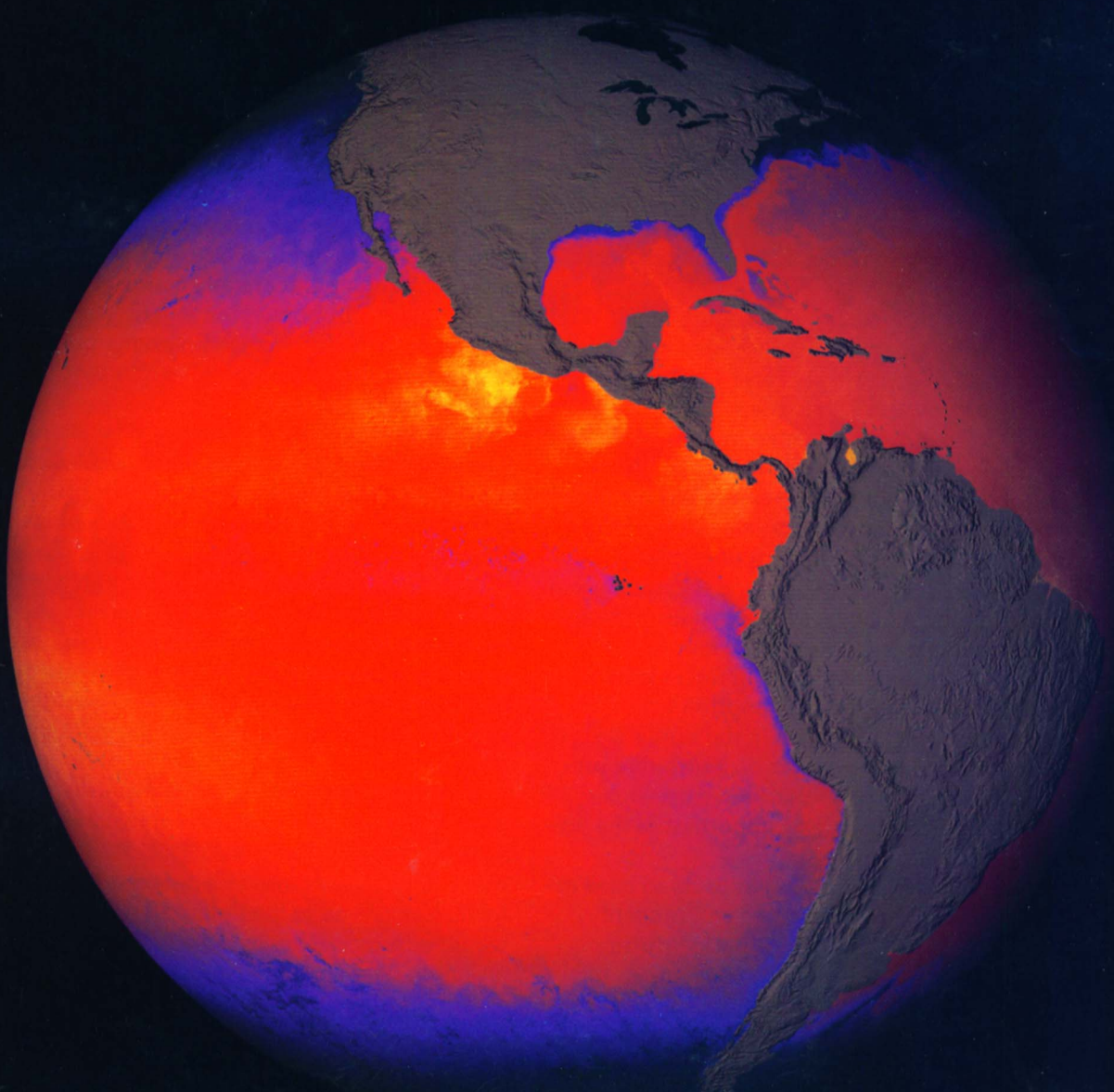
California Agriculture
MAY-JUNE ■ VOLUME 56 NUMBER 3



A warmer California:

Assessing the impacts of climate change

University of California | Division of Agriculture and Natural Resources | Research in Agricultural, Natural and Human Resources

Water will drive California response to climate change

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California's agricultural industry has a comparative advantage in its climate and water supplies. However, global climate change may slowly change both of these foundations (see pages 84 to 96). Clearly, it is useful to understand the fundamental driving forces of climate change and the range of uncertainty around them. Several UC research groups are conducting such analyses; while it is still too early to predict outcomes, it is not too early to conjecture on major effects on California agriculture.

In researching the impacts of global climate change, one is immediately struck by two unusual characteristics. First, knowledge of global climate change is very uncertain. While there is a strong scientific consensus that the global climate is changing, there is much less consensus on its impacts on relatively small areas such as California. For example, there is a wide range of model predictions for future sea level rise and a range of opinion concerning historical climate variability. One approach to such uncertainty would be to not do anything costly until the scientific proof is overwhelming. But there may be a high cost associated with inaction. An alternative approach is to emphasize measures that reduce the apparent driving forces behind global climate change. The implicit assumption is that the expected present value cost of inaction in the future is significantly greater than the current costs of controlling precursors. Clearly, the social costs of alternative decisions under uncertain climate change are as important as the fundamental science of the process.

The second characteristic that makes impacts so hard to measure is the time scale. Climate change will probably occur more slowly than the 50- to 100-year period during which California's natural resources were developed for agriculture. We probably have time to adjust, but may have significant changes to adjust to. In this sense, California agriculture's adaptation may not be greatly different from its adaptations to other long-term trends, such as changing demands and varieties, or improved quality control and marketing, which are necessary in growing regions worldwide. Some of the more significant expected changes are:

Water supply. California's economy runs on a complex network of surface water and groundwater storage and extensive conveyance systems to move water from its natural sources to arid areas where agricultural, urban and residential demands are greatest. Climate change would probably alter the pattern, variability, amount and temperature of precipitation in California. These changes would significantly reduce the ability of the existing surface-water storage infrastructure. In addition, snowpack, which enhances the operating efficiency of dams, would be greatly reduced.

Flood control. The severity and frequency of flood events would be dramatically altered in California. Most storage dams provide water supply and flood protection. Unfortunately, increased flood protection implies reductions in the effective water supply from dams alone. Increases in flood protection capacity require a trade-off against the need for increased surface supply capacity to partially offset reduced snowpack. Conjunctive use of surface and groundwater — moving over-year storage underground — may reduce this problem.

Hydropower. Currently, hydropower plays an important role in generating energy for peak use during the summer. The shift to reduced surface storage, smaller summer snowpack runoff and earlier rainfall would reduce the total quantity of hydropower, but equally significantly, would reduce its flexibility to match varying power demands. The cost of agricultural pumping, particularly during peak periods, is likely to increase.

Crop yields. Crop yields would be altered by temperature and carbon dioxide effects. A middle-range projection is a 4°F rise in average temperature over the next 50 years. A statistical regression on the county yields of California crops shows that the combined effect of temperature, precipitation and carbon dioxide could cause a 12% increase in cotton yields by 2060. However, this increased yield is based on a 9% increase in evapotranspiration, further stressing water supplies. From a statewide perspective, a rise in growing-season temperature would tend to shift growing regions north, and is unlikely to have much statewide impact.

Sea level rise. The forecasted increases in sea levels would mostly affect California agriculture through changes in the Sacramento Delta. Rising sea levels would shift the dynamic and seasonal interface between saltwater and freshwater flows farther into the Delta and increase flood risks. There would be direct effects to Delta growers, and indirect impacts on supplies for southern agricultural regions.

This litany of problems must be viewed in the context of the dramatic changes and challenges that California agriculture has met over the past century. If the effects of global warming proceed as expected by most scientists, California agriculture would have to use the same skills to adjust to increased water scarcity as were used to develop the current bountiful water supplies and adjust to changing markets. Informed discussion is needed on the national costs of actions to control global warming and the costs of response and adjustment by natural resource–based industries. Water supplies will continue to be problematic and require changes, with or without climate change. But California, with its extensive infrastructure and mature organization, should be in a better position to adapt than most agricultural regions of the world.

ANR UNIVERSITY of CALIFORNIA

California Agriculture

News and Peer-reviewed Research published bimonthly by the Division of Agriculture and Natural Resources, University of California
VOLUME 56, NUMBER 3

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Mailed at periodicals postage rates at Oakland, CA and at additional mailing offices. Postmaster: Send change of address "Form 3579" to *California Agriculture* at the above address. (ISSN 0008-0845)

SUBSCRIPTION RATES: Free upon request in U.S.; $18 yearly outside the U.S. (check or International Money Order in U.S. funds payable to UC REGENTS). MasterCard/Visa accepted; requests require signature and card expiration date. Library subscriptions are free. Single copy price $4. For a change of address, send old label or subscription number.

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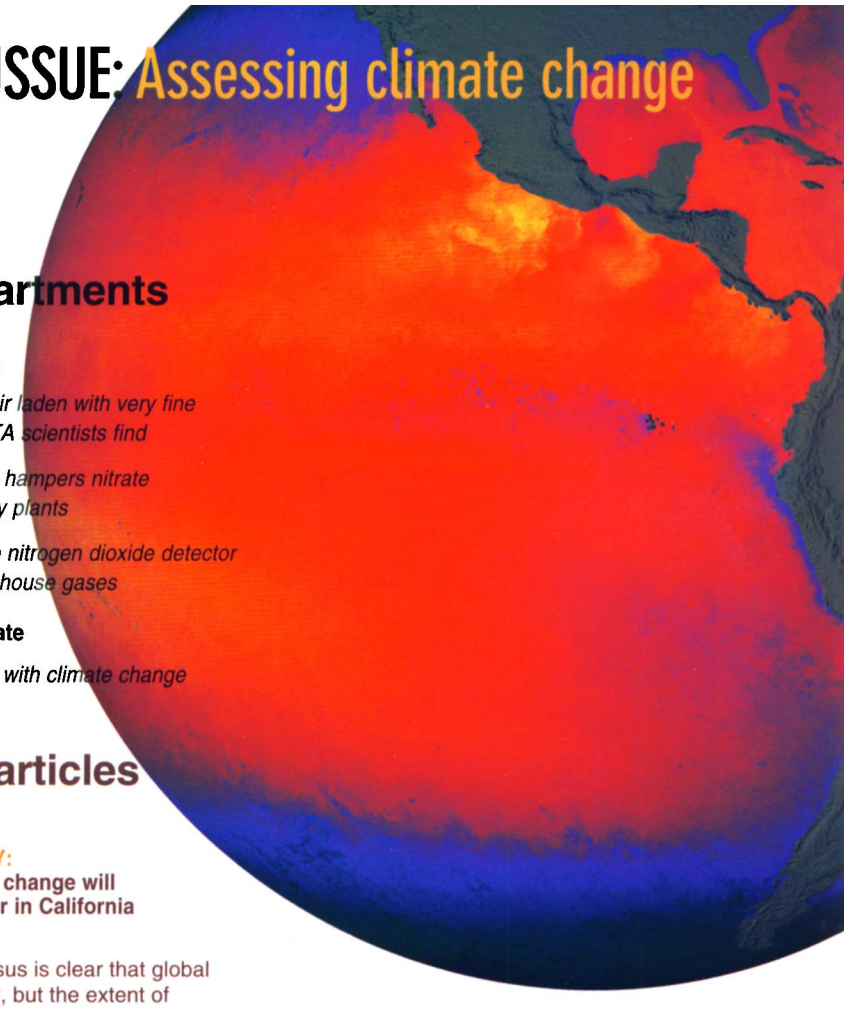


Sea surface temperature

28°F — 95°F

▲ COVER: A new sensor orbiting the Earth aboard NASA's Terra satellite is collecting the most detailed measurements ever made of the sea's surface temperature.

The Moderate-resolution Imaging Spectro-radiometer (MODIS) is measuring sea surface temperature at twice the accuracy of previous satellites. Taken Jan. 1–8, 2001, this image shows cold water upwelling near the coast of Peru and joining the South Equatorial Current, which flows westward across the Pacific Ocean.

Thermal expansion of seawater and widespread loss of land ice due to global warming have very likely contributed to the documented rise in sea level (1 to 2 millimeters annually) during the 20th century.

Image by Jesse Allen, based on data provided by the MODIS OCEAN Team and the University of Miami Rosenstiel School of Marine and Atmospheric Science Remote Sensing Group.

Continuous page numbering

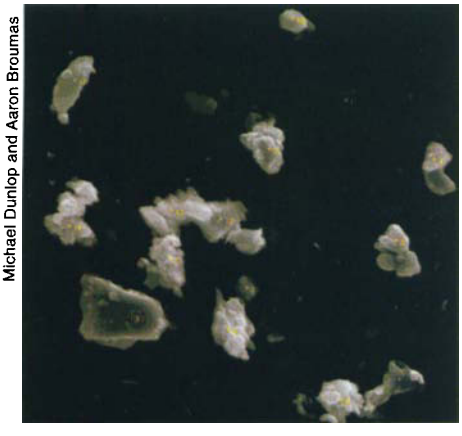
After consultation with our Associate Editors panel, *California Agriculture* initiated continuous page numbering this year. This change brings us into conformity with a standard practice used by the vast majority of peer-reviewed science journals. We understand that this convention may be unfamiliar to some of our lay audience, and apologize for any inconvenience it may cause.

