summer sea ice, used by polar bears as a platform to hunt for seals, has contributed to the rapid decline of the polar bear population, and in December 2006, following a year-long study by the U.S. Fish and Wildlife Service, the U.S. Government proposed listing polar bears as threatened with extinction under the Endangered Species Act.

Retreating mountain glaciers provide one of the most visually compelling examples of the consequences of climate change, and there is a plenitude of examples from Glacier National Park to the Alps to the continent of Africa. Since the middle of the 19th century, glaciers in the European Alps have diminished in area by 30–40 percent (Haeberli and Beniston 1998). The Kilimanjaro glacier has retreated from an extent of 12.1 km^2 of ice in 1912 to only 2.2 km^2 by 2002, and at the current rate of retreat will have completely disappeared by 2020 (Thompson et al. 2002). (Scientists caution, however, that the disappearance of this particular glacier is probably not solely due to 20th century climate change (Cullen et al. 2006.) Nevertheless, global warming is causing, and will continue to cause, the gradual melting of the world's glaciers, and although accounting for only about 1 percent of the world's freshwater storage, they are responsible for supplying more than a sixth of the world's population with drinking water (Barnett et al. 2005). Their disappearance will pose a severe threat to water supply in southern and eastern Asia in particular (WWF 2005).

Extreme weather events are more likely to occur as a result of global warming—the frequency of record-breaking temperatures, more intense precipitation events, more intense tropical storm activity, and more intense and longer droughts. Recent hurricane activity lends credence to such predictions. In 2005 in the North Atlantic, there were the largest number of hurricanes (14) and named storms (27) for a single season, the most intense storm ever (Wilma, with a minimum pressure of 882 hPa), the most intense ever in the Gulf of Mexico (Rita, 897 hPa), and Hurricane Katrina—the most devastating ever (Anthes et al. 2006). In 2004, a record number of typhoons hit Japan (Levinson 2005). Whether an actual trend exists in tropical storm activity is difficult to ascertain, due to the length of the data record. It is statistically imprudent to derive a trend from a small amount of data with a large variability. However, that a connection exists between tropical cyclones and global warming is sound science—tropical cyclones form only over warm water (sea surface temperatures must exceed ~26 °C) where the air is moist, as they gain their energy from the latent heat released during condensation. Tropical oceans are warming (by ~0.5 °C since 1970), and the water vapor content over the oceans has been increasing (by ~1.3 percent per decade over the past 2 decades) (Trenberth 2005). Thus the conditions for tropical storm activity are becoming increasingly more favorable, and will continue to be so.

The effects of warming on the biosphere vary from adaptation, to relocation or migration, to extinction. Ecological responses to recent warming have already been recorded in the phenology of organisms, their range and distribution, and the composition of communities (Walther et al. 2002). Breeding seasons and food phenological cycles may no longer coincide and lead to population declines (e.g., Both et al. 2006). Pests, once killed by frost, may now survive warmer winters. Species may be driven poleward or upward in search of cooler temperatures. However, large numbers of sedentary species may be unable to respond by changing their geographical ranges (Thomas et al. 2001) and may ultimately be unable to adapt. By modeling the association between current climates and present-day distributions of species, climate envelopes can be defined that represent the conditions under which populations of a species exist. These envelopes can then be superimposed on future climate prediction patterns to determine future habitat suitability regions. Using such a methodology, Thomas et. al (2004) found that as many as 24 percent of species could be "committed to extinction."

Effects on California

Every region of the world will suffer its own unique consequences of global warming. In 2006, a study commissioned by the California Energy Commission and the California EPA reported on the potential impacts to California of climate change (Cayan et al. 2006a). The emissions scenarios employed by the IPCC (2001) were utilized in global climate models to simulate changes in the future Californian climate (Cayan et al. 2006b), and a series of reports addressing the impact of these changes on the state's water supply, coastal areas, agriculture, forestry, and public health was published (CCCC 2006). These simulations showed Californian temperatures increasing by 1.5–4.5 °C by the end of the century, with little change in overall precipitation (Cayan et al. 2006b).