Trade Center air laden with very fine particles, DELTA scientists find

In the most thorough analysis yet of the dust and smoke blown through lower Manhattan after the collapse of the World Trade Center, UC Davis scientists identified unprecedented clouds of very fine particles, which can be riskier to human health than larger, coarse particles.

"The air from Ground Zero was laden with extremely high amounts of very small particles, probably associated with high temperatures in the underground debris pile," says Thomas Cahill, UC Davis professor emeritus of physics and atmospheric sciences. "Normally, in New York City and in most of the world, situations like this just don't exist."

Cahill heads the UC Davis DELTA Group (Detection and Evaluation of Long-range Transport of Aerosols), a collaborative association of aerosol scientists at several universities and national laboratories, which monitors atmospheric conditions associated with global warming, weather, disasters and other events.



Michael Dunlop and Aaron Broumas

The UC Davis DELTA Group took air samples about a mile from the World Trade Center in early October 2001, several weeks after the towers collapsed. They identified high levels of coarse particles, *above*, which included powdered concrete and glass with a coating of combustion products, in size range of 5 to 12 micrometers diameter. Very fine particles were found at levels not previously seen in ambient air samples.

The DELTA Group collected air samples at the request of the U.S. Department of Energy from Oct. 2 through mid-December, with a rooftop air monitor about 1 mile north-northeast of Ground Zero.

The results for October were released in early February, and Cahill testified at an investigative hearing before the national ombudsperson for the U.S. Environmental Protection Agency on Feb. 23.

The samples were collected continuously in eight separate-size modes from coarse (12 micrometers diameter) to ultra-fine (0.09 micrometers diameter), and were analyzed for dozens of substances that are likely to be associated with burning office buildings.

Coarse particles are typically filtered by the nose or coughed out of the throat and upper lungs, but they can irritate the mucous membranes and aggravate pre-existing breathing problems such as asthma. Very fine particles, however, can travel deep into human lungs, and are typically removed from the lungs through the bloodstream and heart, increasing the possibility of more serious health impacts.

In the largest spike, the DELTA Group analysis found 58 micrograms per cubic meter of very fine particles in one 45-minute period — "an extremely high peak," Cahill says. "Even on the worst air days in Beijing, downwind from coal-fired power plants, or in the Kuwaiti oil fires, we did not see these levels of very fine particulates."

Virtually all the air samples from the trade center site also carried high concentrations of coarse particles. "These particles simply should not be there," Cahill says. "It had rained, sometimes heavily, on 6 days in the prior 3 weeks. That rain should have settled these coarse particles." The finding suggests that coarse particles were being continually generated from the hot debris pile.

Some metals in the very fine mode, such as vanadium, were found at the highest levels ever recorded in air in the United States. Although some asbestos was used in the buildings for fireproofing and in floor tiles, the DELTA group found very few asbestos fibers, even in the very fine particles.

All evidence indicates that ambient air in New York City is no longer influenced by the World Trade Center collapse, especially since the fires are out and the debris pile has cooled, Cahill says. However, the presence of large amounts of very fine particles as late as October means that the cleanup of indoor air should be undertaken carefully, he warns. Very fine particles penetrate crevices and fabrics in a way that normal dust doesn't, and they are easily resuspended, which can re-expose the room's occupants.

For more information, go to: http://delta.ucdavis.edu.

Carbon dioxide hampers nitrate incorporation by plants

Nitrate fertilizer is not nearly as efficient as ammonium fertilizer when atmospheric carbon dioxide levels are unusually high, according to a study by two UC Davis professors.

Rising levels of atmospheric carbon dioxide — associated with global warming — can interfere with a plant's ability to incorporate nitrogen, Arnold Bloom and David Smart reported in the Feb. 5 *Proceedings of the National Academy of Sciences*. Carbon dioxide concentrations have increased by an estimated 30% during the past two centuries and are likely to double during the next century.

Farmers and gardeners commonly apply nitrogen-rich fertilizers to their crops in order to enhance yields. The UC Davis scientists studied

how wheat plants respond to being fertilized with two different forms of nitrogen, nitrate and ammonium, under varying concentrations of atmospheric carbon dioxide.

The plants receiving ammonium responded much more to the increased carbon dioxide than did the plants receiving nitrate, the scientists found. Elevated carbon dioxide levels inhibited the processing of nitrate in the wheat leaves. When atmospheric carbon dioxide rose to nearly twice the normal level, the leaves of plants receiving ammonium increased in size by nearly 49%, while plants receiving nitrate increased by only 24%.

Additionally, the protein content of the wheat plants receiving ammonium increased 73% under elevated carbon dioxide, compared to only 32% for those receiving nitrate, suggesting that rising atmospheric carbon dioxide levels might diminish the nutritional quality of grain receiving nitrate fertilizer. The work has since been repeated in tomatoes, with similar results.

"We expect that the data will have real-world implications for crop production," Bloom says. "In well-drained soils generally devoted to wheat production, nitrate is the common form of nitrogen available. The study suggests that a shift to increase ammonium availability might be needed."

Furthermore, plant and tree species in natural ecosystems that depend on nitrate conversion into amino acids in their leaves are likely to be at a competitive disadvantage with those species that are either able to convert nitrate into amino acids in their roots or use ammonium as their predominant nitrogen source. "This may result in significant changes in the distribution of plants in the wild as atmospheric carbon dioxide levels continue to rise," Bloom says.

UC Davis

Wheat was grown in a controlled environmental chamber under elevated carbon dioxide. Plants received ammonium (left) or nitrate (right) as their sole nitrogen source. Leaves of plants receiving nitrate are yellowish-green, signaling that they are not assimilating the nutrient as well as plants receiving ammonium.

Super-sensitive nitrogen dioxide detector identifies greenhouse gases

With the aid of the most sensitive nitrogen dioxide detector in the world, UC Berkeley chemists can now quantify certain important contributors to air pollution and global warming.

Human-made nitrogen oxide compounds are emitted by automobiles, industrial smokestacks and other sources; they react with natural hydrocarbons from vegetation to produce ozone smog. "Ozone in the troposphere has doubled in the past century, contributing 10% to 15% of the human additions to the greenhouse effect," says UC Berkeley chemistry professor Ronald C. Cohen. "All of this is driven by nitrogen oxides."

Tim Albrecht

Doug Day checks the performance of the world's most sensitive nitrogen dioxide detector, in a trailer at the UC Blodgett Forest Research Center in El Dorado County. The detector found high levels of previously unquantified organic nitrogen compounds, an observation that current models cannot adequately explain.

Until now, however, as much as half the resulting nitrogen oxides have been unaccounted for in the atmosphere, leaving air pollution models incomplete. Today's smog monitors measure essentially the sum total of all nitrogen oxides in the air, and are unable to break them down into the specific amount of each nitrogen oxide–containing chemical.

Over about 4 years, Cohen and his laboratory colleagues developed a new detector, called thermal dissociation-laser induced fluorescence (TD-LIF), which can monitor nitrogen oxide compounds continuously with sensitivity down to 30 parts per trillion. The technique is a thousand times more sensitive than needed for today's pollution monitoring and sensitive enough for studies in remote locations.

Deploying the detector in downtown Houston and in a remote Sierra Nevada forest, the scientists detected large amounts of organic nitrogen oxide compounds called alkyl nitrates, which were thought to be only a minor constituent of smog.

"If we want to understand quantitatively the effect of local pollution on the global scale, we need to know how and in what form nitrogen oxide is transferred to the rest of the globe," Cohen says.

The research was published in the March 2002 issue of the *Journal of Geophysical Research-Atmospheres*, and is supported by the National Aeronautics and Space Administration.

— Compiled from UC and other news sources

World grapples with climate change

Although for years a small number of scientists argued to the contrary, today there is a scientific consensus that global climate change is well under way.

New and unexpected evidence of global warming came in February and March, as an ice shelf believed to be 12,000 years old collapsed into the Weddell Sea. This huge Antarctic ice shelf — 650 feet thick and covering 1,250 square miles — disintegrated into thousands of icebergs.

Scientists were staggered by the speed of the ice shelf's collapse. "It's hard to believe that 500 billion tons of ice sheet has disintegrated in less than a month," David Vaughn of the British Antarctic Survey said.

The collapse of Larsen B ice shelf was just the latest news about global warming and its impacts. Scientists with UC San Diego's Scripps Institution of Oceanography announced in February that the temperature of the Southern Ocean — which surrounds Antarctica — has increased by a third of a degree in the past half-century. The Southern Ocean is apparently warming faster than the rest of the world's oceans.

"We can think of it as a canary in a coal mine telling us what may happen to the global climate," said Scripps Assistant Professor Sarah Gille, whose research was published in the journal *Science*. A warmer Southern Ocean "could be exchanged into all of the ocean basins and into the latitudes where people live."

Meanwhile, the U.S. National Climate Data Center announced in February that the United States was in the midst of its warmest winter on record. The national average temperature of 39.94°F for November 2001 through January 2002 was 4.3°F above the 1895–2001 average. According to National Aeronautics and Space Administration (NASA) data, the 10 warmest years on record have occurred since 1980.

International science panel

In 1988, the World Meteorological Organization and the United Nations Environment Programme established the Intergovernmental Panel on Climate Change (IPCC), an international network of hundreds of scientists that assess scientific aspects of climate change and evaluates mitigation options. In its Third Assessment Report, released in 2001, IPCC concluded that "there is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities" (see p. 89).

The atmospheric concentrations of key greenhouse gases in the atmosphere — carbon dioxide, methane, nitrous oxide and ozone — reached record levels in the 1990s, IPCC found, "primarily due to the combustion of fossil fuels, agriculture and land-use changes."

According to the IPCC, certain facts about global warming are known:

- Since the period 1000–1750, atmospheric concentrations of carbon dioxide have increased from 280 parts per million (ppm) to 368 ppm.
- The Earth's global mean surface temperature has increased approximately 1.1°F during the 20th century.
- The Earth's global mean sea level has increased at an average annual rate of 1 to 2 millimeters per year during the 20th century; meanwhile, the extent and thickness of Arctic sea ice in spring and summer decreased 10% to 15% since the 1950s.

Global responses

However, considerable scientific and political controversy remains over the extent of the expected changes, how quickly they will occur, and what should be done, if anything.

In 1979, the First World Climate Conference — a scientific gathering — recognized climate change as a serious problem, issuing a declaration calling on the world's governments to "foresee and prevent potential man-made changes in climate that might be adverse to the well-being of humanity." A series of international meetings and

The northern section of the Larsen B ice shelf, a huge floating ice mass on the eastern side of the Antarctic Peninsula, shattered and separated from the continent over a 35-day period beginning Jan. 31, 2002. Scientists were stunned by the speed of its disintegration, and viewed the event as further evidence of global warming. The ice shelf's new front line was photographed on March 13, 2002, by S. Tojeiro, Fuerza Aerea Argentina.

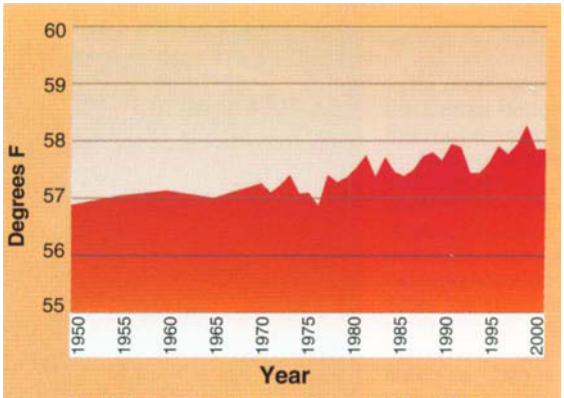
scientific conferences followed.

The most significant, broad-based global approach to emerge is the Kyoto Protocol to the United Nations Framework Convention on Climate Change. Agreed upon at a 1997 meeting in Kyoto, Japan, the protocol seeks to reduce greenhouse gas emissions by an average of 5.2% below 1990 baseline levels, by 2012. (The IPCC provided key scientific input.) The protocol must be ratified by 55 nations to enter into force; as of March 28, 2002, 84 nations had signed the agreement and 51 had ratified it.

In March 2001, President Bush made headlines around the world when he announced that the United States, which is responsible for nearly a quarter of the world's carbon emissions, would not sign the Kyoto Protocol. In a subsequent speech, he termed the protocol "fatally flawed in fundamental ways."

"For America, complying with those mandates would have a negative economic impact, with layoffs of workers and price increases for consumers," Bush said.

In February 2002, President Bush announced his administration's new strategy for "an effective and science-based response to the issue of global warming." Rather than setting mandatory reduction targets, the plan relies on research, new technology, emissions trading and tax incentives to promote voluntary emissions reductions.



Global average temperature, 1950 – 2000. Source: Goddard Institute for Space Studies.

Despite global discussion and efforts for more than two decades, emissions of important greenhouse gases have not substantially declined. Since 1990, Western industrial nations have increased

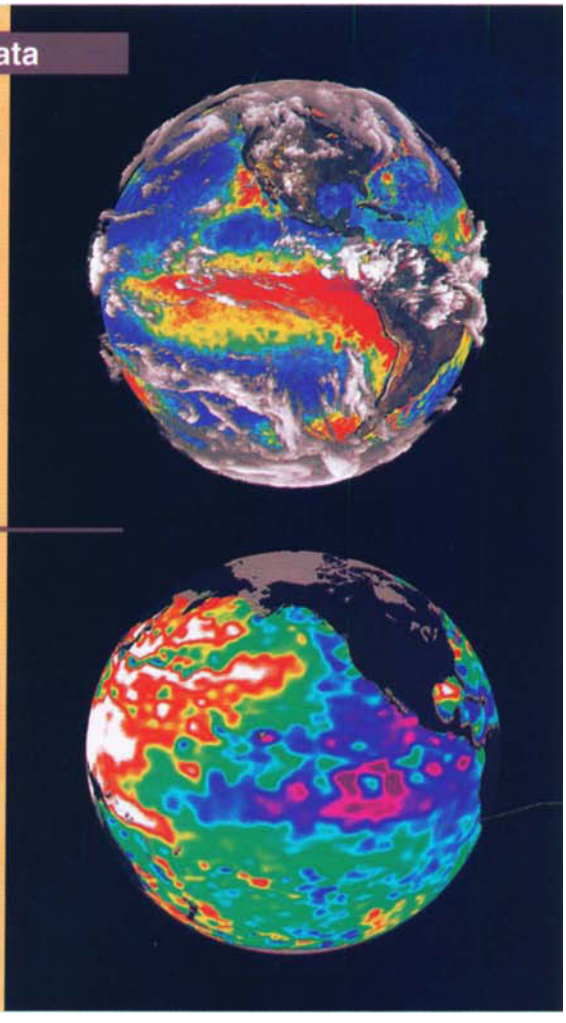
Satellites provide more accurate climate change data

El Niño heats Pacific Ocean

This globe represents the capabilities of NASA's EOS Terra satellite, launched in December 1999, which views the Earth with multiple sensors and a series of interrelated instruments. The red swath in the center is the warm waters of the sea surface that occur in the eastern Pacific Ocean during an El Niño event. Some scientists predict that El Niños will occur more frequently due to global warming, resulting in more floods and droughts. The satellite data is helping scientists understand the cause-and-effect relationships among Earth's lands, oceans and atmosphere in order to better predict what, if any, impacts rapid changes will have on future climate conditions. *Image by R.B. Husar, Washington University; land layer from the SeaWiFS Project; fire maps from the European Space Agency; sea surface temperature from Naval Oceanographic Office's Visualization Laboratory; and cloud layer from SSEC, University of Wisconsin.*

Sea surface heights rising

This globe shows imagery from the U.S.-French TOPEX/Poseidon satellite (NASA Jet Propulsion Laboratory), illustrating a giant horseshoe pattern of higher than normal sea surface heights that has developed in recent years and is beginning to dominate the entire western Pacific and Asiatic oceans. Taken between Dec. 30, 1999, through Jan. 8, 2000, the data show that this slow-developing condition covers most of the Pacific Ocean. Sea surface height is shown relative to normal (green) height and reveals cooler water (blue and purple) between 3 and 9 inches lower than normal along Central and South American coasts, and stretching out into the equatorial Pacific. The giant horseshoe of warmer water (red and white) dominating the western and midlatitude Pacific has higher than normal sea surface heights of between 3 and 9 inches.



their carbon emissions by 9.2% and developing nations by 22.8%. The United States now emits 13% more carbon than it did in 1990.

Looking ahead

Nonetheless, there are signs that the international community is taking the problem seriously. At a meeting in Bonn, Germany, in July 2001, representatives from 178 nations finalized many of the protocol's key rules, without the participation of U.S. negotiators. The World Summit on Sustainable Development, scheduled for September 2002 in Johannesburg, South Africa, will provide another opportunity for the world's nations to move the climate change agenda forward.

With or without an international agreement, significant progress has also been made in developing new technologies and market mechanisms such as emissions trading. In its 2001 assessment, the IPCC found that there are "many opportunities including technological options to reduce near-term emissions." The IPCC pointed to a portfolio of technologies that have developed "faster than anticipated." They include more effective energy use, shifts to technologies that emit less or no greenhouse gases, carbon removal and storage, improved land use and forestry practices, fuel cells and better wind turbines.

The Worldwatch Institute estimated that in 2000, global carbon emissions from fossil fuel combustion dropped by 0.6% to just under 6.3 billion tons, the third consecutive year of decline. The world's estimated amount of carbon emitted per unit of economic output also fell by 3.6% in 2000. Furthermore, a number of major companies, such as Alcoa, Dow Chemical, DuPont and Toyota, have voluntarily set targets for reducing or eliminating greenhouse gas emissions.

The IPCC scientists warned, however, that successful implementation of available and evolving mitigation options would need to overcome a variety of barriers that currently prevent their full exploitation.

In California, the state Assembly passed a bill in January 2002 (AB 1058), which would require reductions in carbon dioxide emitted by cars and light trucks. With about 10% of the nation's new car sales, California in turn accounts for about 2% of global carbon dioxide emissions.

Urging passage of the bill, several dozen UC scientists joined their colleagues in a letter to Governor Davis and members of the state legislature.

"Critical economic drivers in the state, including agriculture, fishing, tourism and timber industries may see devastating reductions in productivity [resulting from global climate change]," they wrote. "We believe the state's immediate implementation of policies to control global gas emissions represents sound public policy based on virtually irrefutable scientific evidence." — *Janet Byron*

Anticipated impacts of climate change

In its 2001 assessment of current science on global warming, the Intergovernmental Panel on Climate Change (IPCC) determined that current and anticipated impacts include:

- More hot days and higher heat indexes.
- Fewer cold/frost days.
- Increases in precipitation over the Northern Hemisphere, and possible decreases in other regions (parts of Africa and the Mediterranean).
- Heavier precipitation events and more severe droughts.
- Retreat of nonpolar glaciers.
- Thawed, warmed and degraded permafrost in parts of the polar, subpolar and mountainous regions.
- Decreases in snow cover.
- Lengthened growing seasons.
- More frequent El Niño weather events.
- Earlier plant flowering, bird arrival, dates of animal breeding and emergence of insects.
- More coral reef bleaching, especially during El Niño events.

Earthrise from the moon, taken by the Apollo 11 mission in 1969.

Jack Kelly Cla

In its most recent report, the United Nations' Intergovernmental Panel on Climate Change concurred that global warming is under way, in large part due to human activities such as burning fossil fuels. By 2050, the snow lines of mountains such as Shasta could go up by as much as 1,000 feet, reducing summer water availability and increasing the risk of winter flooding.

Global climate change will affect air, water in California

Bryan C. Weare

As we enter the 21st century, it is possible to reach beyond the headlines to describe what is now known about climate change. The Intergovernmental Panel on Climate Change evaluated the scientific aspects of global climate change; the current consensus is described in a recent series of reports. Since the 19th century, concentrations of atmospheric carbon dioxide, methane, nitrous oxide and sulfate aerosol dust have increased significantly. While there is scientific agreement that warming is occurring, the controversy now concerns the extent of subsequent impacts in the future. In California, the impacts of global warming are likely to include reduced water availability and quality, poorer air quality, associated economic consequences, biodiversity shifts and health effects. The changes are expected to continue at an increasing pace well into the next century, perhaps outstripping our scientific, economic and social ability to cope with them.

During the past century, perhaps the most controversial subject in atmospheric science has been the question of whether humans are having a significant impact on climate. Anyone who picks up a newspaper is familiar with conjectures that within this century, average temperatures will be 5°F, 10°F or 15°F above their current values, precipitation patterns will substantially decrease the water available for agriculture, and a rise in the sea level will flood coastal regions. As we enter the 21st century, it is now possible to reach beyond the headlines and the controversies to describe what is known about climate change in the recent past and what is most likely for the future. It is also possible to summarize the likely consequences of global climate change for California and the southwestern United States.

The scientific aspects of global climate change have been evaluated recently in a set of extensive reports by the Intergovernmental Panel on Climate Change (IPCC), which were released over several months leading up to a synthesis report (Watson et al. 2001). These reports, compiled by a panel of hundreds of atmospheric scientists from around the world under the umbrella of the United Nations, describe the current consensus concerning the science of global climate change. This article emphasizes those factors that influence and are influenced by agriculture and forestry in the western United States.

Few scientists dispute that human activity is causing the atmospheric concentrations of greenhouse gases and particles to increase, and that this, in turn, is leading to global climate change. From about 1900 to the present, concentrations of atmospheric carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) have increased substantially (fig. 1). The estimates of concentrations before the 20th century are derived mainly from analyses of air trapped in the ice of large glaciers; the more recent values are from well-calibrated direct observations. The concentrations of all three gases were relatively constant until the late 19th century. Since then, the numbers have risen dramatically. The rise in the carbon dioxide concentrations is closely tied to the burning of fossil fuels. Interestingly, only about half of the fossil fuel–related carbon dioxide released into the atmosphere has remained there. The other half has been deposited primarily into the deep oceans and terrestrial biomass -– forests and soil humus. The increasing concentrations of methane are be-

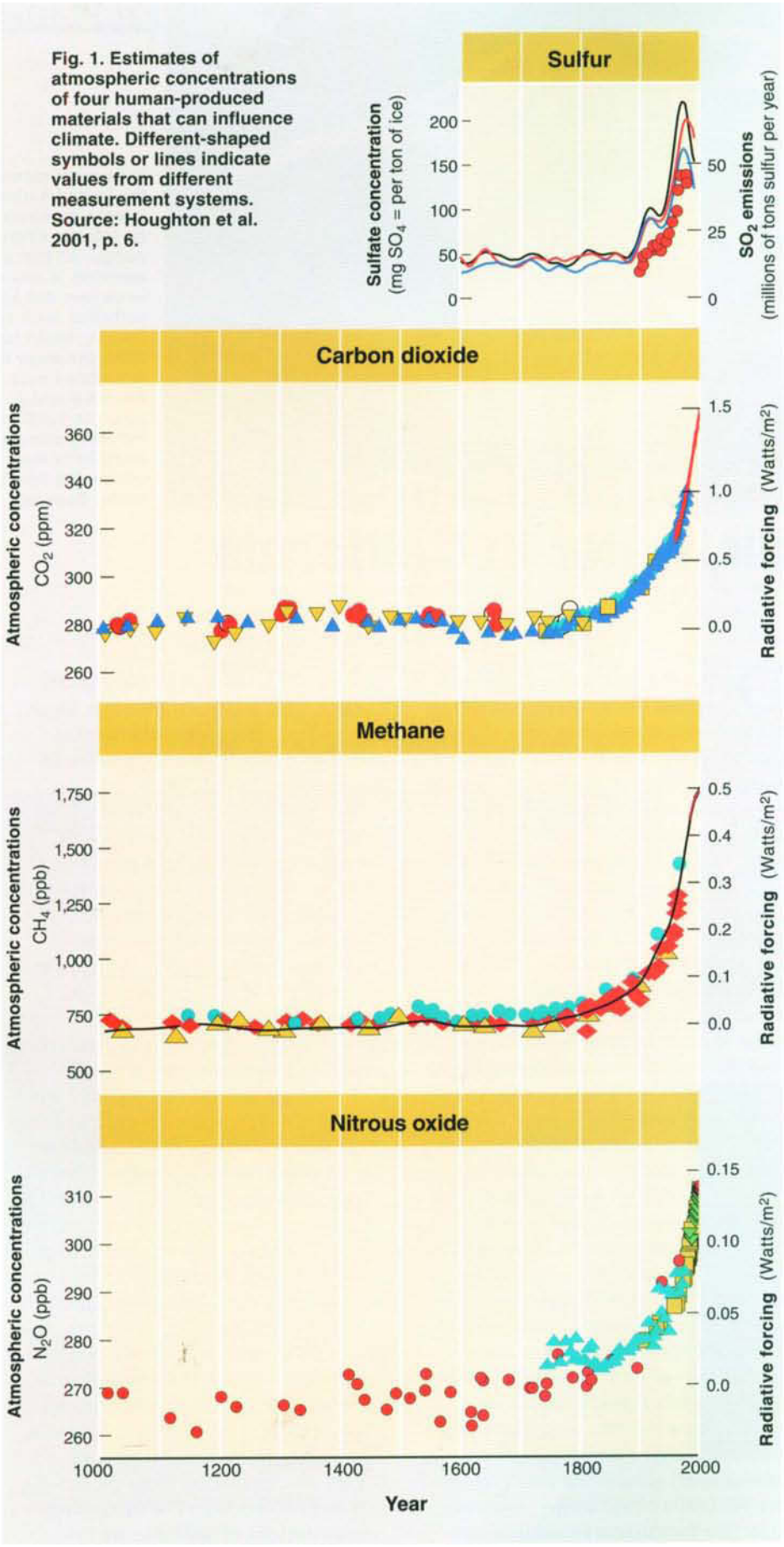


Fig. 1. Estimates of atmospheric concentrations of four human-produced materials that can influence climate. Different-shaped symbols or lines indicate values from different measurement systems. Source: Houghton et al. 2001, p. 6.

lieved to be largely related to natural gas drilling and distribution activities, feedlot emissions and decomposition in landfills and rice fields. Increases in nitrous oxides are related to agriculture, industrial activities and livestock waste management.