As a result of warmer winters, more of the precipitation will fall as rain rather than snow, and the snow that does fall will melt earlier. This will reduce the spring snowpack by the end of this century by as much as 70–90 percent of its historical volume (CCCC 2006). Since the Sierra Nevada snowmelt has a volume equal to approximately half of the man-made reservoirs in California, the impact of its partial loss on the state's water supply will depend on whether alternative storage can be built. The timing of the snowmelt will cause maximum runoff to occur about a month earlier than now, and if storage capacity is insufficient, there is a danger that much of this could be discharged directly to the ocean (Barnett et al. 2005). Shifting of snowmelt timing also means that late-spring stream flow will decline (by as much as 30 percent by the end of the century). This will impact agricultural areas and leave them significantly short of their requirements (Cayan et al. 2006a). Higher temperatures will exacerbate the problem by increasing evaporation rates from plants and soil and thus increase water demand on a system already stressed. The loss of snowpack will have other important economic consequences for California—in particular, income derived from winter sports and recreation. The ski season could shorten by a month or more, and lower-elevation resorts might struggle to survive.

Sea levels along the coast of California have risen by 10–20 cm over the past century, a rate similar to the global trend. A more substantial rise is projected to occur over this century as a result of thermal expansion and melting ice sheets, with model simulations giving a range of 14–61 cm increase (for moderate emissions) by the end of the century (Cayan et al. 2006c). Although any sea level rise is a concern in and of itself, the biggest impacts will be the result of the combined higher sea level with high tides and winter storm surges that bring heavy surf and wind-driven waves with them. Such conditions can cause massive devastation of coastal property. The frequency of these extreme events is expected to escalate, and regions such as the San Francisco Bay and Delta and the Sacramento/San Joaquin Delta are particularly susceptible to damage. Levee breaches would threaten freshwater supplies, damage marine estuaries and wetlands, and potentially flood low-lying inland areas. Coastal erosion from the combination of rising seas and intense winter storms is already a problem along much of California's 1,100 miles of coastline. Nourishment programs in which sand is shipped in from other sources as the natural sand is washed away protect many beaches. These replenishment programs, which currently cost the state millions of dollars a year, will become even more expensive in the future.

Californian agriculture will be impacted by global warming by increasing water demand for crops from a supply already strained. In addition, crops and livestock will suffer from an increased frequency of pests and disease, an increased susceptibility to these, and from heat stress (CCCC 2006). California houses the largest agricultural industry in the country and is responsible for the production of half of the country's fruit and vegetables. Although enhanced photosynthetic activity can occur in plants as a result of higher temperatures and CO_2 concentrations, the increased rate is not sustained and eventually diminishes (Baldocchi and Wong 2006). Potential problems of temperature increases include premature ripening of fruits and increased incidence of plant burn. Certain crops are particularly susceptible. Wine grapes may mature prematurely by as much as 2 months, reducing their quality, and fruits that require a minimum number of chill hours may not develop properly. The milk production capability of cows is also lowered as temperatures increase and they experience heat stress. Weeds and pests grow faster and their habitats expand, creating the need for more extensive pesticide use. The extent of forests and other ecosystems will be changed by a warmer climate, and species are likely to shift their distribution pattern. This can have unpredictable effects on the food chain. The risk of large fires could rise by as much as 55 percent by the end of the century and increase associated damage costs by as much as 30 percent (Westerling and Bryant 2006). In addition, wildfires add significantly to atmospheric carbon dioxide emissions, so that the expected increase in their frequency will further accelerate global warming (Running 2006).