Concentrations of sulfate aerosol dust (SO_4) have also increased. These particles are primarily the result of large volcanic eruptions and the burning of fossil fuels, mainly soft coal. The aerosol estimates are derived from analyses of materials in Greenland ice cores and probably represent the higher latitude Northern Hemisphere, rather than the global variations, since aerosols tend to fall from the atmosphere within a few days of their emission. Sulfate concentrations appear to have peaked in the middle of the 20th century (fig. 1). This is believed to be the result of environmental regulations, which limited emissions of sulfur dioxide (the chemical precursor of sulfate) from the burning of coal and oil.

There is little scientific controversy that these changes are having an impact on the global climate. In general, the temperature of the Earth-atmosphere system remains relatively constant because the amount of trapped sunlight is offset by a nearly equal amount of heat being lost into deep space (fig. 2). Climate change will occur if, over years or decades, either the amount of trapped sunlight or emitted heat changes. The amount of absorbed sunlight can decrease for a variety of reasons, including an increase in cloud cover, the replacement of a dark surface such as asphalt by light materials like concrete, and an increase in snow cover. In addition, increases in sulfate aerosols (dust) lead to more sunlight being reflected back to space and less solar heating. Under con-

ditions of increased sulfate, if all other things remain constant, the Earth-atmosphere temperature should decrease.

In contrast, carbon dioxide, methane and nitrous oxide reduce the loss of heat into outer space. All of these gases absorb heat as it leaves the relatively hot surface of the Earth and heads to space through the atmosphere. Once one of these molecules absorbs a tiny portion of heat, it must release it almost immediately. This release occurs in all directions, so that part of the heat, which was originally traveling upward out of the atmosphere, is redirected back down to the ground. This means that less heat escapes to outer space and more heat heads toward the Earth, increasing surface temperatures. There is virtually no controversy over these phenomena, or that the increases in certain gas concentrations are having an effect on the Earth's climate.

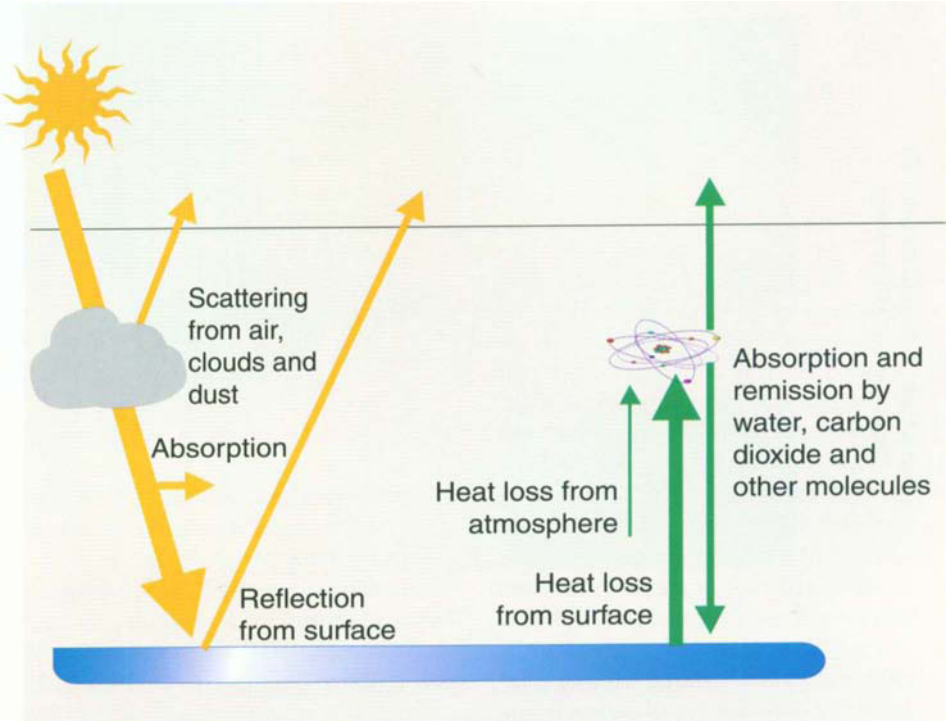


Fig. 2. Interactions of sunlight (yellow) and heat (green) with aerosols (clouds and dust) and gases (water, carbon dioxide and others) in the atmosphere.

Observing climate change

Over the last century, several key measures of global climate have changed significantly — also facts few scientists dispute (table 1). Clearly the most discussed change is the rise in global surface temperature (fig. 3). These data strongly suggest a shift around the turn of the 20th century, a time of rapid growth in gasoline-consuming cars and trucks and the expansion of electrical networks fueled primarily by coal. Despite the considerable uncertainties in the temperatures of the past, it now seems clear that recent global mean temperatures are at least 1°F higher than any that have been observed in the past 1,000 years.

Changes other than in global surface temperature are also important. Many individuals care most about the changes closest to home. The left panels of figure 4 show the estimated temperature and precipitation changes in the southwestern United States in the past century. The temperature increases for the western United States are larger than those of the globe. There is also good evidence to suggest that these mean temperature increases are largely due to increases in nighttime low temperatures rather than daytime highs. The pattern for regional precipitation changes is more mixed: Some areas are up and some down, as is true for the Earth as a whole. However, there is reliable evidence that the frequency of extreme precipitation events — floods and droughts — is increasing, in part due to the increased intensity of both El Niño (generally bringing greater rainfall to California) and La Niña (often associated with drier periods in California) events.

These findings are relatively noncontroversial. However, important discussions continue as to the magnitude of the change. The measurements shown in figures 3 and 5 were taken at

TABLE 1. Selected 20th-century changes in Earth's climate

Variable	Observed change	Confidence
Global mean surface temperature	Increased 1.1 ± 0.4°F (0.6 ± 0.2°C) this past century; land areas warmed more than oceans	Very likely
Diurnal surface temperature range	Nighttime minimum temperatures increased at twice the amount of daytime maximum temperatures	Likely
Cold/frost days	Decreased for nearly all land areas	Very likely
Continental precipitation	Increased 5% to 10% in Northern Hemisphere	Very likely
Global mean sea level	Increased at an average of 4–8 inches (10–20 cm)	Very likely
Northern Hemisphere snow cover	Decreased in area by 10% since 1960	Very likely

Source: Houghton et al. 2001, p. 2, 4.

"... despite occasional ridicule on late-night talk shows, these models very

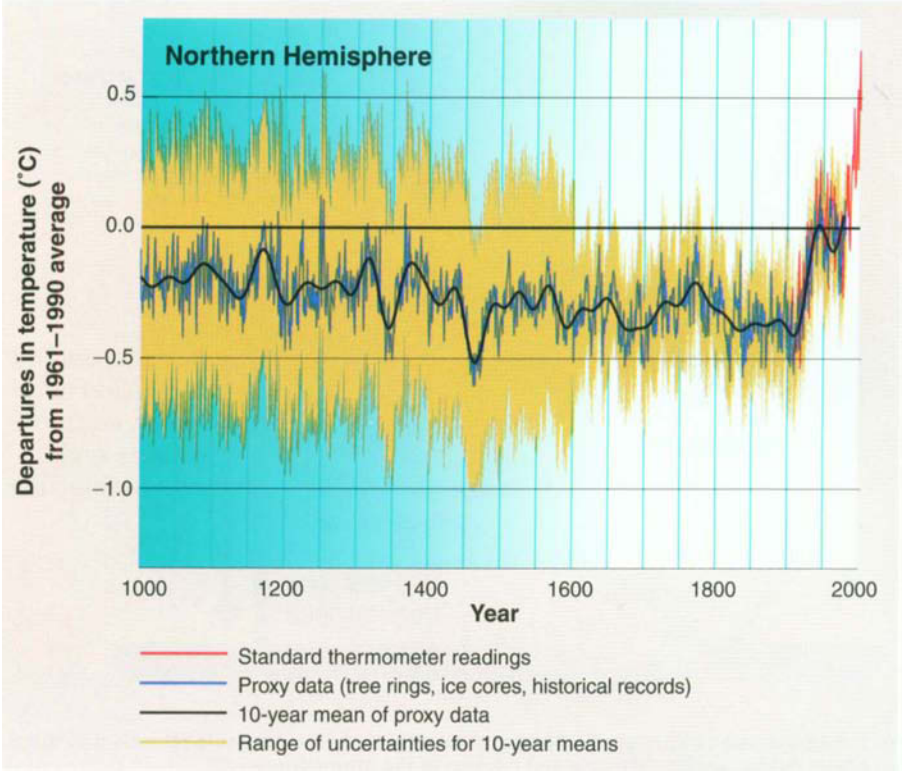


Fig. 3. Northern Hemisphere temperature changes. Source: Houghton et al. 2001, p. 3.

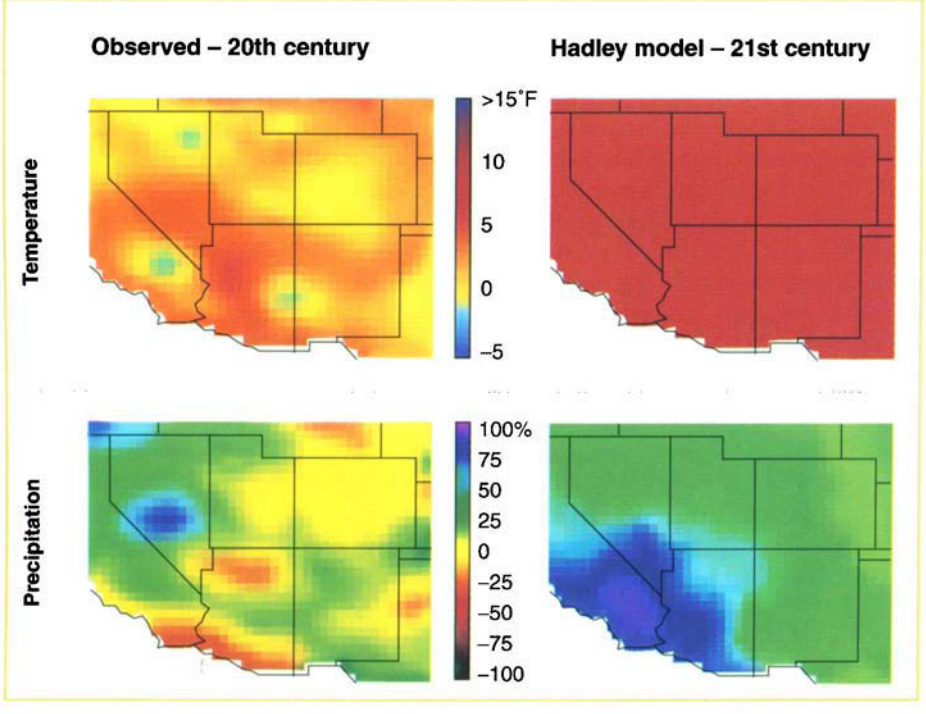


Fig. 4. Temperature (°F) and precipitation (%) changes from 1961–1990 means over western United States. Observed changes are for approximately 100 years of the 20th century. Predicted 21st-century changes are from British Meteorological Office's Hadley model, based on middle-range IPCC "greenhouse" gas assumptions. Source: NAST 2000, p. 65.

weather stations that are irregularly spaced around the globe. The oceans, for example, are relatively poorly sampled. It is also well known that station temperatures may be influenced by the "urban heat island" effect, by which temperatures taken in cities are higher than those in nearby rural areas. (Warmer urban areas are primarily the result of waste heat from buildings and the lack of the cooling effect of vegetation.) Finally, there is concern that "surface" temperature measurements made from satellite instruments, which sample the whole Earth, do not in their relatively short records show changes as large as those of the station data.

The criticisms of the station data have been carefully investigated and addressed. For example, stations with a heat island signature have been excluded from summaries discussed in this paper, such as those in figure 3. The satellite data are also subject to criticism. Some scientists have noted that they are created not from the measurements of a single satellite, but from about a dozen satellites, each of which falls slowly toward the Earth. As a result, daily temperature samples are made at different times of day, in one year when it is relatively warm and another when it is relatively cool. This problem has also been addressed, but some controversy remains with respect to both the surface and satellite data.

Predicting climate change

The main scientific controversies regarding the climate concern predictions for the future. The basic methodology for making these predictions is to combine social-economic estimates of fossil fuel usage, farming practices and pollution control with sophisticated computer models of the weather. The social-economic estimates are cast in terms

TABLE 2. Projected changes in Earth's climate during 21st century

Changes	Confidence
Higher maximum temperatures, more hot days and heat waves over nearly all land areas	Very likely
Higher (increasing) minimum temperatures, fewer cold days, frost days and cold waves over nearly all land areas	Very likely
More intense precipitation events	Very likely over many areas
Significant rise in sea level during 21st century will continue for subsequent centuries	Very likely

Source: Houghton 2001, p. 13, 15, 16.

of "scenarios," forecasts based on different economic projections and social constraints, such as global legislation that limits the release of carbon dioxide to some fraction of a baseline level. Although there are substantial differences in these scenarios, they do not affect the ultimate temperature change projection as much as they influence the expected decade during the next century when a particular change is likely to occur (table 2).

The economically and politically based scenarios are translated into climate change predictions using global climate models. These state-of-the-art computer models are the outgrowth of weather forecast models, which are used to make regular forecasts 1 to 10 days into the future. These models divide the atmosphere into three-dimensional grids that are generally between 50 and 150 miles east-west and north-south, and as much as a few thousand feet in elevation. The models mathematically solve the basic laws of physics — which describe the interaction of grid mean temperature, humidity and winds — and carefully tested approximations of "subgrid scale" processes that occur in small spatial regions — which are much smaller than the model grids in even the most sophisticated global model. An example of this is interactions with clouds, which are almost always smaller than the grids of even the most sophisticated weather models, but which also are vitally important for determining the amount of sunlight heating the ground or precipitation reaching a crop. Most recent climate models also include submodels of the oceans and high-latitude glaciers.

All of the relevant equations are projected from an initial known condition into the future, in intervals of a few minutes or less. These simulations are regulated or "forced" by climatic factors like the amount of sun at the top of the atmosphere, the chemical composition of the atmosphere and the physical properties of the land surfaces and ocean. (This simulation process is something like an income tax program in which your income is the forcing and the tax rules are the laws of atmospheric and ocean physics.) This process creates pictures of day-to-day weather a month or a year or decades into the future; from this, mean temperatures and other meteorological variables can be created.

How good are these models? The weather-forecasting models, which underlie these climate models, have been carefully evaluated for decades. In general, despite occasional ridicule on late-night talk shows, these models very accurately predict regional temperatures about a week in advance; they perform less well for regional precipitation. The quality of forecasts decreases somewhat if one focuses down to a specific locale, which is much smaller than the model grid. Winter forecasts tend to be slightly better than summer.

Uncertainties with models

The uncertainties associated with climate predictions fall largely into two basic categories. First, there are complex climate feedbacks — interactions that can either amplify or diminish an initial tendency. For example, an increase in surface temperature due to increasing carbon dioxide concentrations in the atmosphere might lead to more and thicker clouds, which would reflect more sunlight back to space and cool the Earth's surface. Another feedback occurs when warmer temperatures reduce the amount of snow and ice at the Earth's surface, which in turn diminishes the amount of sun reflected to space, leading to additional warming. Although many such feedbacks are known to exist, none seem to have the possibility of changing an initial warming to a cooling or vice versa. However, they can substantially alter the magnitude of the temperature change. In nearly all models, the primary effect of a doubling of current carbon dioxide concentrations is a gradual increase in global average temperature of about a 2°F, whereas the cumulative effect, including all of the feedbacks, is typically between 5°F and 10°F. Understanding and correctly modeling feedbacks is critical to making reliable forecasts.

The second set of uncertainties is related to the problem scientists encounter in trying to gauge longer-term climate shifts in a system in which weather and climate are always naturally changing. How can we know whether or not an observed change over 10 years, for example, is due to outside factors such as human activities or to natural variability over dozens or hundreds of years? The way scientists usually try to deal with this question is by identifying as many features of natural variability as possible. Those factors are then included in the computer models, which are then forced with and without these variations plus those thought to be due to humans.

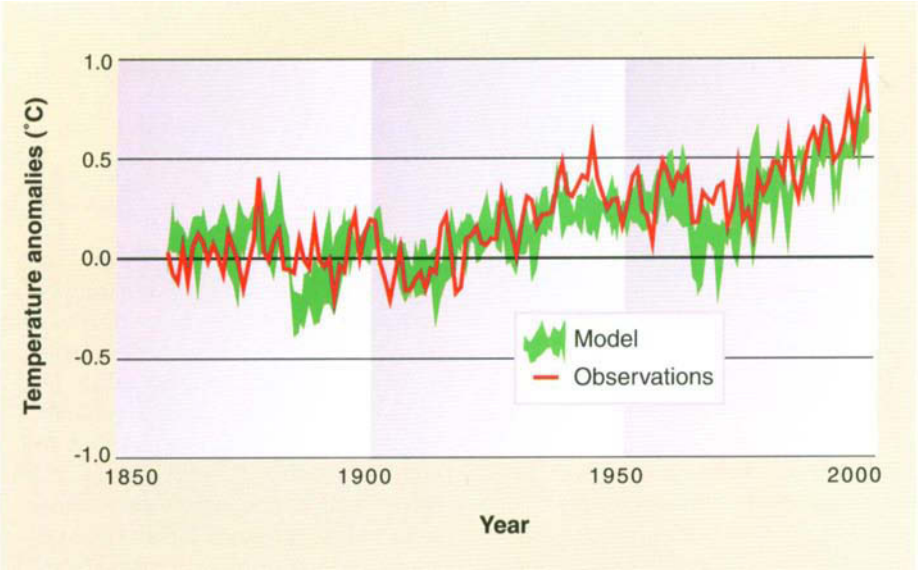


Fig. 5. Observed and modeled Northern Hemisphere surface temperature changes. Observations are by standard thermometer readings (see fig. 3). Model is average predicted value of British Meteorological Office's Hadley climate model, based on combination of natural and human-induced climate change forcing mechanisms. Source: Houghton et al. 2001, p. 11.

Hadley model shows dramatic change

The British Meteorological Office's Hadley global climate model has been used to reproduce surface temperatures for the past 140 years. The variations in the Hadley model are forced by the internal weather variability in the model plus a combination of natural and human-induced factors (fig. 5). The natural factors include the estimated amounts of dust inserted into the atmosphere following the strongest volcanoes and the estimates of changes in solar output associated with the 11-year sunspot cycle. The human factors include the effects of added carbon dioxide, nitrous oxide, methane and sulfate. Also included are variations in chlorofluorocarbons (CFCs/freon), which absorb heat and have a large influence on the amount of stratospheric ozone, which absorbs sunlight. Not only can this model reproduce all of the major changes in 10-year mean global temperatures over this time period, but it can also accurately simulate the magnitude of the year-to-year variability. Overall, the model shows that the human-related modifications to climate account for by far the largest part of the recent dramatic changes. These results are especially compelling when one notes that this model was run day by day for each point of the Earth starting in about 1860.

Other models. Many other models have been developed that give similar, but sometimes less conclusive results. In general, climate models are most accurate in replicating changes in global and hemispheric temperatures. They do slightly less well for regional (such as the southwestern United States) temperature and hemispheric precipitation. They do even less well for regional-scale cloudiness and precipitation. They probably have little value in predicting changes for individual weather stations or locales.

A number of models have been used to continue the forecasts from 2000 to 2100 using the best estimates of the likely human-induced forcing. These model predictions of temperature, precipitation and other meteorological variables are the basis for not only the assessments of likely climate change, but also of the potential impacts on agriculture, ecology, human health and global economies. The evidence for a moderate temperature increase in the western United States is strong, while there is a mixed picture for the expected precipitation changes (fig. 4).

As a result of global warming, sea levels are expected to rise an average of 1 foot in the next century, resulting in the direct loss of valuable coastal farmland. In Santa Cruz County, broccoli is cultivated along the coast near Pigeon Point lighthouse.

Temperature. The global temperature change over the next 100 years, calculated by the Hadley model using a climate forcing near the middle of the range of the "realistic" social and economic projections, is about 7°F (4°C)(fig. 4). The IPCC report characterizes this general result as "very likely." The authors add that, "The possibility of abrupt and irreversible changes in the climate system exists." This statement is based on the forecasts from a number of climate models utilizing various "reasonable" economic and regulatory scenarios (Houghton et al. 2001).

Clearly, temperatures are predicted to increase substantially everywhere in the Southwest. Globally, the largest increased temperature would be in the Arctic region and the smallest changes over the tropical oceans and the Southern Hemisphere. For the United States, the changes are in the range of 7°F to 9°F (4°C to 5°C) and are relatively uniform over the continental United

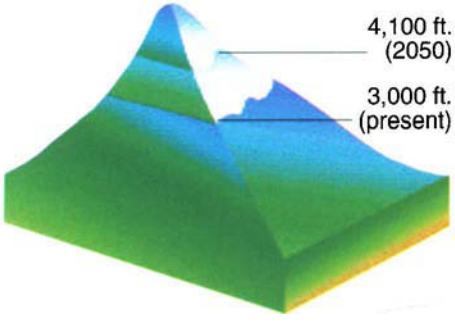
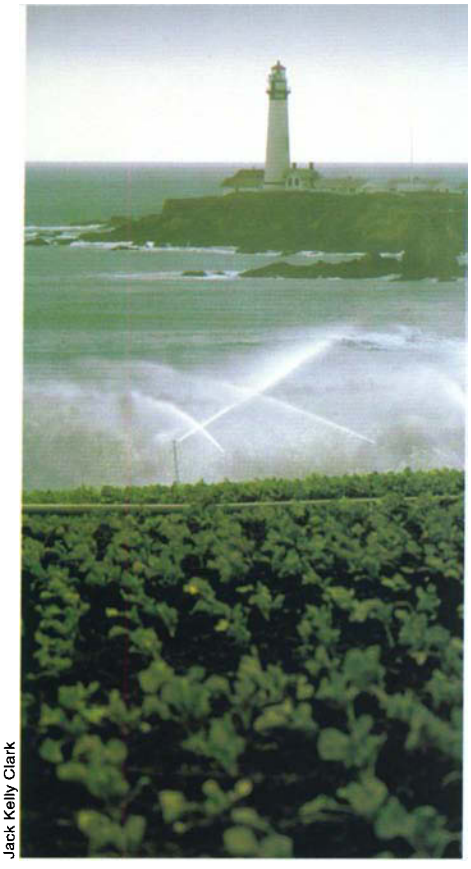


Fig. 6. Estimate of how much snow lines in Pacific Northwest are likely to shift by 2050, assuming about 4°F regional warming. Source: NAST 2000, p. 97.



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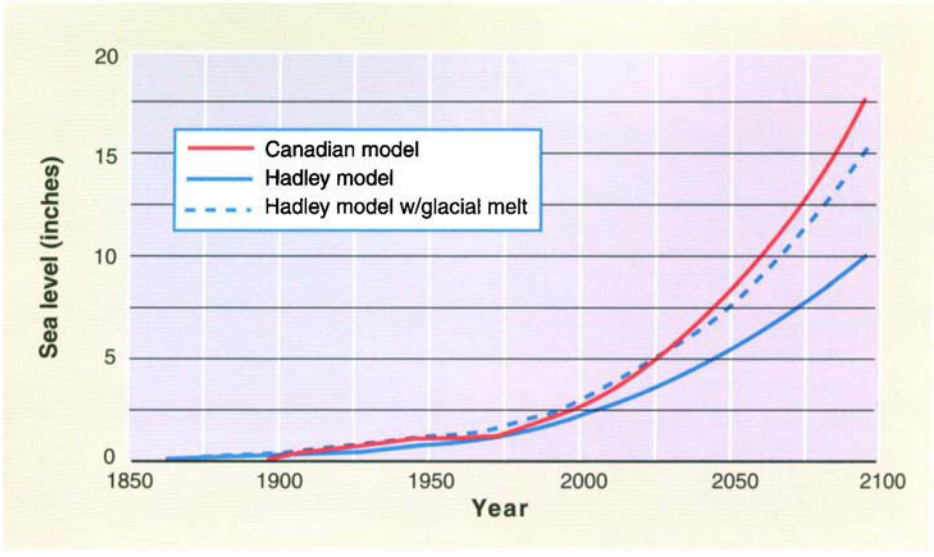


Fig. 7. Projections of sea level rise using the Canadian Climate Center and British Meteorological Office's Hadley global climate models. Solid lines represent changes directly due to increased ocean temperatures; dashed lines add influence of partial melting of Greenland. Estimates to about 2000 are in general agreement with observations. Source: NAST 2000, p. 112.

States, and between summer and winter. These changes will be primarily due to relatively large increases in nighttime low temperatures and smaller increases in daytime high temperatures.

Precipitation. The patterns of precipitation change are more complicated. The Hadley model predicts substantial increases in precipitation in the Southwest, especially in Southern California. Globally, most models suggest that the Arctic region and the equatorial zones will be wetter, and the subtropics drier. However, there are a relatively large number of zones in which the seasonal changes are inconsistently predicted by different models. Overall, the United States is expected to be slightly wetter than today, especially in winter. This is partially due to the expected increased frequency of El Niño events in the equatorial Pacific and their influence on winter precipitation in both the western and southeastern parts of the country. Other analyses suggest that summer soil moisture will be less than today because greater drying associated with higher temperatures and lower cloud cover will more than offset the slightly greater precipitation.

Consequences for California

Water availability. What do these and other "forecasts" mean for agriculture in California? The most important factor is related to water availability during the summer. A key aspect of the overall higher temperatures will be a dramatic increase in the mean snow line accompanying winter storms (fig. 6). Because of the roughly conical shape of most mountains, a relatively small rise in the snow line will dramatically reduce the area covered by snow and the associated water storage. This will not only lead to more runoff and heightened chances of winter flooding, but also to reductions in the water supplies from reservoirs that are available for irrigation and other uses in summer. This summertime reduction will be due to two factors: the decreased storage of water in the snowpack and the requirement that reservoirs be kept at relatively low levels throughout most of the winter to reduce the chance of flooding. Furthermore, this reduced irrigation water availability will coincide with a greater likelihood that water will evaporate more readily from irrigated fields.

Water quality. Another result of the predicted warming will be a reduction in water quality in a number of regions of the West. Mean sea levels are expected to rise about 1 foot, mainly due to heating of the ocean surface (fig. 7). Warm water occupies a slightly larger volume than an equal mass of cold water. These higher sea levels could lead to increased saltwater intrusions in the Sacramento Delta and well water in coastal plains. Furthermore, the higher sea levels could readily result in the direct loss of valuable low-lying farmland because of flooding.