Air pollution is a particular public health concern in southern California, and Californians already suffer from exposure to the highest ozone and particulate matter (PM) concentrations in the country. Ozone is a secondary pollutant formed through photochemical reactions involving nitrogen oxides (NO_x), carbon monoxide, and volatile organic compounds released from transportation and industrial sources. It causes respiratory problems and asthma, and damages crops and natural ecosystems. The background concentration of pollution ozone has approximately doubled over the past century as a result of increased industrial activity and automobile use. Particulate matter (PM) refers to small (generally a diameter of less than 10 μm) suspended particles with a wide range of chemical compositions—including sulfates, nitrates, soot, organics, and mineral dust—that pose a significant health risk when they enter the lungs. Ozone and PM are of particular concern because they stay in the atmosphere long enough to affect air quality in regions far from their sources (NRC 2000). The "clean-air" baseline levels for ozone upon which pollution builds are projected to increase over the next century, with several potential emissions scenarios predicting ozone increases of more than 20 ppb (parts per billion). Such large increases in the background level will lead to many more days in which air quality standards (in the U.S. the 8-hour standard is 80 ppb, and 70 ppb in California) are exceeded (Prather et al. 2003). At northern mid-latitudes around the world, in the summer the background level may exceed air quality standards without even the addition of local emissions (IPCC 2001). Global warming compounds the pollution problem; if temperatures rise as predicted, there will be about 80 percent more days with weather conducive to ozone formation in Los Angeles and the San Joaquin Valley (CCCC 2006). In addition, the increased use of air conditioners will increase the levels of ozone even further by emitting one of its precursors, NO_x. There are other health-related concerns related to higher temperatures, including heat stress, dehydration, heart attack, heat stroke, and respiratory distress. In the state's metropolitan districts, there could be two to three times as many heat-related deaths by the end of this century (CCCC 2006).

Mitigation Measures

The Kyoto Protocol, an international agreement to reduce emissions of six greenhouse gases, came into effect on February 16, 2005, 90 days after the USSR ratified it and ensured that the signatory nations together accounted for more than 55 percent of global GHG emissions. The protocol sets mandatory limits on greenhouse gas emissions for each of the party nations according to their consumption and projected needs, with the goal of reducing total global emissions to 5.2 percent below their 1990 values by 2012. One hundred sixty-six countries have now ratified the agreement; the United States and Australia are the only two industrialized nations that have not. Although the United States initially signed the agreement in 1998, the treaty was never approved by the Senate. President Bush has been vocally opposed to it on the grounds that developing nations are not yet required to make cuts, and that it would place too great a burden on the U.S. economy. Although the European Union has always been its biggest supporter, the Agreement has now gained almost universal worldwide support as the impacts of global warming are becoming more readily apparent.

Once the Kyoto Protocol became law, signatory nations have been challenged to achieve their emissions targets. The Europeans, who had initially toyed with the idea of a punitive scheme for companies failing to meet emissions limits, have instead adopted a market-based incentive scheme. Under this “cap-and-trade” scheme, power plants and other industrial sources of GHG emissions are issued carbon credits according to their capacity, each credit permitting the emission of one tonne of carbon dioxide. The total number of credits issued by each country is designed to bring it into compliance with Kyoto targets. Companies undertaking efficiency measures may accumulate unused credits, which they can sell to those exceeding their allowance. Thus an economic incentive has been created for improved efficiency and cleaner technology. In addition, credits can be earned by the implementation of GHG-removal mechanisms such as reforestation and revegetation.