Air pollution. Increased surface temperatures will likely be associated with more incidents of extreme air pollution. An increase in temperature of about 9°F (5°C) will lead to as much as double the typical maximum daily ozone concentration (fig. 8). The reasons for this are quite well understood. The burning of fossil fuel, largely from cars and trucks, produces the precursors of ozone. These undergo chemical reactions, which require sunlight and generally proceed faster at higher temperatures. Clear, hot days tend to produce more ozone for a particular

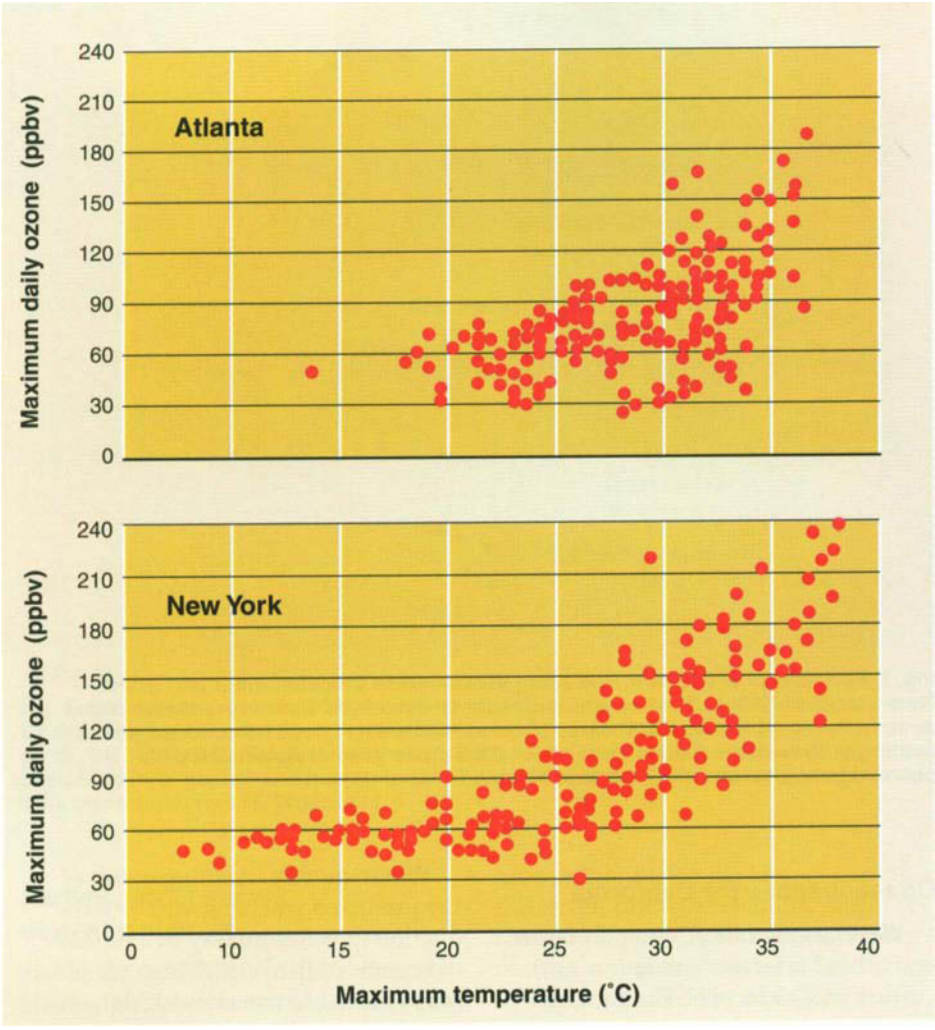
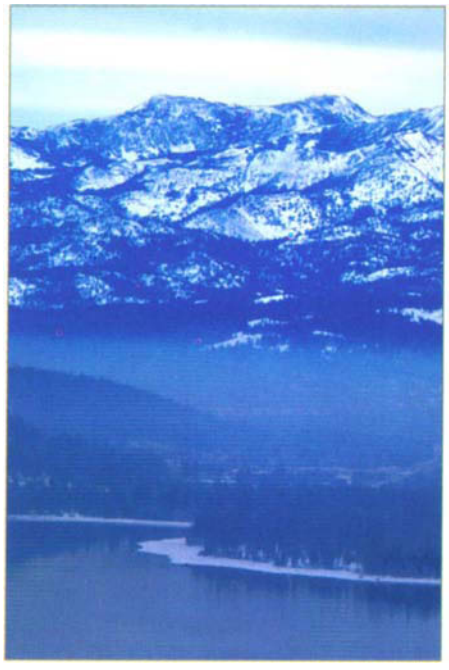


Fig. 8. Associations between observed ground-level maximum daily ozone concentrations (parts per billion by volume) and temperature for Atlanta and New York. Source: NAST 2000, p. 104.



Phil Schermeister

Increased temperatures will result in the production of more ozone-related smog. Air pollution from wood smoke is already a significant problem at Donner Lake, near Truckee.

quantity of direct pollutants. Also, in the West, hot summer days are often associated with evening thermal inversions — temperatures that increase with height — which leads to a trapping of the pollutants. This in turn results in higher concentrations of pollutants near the ground.

Other impacts. There are many more possible impacts of global climate and environmental changes. These include crop yield fluctuations and associated economic consequences, biodiversity shifts and health effects related to extreme weather events. Of course, not all aspects of global change are necessarily bad for California and the West. Increased atmospheric carbon dioxide concentrations are expected to enhance crop and forest growth. However, recent studies suggest that this enhancement may be quite temporary unless increased amounts of fertilizer and adequate irrigation are applied.

Coping with climate change

Regardless of the consequences, we know that relatively large global and regional climate changes have been occurring. Our best scientific evidence strongly suggests that an important component of these changes is due to human activity. Furthermore, evidence indicates that the changes will continue at an increasing pace well into the next century. The rate of those changes may well outstrip our scientific, economic and social ability to effectively cope. It is important for all Californians to understand the causes of those changes, their likely implications and the nature of possible remediation.

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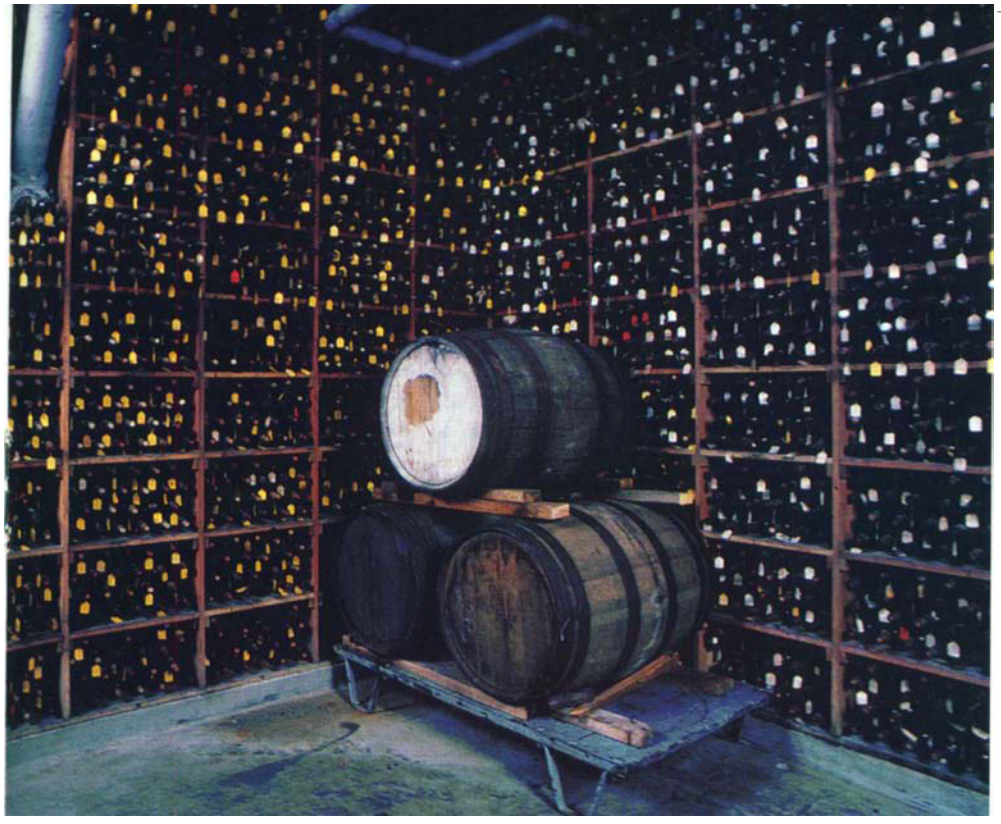

Jack Kelly Clark

Ninety-six percent of U.S. wine grapes are grown in California. Like many other agricultural commodities, the wine grape industry utilizes contracts to codify the relationship between growers and buyers. Wine is stored in cellars, such as this one at UC Davis, built in 1938.

Contract use widespread in wine grape industry

Rachael E. Goodhue ■ Dale M. Heien
Hyunok Lee ■ Daniel A. Sumner

The use of agricultural contracts between farmers and processors or other buyers has increased substantially in recent years. Roughly half of all U.S. fruit and vegetable production is under contract. Contract usage varies widely across agricultural products. For example, 95% of poultry is raised under contract while only 13% of corn is. The wine grape industry utilizes contracts, yet little is known about the extent of contract use, or the use of specific terms and objectives. We used a survey to analyze contract use among wine grape producers, determine which users are utilizing contracts, and identify how they differ from nonusers. Ninety percent of the growers who responded to the survey have contracts, the majority of which were multiyear, averaging 3.7 years. Growers with more experience, larger vineyards, more expensive grapes and longer relationships with the buyer were more likely to enter into contracts.

Contracts between agricultural producers and processors are becoming more common. Generally, these contracts specify one or more conditions of sale, such as the price, and/or production methods, such as the trellising system. As the use of contracts increases nationwide, agricultural observers have expressed growing concerns about the impact of these arrangements on risk and returns (USDA 2000). While several theoretical studies address these issues, relatively few have examined agricultural contracts empirically (Knoeber and Thurman 1994; Goodhue 1997, 1999).

The California wine grape industry provides a good case study of contract use, as wine grapes are an economically significant crop for the state. With a production value of $2.7 billion in 1999, grapes are the most valuable U.S. fruit crop, and more than three-fourths of the grape crop's value comes from wine grapes.

Ninety-six percent of U.S. wine grapes are grown in California (Sumner et al. in press). In 1997, grapes were California's second largest agricultural product in terms of production value (Heien 1999).

Economic aspects

The economic literature on agricultural contracts often is based on the presumption that information differences exist between the parties involved in a transaction, and that these differences may result in incentive problems. Specifically, the profits of one party, the "principal," are dependent on information known only to the

other party, the "agent." In the cases analyzed, the agent will not act in the principal's best interests unless provided with an incentive to do so, such as a payment linked to the principal's profits. More recently, interest has extended to the way U.S. agriculture is organized economically (Boehlje 1995, 1996; Barkema et al. 1993; Barkema 1994; Barry 1995; Boehlje and Schrader 1998; Drabenstott 1994, 1995; Urban 1991).

Greater vertical integration and coordination has coincided with a movement away from a homogeneous commodity system to one emphasizing product differentiation. Increased coordination between buyers and sellers allows sellers to tailor their production to buyers' needs. In the case of wine grapes, contracts between growers and vintners help growers to deliver grapes with the quality attributes that vintners want, by means of cultural-practice requirements (such as trellising method), and price bonuses and penalties based on grape attributes (such as sugar and acid)(Goodhue 1999).

The California wine grape industry clearly produces a differentiated product, as a casual comparison of the average California supermarket's wine and produce aisles will confirm. A significant proportion of this differentiation is generated at the farm level, by variables such as region and variety. The quality of wine grapes is partly based on observable characteristics — sugar content (brix), acid and pH — while more subtle characteristics are harder to measure. With no explicit industrywide grading process that links quality to these characteristics, individual wineries use standards that may be specified in contracts.

Wine grape grower survey

In June 1999, the UC Agricultural Issues Center conducted a survey of contract use in the California wine grape industry. The survey questionnaire was mailed to the 12,000 growers and winery owners listed in the California Agricultural Statistics Service (CASS) grape acreage database. This database includes all known grape growers and wineries in the state. About 10% of the total are engaged in winemaking, either as an independent winery that purchases all of its grapes, or as a winery that produces at least some of the grapes used in its wine. The center received more than 2,000 responses, nearly 20% of the surveys mailed out. To ensure a good response rate, the questionnaire was one page with 18 questions, mostly yes/no (Goodhue et al. 1999).

The respondents were divided into four regions. In order of declining average price per ton for wine grapes, the regions are North Coast, Central Coast, central San Joaquin Valley, and southern San Joaquin Valley plus other areas, such as San Diego County. Napa and Sonoma counties, perhaps the most famous wine-growing regions, are included in the North Coast. Generally, California's premium grapes are grown in coastal areas (North and Central Coast regions), while the lower-priced grapes are grown in the Central Valley (central San Joaquin, southern San Joaquin, and others).