This scheme is modeled on a similar one introduced a decade ago in the United States to tackle the problem of acid rain (EPA 2006a). Acid rain has historically been a problem in the northeastern U.S., eastern Canada, and northern Europe as a result of sulfur dioxide emissions from coalburning power plants. The sulfur dioxide (SO_2) dissolves in cloud droplets to produce sulfuric acid rainwater, which has caused extensive damage to ecosystems and natural habitat in the regions where it falls. Under the Clean Air Act, annual SO_2 emissions were targeted for reduction. To achieve this, the EPA enacted an SO_2 trading scheme in which allowances were allocated to polluting sources according to their capacity, such that the total number distributed equated to the EPA emissions target for the year (EPA 2006b). These allowances are fully marketable commodities and can be bought, sold, or traded on the open market. The system allows the utilities that are regulated to decide the most economic way to comply with emissions targets. Some employ conservation measures or alternative energy; others switch to low-sulfur fuel or employ other strategies. The first phase of the program went into effect in 1995, and allowances were later reduced in the second phase that began in 2000. Although there was resistance to the scheme upon its introduction, it has met with a high degree of success, with the national average SO_2 concentrations declining by 48 percent since 1990 and 63 percent since 1980 (EPA 2006c).

Ironically, whereas the economic cost to U.S. industry of reducing GHG emissions has in the past led to opposition to restrictions such as those imposed by the Kyoto Protocol, many industries in this country are now attracted by the possibility of profit under a trading scheme. Many U.S. businesses are now encouraging the adoption of a national cap and trading scheme for carbon emissions, and groups such as the U.S. Climate Action Partnership, comprised of environmental interests and major corporations including Alcoa, BP America, DuPont, and General Electric, have formed to put pressure on the federal administration to take action. In California, Governor Schwarzenegger has dismissed allegations that carbon limits would hurt businesses in California by recognizing the long-term economic incentives that exist, and has held talks with European leaders over the possibility of a trans-Atlantic carbon trading program. Although the Europeans are currently the only ones with such a program in place, a similar one is planned in Canada, and regional plans are being discussed in other parts of the U.S..

California is the 12th-largest emitter of carbon dioxide in the world. Recognizing the potentially disastrous effects of global warming and the role that California plays, on June 1, 2005, Governor Schwarzenegger signed Executive Order S-3-05, which establishes GHG emissions targets for the state. The targets reduce GHG emissions to 1990 levels by 2020 and to 80 percent below 1990 levels by 2050. The order also calls for biannual reports on the progress toward the attainment of these targets. On August 31, 2006, Assembly Bill 32, the California Global Warming Solutions Act, was passed by the state legislature, and was signed into law by Governor Schwarzenegger on September 27. This bill sets as emissions standards those specified in S-3-05 and requires the California Air Resources Board to help with its implementation by establishing the baseline 1990 levels, creating and monitoring an emissions reporting system, preparing a plan for achieving the established caps, and enforcing the necessary regulations. The California legislature and Governor Schwarzenegger should be applauded for their action. As a Republican, the governor had support in the Assembly from only one of his own party and from none in the Senate. Some refuted the scientific evidence for global warming, while others saw the bill as a "job killer" (California Progress Report 2006). Schwarzenegger is promoting the bill to businesses through market-based incentives such as carbon trading, and through opportunities to invest in the burgeoning industry of clean technology development.

On January 18, 2007, the governor took further action to reduce GHG emissions, establishing a low-carbon standard for transportation fuels (LCFS). The new LCFS requires fuel providers to gradually reduce the carbon content of passenger vehicle fuels sold in California. Transportation accounts for 40 percent of California's GHG emissions, and 96 percent of these fuels are petroleum based. The new LCFS requires that fuel providers reduce the carbon content of fuels by 10 percent by the year 2020. These reductions will be accomplished through a combination of technologies such as the blending of ethanol with gasoline, the use of electric and hybrid vehicles, and the development of alternative-fuel vehicles. A study by the University of California estimates that the governor's initiatives could increase the gross state product by $60 billion and create more than 20,000 new jobs in the research and development of new clean technology and alternative fuels (Governor 2007).