The percentage response from each region closely matches the grower population percentage in that region (table 1). This is one indication that our survey is roughly representative of the population of growers. Within each region the survey respondents were generally operators of larger vineyards, as indicated by acres per grower, than the average grower in that region. However, the relative sizes across regions in the CASS data are similar to our survey's relative acres per grower across regions.

The survey included questions on contract use, contract provisions and grower characteristics. Growers were asked the varieties they produced, total acreage, the length of their current buyer-seller relationship and the length of time they have been in the grape business. Contract use was re-

TABLE 1. Regional distribution of wine grape growers, 1999 survey

Region	Source	All	North Coast	Central Coast	San Joaq. central	San Joaq. south/other
Acres	CASS*	752,000	96,000	65,000	103,000	488,000
Total no. growers	CASS	11,726	3,430	1,018	1,834	5,444
Grower respondents	Survey	1,362	341	144	353	524
% growers	CASS	100%	29	9	16	46
% respondents	Survey	100%	25	11	26	38
Acres/grower	CASS	64	28	64	56	90
Acres/grower	Survey	118	59	107	109	179

*California Agricultural Statistics Service.

The authors found that 90% of surveyed *growers produce wine grapes under* contract.

Jack Kelly Clark

"Contracts are more likely to specify production practices in premium grape-growing regions, while price incentive provisions are more common in nonpremium regions."

TABLE 2. Contract types (%) among wine grape growers

	All	North Coast	Central Coast	San Joaq. central	San Joaq. south/other
No contract	10	4	11	6	18
Written only	70	71	56	68	74
Oral only	11	13	20	15	4
Both	9	12	13	11	4
Planting contract	10	9	13	21	8
Evergreen clause	30	45	34	13	9

TABLE 3. Average farm characteristics and years of contracts

Farm characteristics	All	North Coast	Central Coast	San Joaq. central	San Joaq. south/other
Years with buyer	9.7	7.9	7.5	12.3	9.6
Years in business	20.6	18.3	15.8	21.1	23.6
Regional price ($/ton)	787	1,710	1,256	477	276
Years of contract	3.7	4.0	4.5	4.8	2.5

ported for written contracts, oral contracts, both and neither. Oral contracts are verbal arrangements made prior to the time of sale that specify one or more conditions of sale or production. Most commonly, oral contracts specify the delivery price. Some respondents had multiple buyers (or sellers), which in some cases meant that an individual used both a written and an oral contract.

The survey also included questions on contract provisions such as price incentives, bonuses and penalties; evergreen renewal clauses, which provide for automatic renewal unless one or both parties opt out; clauses specifying viticultural practices; and price determination methods, such as a price tied to last year's crush price, or a fixed price per ton.

Our survey data show that 90% of surveyed growers produce wine grapes under contract, and that most of those contracts are written (table 2). About 10% of the written contracts are planting contracts, which are signed prior to the establishment of the vineyard.

Planting contracts help growers secure financing for new vineyard development; this percentage is highest in the Central Valley where the share of new wine-grape acreage is also high. Contracts with evergreen clauses are common, accounting for 30% of all contracts, and as much as 45% on the North Coast.

We obtained the regional price of wine grapes using price data from the *Final Grape Crush Report* (CDFA 1999). These data represent average transaction prices per ton for the region. Comparison of the regional averages, acres and regional ton price shows a distinct pattern: farm size becomes smaller as regional prices increase (tables 1 and 3). Sellers have been in the grape-growing business for an average of 20.6 years; this number varied little by region.

The extent of bonuses and penalties for sugar, acids, material other than grapes (MOG) and defects (such as rot and mildew) are also important contract features. Penalties are more prevalent than bonuses, although 33% of contracts in the southern San Joaquin region provide for a sugar bonus (table 4). Overall, only about 10% of contracts have bonus provisions, while over 35% have penalty provisions. Price provisions are largely in two categories: fixed in contract or adjusted yearly. Fixed in contract means that the buyer and seller agree to a fixed price or a fixed price schedule over time. The majority of the contracts have price provisions that adjust yearly, often on the basis of a reference price such as last year's average crush price.

TABLE 4. Contract provisions (%) reported by wine grape growers using written contracts

Cultural practices	All	North Coast	Central Coast	San Joaq. central	San Joaq. south /other
Specific practices					
Required	16	15	8	15	21
Suggested	37	44	56	32	30
Inform of chemical use					
Before use	45	39	31	45	55
After use	71	62	53	76	83
Bonus					
Sugar	18	11	7	17	33
Acids	4	3	3	3	6
MOG*	9	7	5	10	13
Defects	10	8	10	10	15
Penalty					
Sugar	42	13	40	57	34
Acids	10	11	9	12	7
MOG	43	39	37	59	48
Defects	47	45	41	60	48
Price determinations					
Fixed in contract	31	26	27	30	35
Adjusted yearly	52	71	63	56	33
Per acre price	1.4	2.0	2.8	0.8	0.9

*Material other than grapes.

TABLE 5. Statistical analysis of the probability of contract use among wine grape growers

Explanatory variable	Written or oral vs. none	Written vs. oral
Years with buyer	0.075%*	–0.010%
Years in business	0.020%*	0.33%*
Acres	0.011%*	0.061%*
Regional price	0.0004%*	–0.0019%*
Sample size	All growers 1,362	Written contracts only or oral contracts only 1,145
McFadden R^2†	0.352	0.110

* Statistically significant at 10% level.

† McFadden R^2 is a measure of how well the estimated equation explains the data.

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The wine industry values variety and differentiation, rather than a uniform product. The quality of wine grapes is measured in terms of sugar content, acid, pH and other less tangible characteristics. Many grower contracts require specific quality attributes.

Contract provision determinants

While contracts are the norm, their forms vary. Some are written and others are oral, some have price incentives such as penalties or bonuses and others use provisions specified in nonprice terms, such as viticultural practices. We have drawn some statistical inferences regarding which factors influence contract provisions.

As noted, most of our data consisted of yes or no answers. This includes important information, such as the inclusion of specific provisions. In order to analyze the determinants of yes/no choices, we employed a discrete choice (logit) technique. This technique estimates the probability that a grower with a specific set of characteristics will have a written contract, enter a fixed-price contract and so on. We looked first at factors that influence whether a grower produces under contract, and whether the contract is written or oral. Then we examined the factors that influence the choice of contract terms such as price incentives, winery involvement and price determination. In each case we sought to discover which characteristics are statistically significant. Our survey did not ask for price information because we expected that question to be particularly sensitive for respondents. Instead we matched the region of the grower with the crush district price. In our analysis, a higher regional price is an indication of better quality.

There are three categories for contract use: no contract, oral contract or written contract. For our statistical analysis, we omit respondents who used both written and oral contracts. The remaining three categories can be viewed as a sequence of stages. Each stage involves dichotomous outcomes, contract or no contract for the first stage, and, for those with contracts, whether the contract is oral or written in the second stage (table 5). In the first equation, all four characteristics have a positive but very small effect on the probability of having a contract.

The numbers associated with each characteristic report the increase in the probability of having a contract when the characteristic increases by one. For example, one additional year with a specific buyer will increase the probability of having a contract by 0.075%. All characteristics are statistically significant at the 10% level. This means that we are over 90% certain that the specific characteristic has an impact different from zero. An increase in any one of these characteristics will increase the probability that the grower will have a contract.

Contract type. Regarding the likelihood of engaging in a written contract as opposed to an oral one, our results indicate that the contract type is closely related to grower and farm characteristics. All explanatory variables, except years with buyer, are statistically significant. The likelihood of engaging in written contracts increases with business experience and vineyard size, but decreases with the price of wine grapes.

Quality control. We examined quality control issues based on bonuses and penalties, cultural practices and price determination. For these three equations, we included additional characteristics (independent variables): whether the contract includes an evergreen clause, whether the contract is tied to planting and the length of the contract (tables 6 and 7). These variables are also binary (a grower either has a planting contract or doesn't have one). Hence, the effect is discrete. For example, if the grower has a planting contract, the probability of a specific production practice being required increases by 9.57% (table 6).

About half of the contracts had a provision suggesting or requiring specific grower practices. Such provisions are significantly more likely when the contract also has an evergreen provision and when the grapes are from a high-priced district (table 6). Years with buyer, years in business and presence of a planting contract also have positive effects. Also, because planting contracts apply to new vineyards, their positive effect may mean that requiring or suggesting specific production practices is a relatively new phenomenon.

Quality characteristics such as sugar, acids, MOG and defects are observable at harvest, so they can be verified at that time. For the "any bo-

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In regions that grow higher-quality grapes, such as Napa and Sonoma, contracts are more likely to include quality-related production requirements and less likely to include price incentives. Buena Vista Winery, near Sonoma, was established in 1857.

nus or penalty" model, all three farm characteristics, except years with buyer, are significant. The coefficient on price is significantly negative at the 1% level (table 6).

Regional price. It is interesting to note that the regional price is statistically significant with opposite signs in explaining specific practice requirements and price incentives. That is, with higher-quality grapes (and where the industry is more differentiated), production requirements are more likely to be included in the contract, but price incentives are less likely to be included (conversely, price incentives are more likely to be used in lower-priced areas).

One interpretation of these results is that we would expect more use of price incentives in those regions where quality attributes are more easily measured and less use of price incentives where the most important quality attributes cannot be measured well at the point of delivery. According to viticulture and enology experts, sugar content is the most important product characteristic for lower-priced grapes and in regions that generally produce lower-quality wine. Sugar content is measured at harvest, when the winery crushes the grapes. In the premium grape regions, quality is often based on the historical track record of the vineyard. For grapes used to make the more expensive wines, sugar and similar easily measured characteristics are not necessarily the most important factors.

Price provisions. Finally, almost all written contracts have some type of price provisions. We grouped observations with written contracts into two groups: fixed price provisions and nonfixed price provisions. Nonfixed price provisions include reference prices that are adjusted yearly, and per acre prices that do not depend on the harvested tons. Our results indicate that a fixed price provision (dependent variable = 1) is less likely when the contract also is a planting contract, or when the contract has an evergreen clause (table 7). Fixed price provisions are also less likely when the farmer has more years dealing with the same buyer. However, the fixed price is more likely when the farmer has more years in the grape-growing business and has a larger vineyard. The negative effects of most of these characteristics may indicate that fixed price

TABLE 6. Production specifications and price incentives in written wine grape grower contracts

	Effect on probability of contract having a specific clause	
Explanatory variable	Specific production practices required/suggested (%)	Bonuses or penalties for quality attributes (%)
Contract characteristic		
Planting contract	9.57*	8.30*
Evergreen clause	9.32*	4.49*
Years of contract	0.45	0.55*
Grower characteristic		
Years with buyer	0.40*	0.22
Years in business	0.22*	0.422*
Acres	–0.0076	0.047*
Regional price	0.0077*	–0.0046*
Sample size	976	976
McFadden R^2†	0.032	0.14

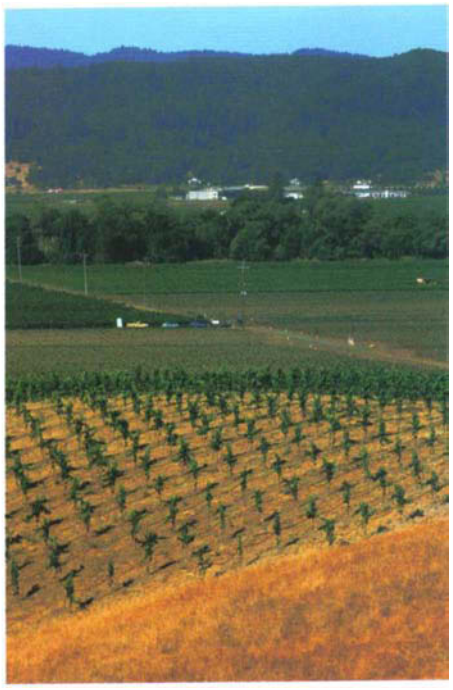
* Statistically significant at the 10% level.
† McFadden R^2 is a measure of how well the estimated equation explains the data.

TABLE 7. Price provisions in written wine grape grower contracts

Explanatory variable	Effect on probability of contract including fixed price provision
Contract characteristic	
Planting contract	–14.84*
Evergreen clause	–24.46*
Years of contract	–0.35
Grower characteristic	
Years with buyer	–0.99*
Years in business	0.57*
Acres	0.057*
Regional price	–0.0023
Sample size	976
McFadden R^2†	0.094

* Statistically significant at the 10% level.
† McFadden R^2 is a measure of how well the estimated equation explains the data.

Photos: Jack Kelly Clark



About 10% of contracts in the wine grape industry are planting contracts, which help growers to secure new financing. *Right,* A Merlot vineyard has been replanted in the Alexander Valley. *Left,* An older grapevine.

contracts are not as attractive as those that have price escalator clauses. The results on contract length and price of grapes are not significantly different from zero.

Who uses contracts

We found that contract usage is widespread in the wine grape industry. More experience, a larger vineyard, more expensive grapes and a longer relationship with the buyer were all related to the higher likelihood of a grower being engaged in a contract. Written contracts, relative to oral contracts, are associated with growers with larger vineyards, more years of experience and fewer premium wine grapes.