Discussion

On purely economic grounds, President Bush and others have expressed concerns over the costs of mitigation measures. However, it is now clear that the cost of doing nothing has the potential to far exceed that of acting. A comprehensive review on the economics of climate change was commissioned by the British government in 2005 and carried out by the former

World Bank chief economist (Stern 2006). Risk analysis was employed to compare the costs and impacts of uncontrolled climate change with those of mitigating action. The report notes that "every country will be affected by climate change but the poorest countries will suffer the earliest and the most, even though they have contributed least to the causes of climate change." This certainly raises the ethical question of responsibility. The report estimates that the overall costs associated with even moderate impacts are equivalent to a loss of at least 5 percent of global GDP each year, "now and forever," and the damage could be as much as 20 percent GDP. If no action is taken to curb emissions, each tonne of CO_2 emitted causes damage worth at least $85. Worldwide per capita emissions of CO_2 are 4.24 tonnes per year; in the U.S. they average almost five times that at 20.18 tonnes per year; and in Africa they are a mere 1.13 tonnes (2004 data; EIA 2006). Presently damage costs are not passed on to consumers. If action is taken to limit GHG emissions now, the impacts will be limited so that costs could be contained at around 1 percent GDP per year (Stern 2006).

The Kyoto Protocol is only a first step in tackling global warming and thereby bringing emissions under control. The longer-term goal is the stabilization of GHG concentrations at a level that prevents dangerous anthropogenic interference with the climate. This target stabilization level is still the subject of much debate. Stern (2006) recommends stabilizing concentrations at 450–550 ppm in order to limit the global temperature increase to no more than 2°C. In order to accomplish such a target, GHG emissions must be reduced substantially below current levels and become progressively tougher throughout this century. Within a few decades, emissions would need to be reduced below the 1990 levels and 25 percent below current levels. The longer the delay in cutting emissions, the greater the cuts that will eventually have to be made, and the higher the eventual CO_2 stabilization level. It is already probably too late (too costly and too difficult) to stabilize the level at 450 ppm. The Kyoto Protocol expires in 2012. Its implementation alone will have little long-term effect on CO_2 concentrations, reducing them just a few ppm and inspiring its criticism (Lomborg 2001). Negotiations are underway on the extension of the Kyoto Protocol beyond its current expiration date, but in order to tackle the problem of long-term climate change, all countries will need to cooperate.

The European Union has already taken a leading role and has established the world's first cross-border emissions trading scheme. China is the world's second-biggest emitter of GHG, but, as a developing nation under the Kyoto Protocol, is not yet required to cut its emissions. The Chinese currently consume only 10–15 percent as much energy per capita as the average U.S. citizen, but energy use in China is accelerating rapidly. China's Five Year Plan for 2006–2010 set an ambitious target for reducing energy consumption by 20 percent per unit of GDP, but has failed to meet its first-year (2006) target. Meeting its own ambitious targets is expected to be a problem for China, with some 1.32 billion people, rapid economic growth, and massive increase in personal automobile use (up by 36.9 percent in 2006 alone) (Spiegel 2007). However, China has pledged to build an energy-efficient society over the next 5 years, has set energy-efficient standards for all new buildings, levied taxes on larger vehicles, and established research-and-development programs for advanced vehicle technologies. Already its vehicle fuel efficiency ratings exceed those of the U.S. India, a country where half the population does not yet have electricity, will potentially suffer from the most devastating consequences of global warming. More intense rain events, longer periods of drought, extreme vulnerability to sea level rise, and increased rates of disease are some of the direct impacts on the country. Although India ratified the Kyoto Protocol in 2002, it faces challenges similar to—and perhaps greater than—those of China in its development, and will require the assistance of the developed world in controlling its energy consumption and emissions.

Carbon dioxide concentrations in the atmosphere continue to rise at a rate of more than 2 ppm per year, and even if global emissions are held at today's values, atmospheric concentrations will continue to rise above current levels because the gases are accumulating in the atmosphere faster than they are removed by the land and the oceans. It behooves us to act now to forestall the warming before it is too late, but it will take individuals acting and pressing their leaders into action, and it will take leaders with the foresight, initiative, and will to act.

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