In written contracts, we found that provisions related to production practices, price incentives and price determinations are common. Particularly, penalties are more common than bonuses for the enforcement of certain quality standards. Contracts are more likely to specify production practices in premium grape-growing regions, while price incentive provisions are more common in nonpremium regions. This observation indicates that price incentives are more likely when important product characteristics can be accurately observed at harvest. Price incentives for grape characteristics observed at harvest are more likely to be used in the regions with lower grape prices that emphasize sugar content. Furthermore, a fixed price provision is less likely to be included in a planting contract or with an evergreen clause. However, fixed price provisions are more likely with greater farming experience, larger vineyards and fewer years with the same buyer.

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Avocado thrips, *above* (adult female), were first discovered in California in 1996. They have since become a major pest, with 80% of commercial orchards reportedly spraying to control them. On maturing fruit, *left*, avocado thrips cause elongate feeding scars.

NEW PESTS and PLANT DISEASES

Avocado thrips: New challenge for growers

Mark S. Hoddle ■ Joseph G. Morse ■ Phil A. Phillips ■ Ben A. Faber ■ Karen M. Jetter

Avocado thrips arrived in California in 1996. Since then, we have made substantial progress in our understanding of this pest. We now know the area of origin of the avocado thrips and have compiled an inventory of other potential pest thrips species on avocados in Mexico and Central America. Trials have helped us to identify several selective insecticides for use in treating avocado thrips in orchards. We have also determined the relationship between thrips densities on leaves and fruit scarring, and are studying cultural and biological control practices for use in an evolving integrated pest management (IPM) program.

Avocado thrips is a new pest of major economic significance in California avocado orchards. This insect was first discovered on avocados in June 1996, near Port Hueneme in Southern California. Soon afterward, populations damaging fruit and foliage were discovered in Saticoy and Oxnard, Ventura County, and in orchards in Irvine, Orange County. By July 1997, infestations of avocado thrips had spread north into San Luis Obispo County and south into San Diego County. Heavily infested orchards in Ventura County experienced 50% to 80% crop damage in 1997, and much of the fruit was either unmarketable or was downgraded in packinghouses. California is the only state in which avocado thrips have been reported as a major pest; they currently infest 95% of the state's 59,000 avocado acres. Approximately 80% of commercial orchards require pesticide applications to control this pest.

Avocado thrips was previously an undescribed species, and its country of origin was not known at the time of its discovery in California. Taxonomic work by Dr. S. Nakahara with the U.S. Department of Agriculture/Agricultural Research Service's Systematics Laboratory produced the official scientific name, *Scirtothrips perseae* (Thysanoptera: Thripidae)(Nakahara 1997). The recommended common name is avocado thrips. Morphological comparisons have determined that avocado thrips is more closely related to *Scirtothrips* species in Central America than to *Scirtothrips* species (for example, citrus thrips, *Scirtothrips citri*) in North America. Furthermore, in 1971, undescribed specimens of *Scirtothrips* were found on smuggled avocados from Oaxaca, Mexico, at the Port of San Diego. These specimens, morphologically very similar to *S. perseae*, are considered to be the same species.

Avocado thrips are small, slender, yellow-colored insects that are about one-sixteenth inch in length. Adults are winged but are poor fliers, and females lay eggs inside immature leaves and fruit about 1 to 2 inches long. Thrips larvae and adults can build up to such high densities on young leaves during the spring that subsequent feeding damage can cause premature leaf drop. The main source of economic loss attributable to avocado thrips is scarring of immature fruit in late spring by larvae and adults. Scarring can be severe enough to render the entire fruit surface brown, and a

Potential avocado pests and biological controls, identified in foreign exploration:

Phytophagous thrips species:

Caliothrips phaseoli

Frankliniella bruneri
F. brunnea, F. cephalica, F. chamulae, F. condei, F. cubensis, F. fallaciosa, F. gardeniae, F. gemina, F. gossypiana, F. occidentalis, F. parvula, F. rodeos, F. schultzei, F. williamsi

Heliothrips Haemorroidalis

Leucothrips furcatus

Neohydatothrips burungae
N. geminus, N. tibialis

Pseudophilothrips perseae

Scirtothrips aceri
S. citri, S. inermis, S. lumarius

Selonothrips rubrocinctus

Predator thrips (potential biological controls):

Franklinothrips orizabensis,
F. vespiformis

Leptothrips mcconnelli

Scolothrips pallidus

Fig. 1. Locations of foreign exploration for avocado thrips *(Scirtothrips perseae)* in Mexico and Central America.

characteristic "alligator skin" appearance results. Fruit that are entirely scarred can continue to grow, and the flesh of the fruit is a healthy green. However, even partial fruit scarring results in downgrading in packinghouses because of cosmetic damage.

Natural enemies

In order to identify host-specific natural enemies that are climatically preadapted to California and successfully establish biological control of this pest, it is essential to determine the geographic distribution of avocado thrips in its native habitat. Our host-plant surveys in California indicate that avocado thrips feeds and reproduces only on avocados. We suspect that the natural range of this pest is closely correlated with the centers of origin of the host plant. Three distinguishable ecological races or subspecies of avocado *(Perseae americana)* are recognized: (1) Mexican *(P. americana* var. *drymifolia)*, (2) Guatemalan *(P. americana* var. *guatemalensis)* and (3) West Indian or Caribbean *(P. americana* var. *americana)* types (Scora and Bergh 1990). We have explored the areas of origin of these avocado races for avocado thrips.

Foreign exploration for avocado thrips and natural enemies was completed in Mexico (Atlixco, Coatepec-Harinas, Oaxaca, Uruapan and the Yucatan), Guatemala (around Guatemala City and Antigua), Costa Rica (orchards around San José), the Caribbean (Dominican Republic and Trinidad) and Brazil. We have received considerable assistance from Mexican and Central American colleagues who helped us locate backyard and roadside plants, as well as trees in abandoned and commercial orchards, to sample for avocado thrips and associated natural enemies. Foreign exploration efforts have located avocado thrips only in Mexico and Guatemala (fig. 1). The most common natural enemies associated with avocado thrips in Mexico and Central America are predatory thrips belonging to the genera *Franklinothrips* and *Leptothrips*.

Foreign exploration allowed us to compile a list of other thrips (47 species in 19 genera) that are not presently established in California but that could become serious avocado pests if they arrive here (see box). One species, *Neohydatothrips burungae*, is as common as avocado thrips on avocados in Mexico but is not known to be present in California. Given the common occurrence of *S. perseae* in Mexico and Guatemala on avocados and its pestiferous nature in California, *N. burungae* could also pose a threat to California avocado growers if it became established.

Progress toward IPM

Densities, fruit size, economic scarring. Young fruit are vulnerable to avocado thrips feeding damage. As young foliage from the spring growth hardens during the time of fruit set (late May and early June), adult female avocado thrips move from the foliage to oviposit into young fruit. Feeding by the emerged larvae results in damage to the skin of developing fruit. Laboratory observation of field-collected fruit indicates that females lay eggs in fruit ranging from 0.16 to 3.0 inches in length. The majority of larvae (more than 95%) emerged from fruit ranging from 0.59 to 2.5 inches in length, with the highest numbers emerging from fruit 1.5 to 1.75 inches in length. Once fruit exceed 2 inches in length, avocado thrips are found primarily on young leaves.

Field biology studies conducted over 3 years, at three sites with different temperatures in Ventura and Santa Barbara counties, indicated that fruit are most susceptible to damage over a 2-week growing period just after fruit set, when fruit are 0.2 to 0.6 inches in length. These studies also indicated that when approximately three to five thrips were consistently found per leaf during fruit set, feeding caused 6% to 15% economic scarring damage on fruit. Furthermore, young fruit 0.5 inches long or less that were infested with an average of 0.5 to 1.5 larvae per

fruit in May and June resulted in 22% to 51% economic scarring.

In all years and sites, thrips were generally more abundant on young leaves than on fruit from early to mid-June when fruit were setting. When leaves aged and hardened from late June through August, equal or higher numbers of thrips were generally found on fruit, although overall numbers of thrips declined during this period with increasing summer temperatures (Yee at al. 2001).

Our results suggest that thrips numbers on leaves prior to or during fruit set can be used to predict scarring damage on fruit, and that the economic injury level may be less than five larvae per leaf during this time. Because low numbers of larvae on fruit in the sensitive 2-week post-fruit-set period can result in high levels of scarring, early insecticide treatments when thrips are on leaves, but before they move onto fruit, may help prevent damage to fruit. Many avocado orchards are located on rugged, hilly terrain that can be sprayed only by helicopter. For those orchards, earlier, pre-fruit-set treatments may be especially important. Furthermore, the small window of opportunity for treatment during fruit set can create insecticide application scheduling problems resulting in delayed or missed applications and significant fruit damage.

Spray trials, resistance monitoring. Avocado pest management in California has historically relied on biological control with minimal use of pesticides. As avocado thrips became a serious problem in California, our initial response was to search for selective pesticides (that is, those with minimal impact on beneficial biological control agents) that might help alleviate the problem until longer-term research could identify nonchemical solutions for managing avocado thrips. Because avocado thrips is taxonomically related to citrus thrips (both are in the genus *Scirtothrips*), we borrowed heavily from past research done with citrus thrips on citrus.

Laboratory and field pesticide efficacy studies conducted on avocados in San Diego and Ventura counties identified three pesticides as being both efficacious and relatively selective: sabadilla (Veratran D, Dunhill Chemical Co.), abamectin (Agri-Mek, Syngenta) and spinosad (Success, Dow AgroSciences). With the assistance of the companies producing these materials, the California Avocado Commission, and the California Department of Pesticide Regulation, we worked toward making all three pesticides available for use by avocado growers so that the materials could be used in rotation to avoid the development of pesticide resistance (historically a serious problem with pestiferous thrips species).

While individually quite small, avocado thrips can build up at such high densities on young leaves that premature leaf drop occurs. Larval and adult feeding damage is concentrated along the midrib and between veins on the leaf's underside.

Sabadilla was the first pesticide to be made available for control of avocado thrips under a Special Local Needs (24C) permit in 1997 and was fully registered in 1998. Abamectin was made available in 1999, 2000 and 2001 under a Section 18 Emergency Exemption, and spinosad was registered for use on avocados in 2000. Before each pesticide was made available, we initiated baseline pesticide resistance monitoring to determine the inherent susceptibility of avocado thrips to each material. Using these data, any future cases of low field efficacy can be evaluated to determine whether the avocado thrips are actually developing resistance to the product, or whether there are other causes, such as severe population pressure, poor timing of treatment or improper application (Phillips et al. 2000). Resistance development to sabadilla by some avocado thrips populations has been identified in some orchards that have used this insecticide multiple times in one season.

Cultural and biological control. Combined field and laboratory studies indicate that approximately 77% of *S. perseae* larvae drop from avocado trees to pupate in the upper 2 inches of leaf duff beneath the tree canopy, before emerging as winged adults that fly back up into the canopy to commence feeding and reproduction. One strategy for increasing thrips pupation mortality rates beneath trees is to use composted organic yard waste for control of avocado root rot (*Phytophthora*

Economic losses from avocado thrips are the result of scarring on immature fruit by larvae and adults. Impacts include feeding damage, *left*, and alligator skin, *right*. While the edible flesh of avocados that mature with thrips damage is usually healthy, scarred fruit is often downgraded at the packinghouse.

cinnamomi). We are currently investigating this strategy.

Preliminary data indicate that coarse, composted mulch placed around trees and over existing leaf mulch to a depth of about 12 inches and spread to the edge of the canopy can reduce peak emergence rates of adult *S. perseae* by approximately 50% in comparison to emergence rates from naturally occurring leaf duff under avocado trees that lack mulch (fig. 2). The exact mechanism that causes reduced adult thrips emergence from mulch is not known at this time but may be due to antagonistic microarthropods associated with the mulch; release of secondary plant compounds from decaying yard waste; or a more favorable habitat for entomopathogens such as fungi (for example, *Beauveria* spp.) or nematodes (for example, *Steinermema* spp.) that we have recovered from the mulch. We are continuing to work on mulches and on determining the mechanisms responsible for suppressing avocado thrips.

We are also studying a second noninsecticide strategy for controlling *S. perseae*, the use of augmentative releases of mass-reared *Franklinothrips orizabensis*. This native predatory thrips is the key natural enemy associated with *S. perseae* in California avocado orchards.

Preliminary trials of releasing mass-reared *F. orizabensis* that were shipped from a commercial insectary in Europe were not successful in controlling *S. perseae*. One major problem with this experiment was the poor quality of adult predators after shipping; more than 50% of aspirated and shipped adults died in transit, and the survivors were of marginal health (Silvers 2000). Therefore, we decided to mass-rear this predator in California. We evaluated 10 diets from commercially available food items to determine their suitability. The best diet tested was irradiated *Ephestia kuehniella* eggs (used for mass-rearing *Trichogramma*) combined with *Tetranychus pacificus* eggs (used for mass-rearing predatory phytoseiid mites)(Hoddle, Jones et al. 2001).

To reduce handling and transit mortality, we developed a harvesting technology that uses clear plastic tubes to collect pupating predators. *Franklinothrips* larvae spin silk pupation cocoons in the tubes, which are easy to harvest and protect pupating predators from damage during shipping. In shipping trials, this technique reduced predator mortality rates to 2% to 3%. In comparison, more than 50% mortality results from shipping aspirated adult *F. orizabensis* (Hoddle, Oishi et al. 2001). This mass-rearing and harvesting technology has been extended to two commercial California insectaries, and large-scale field trials are currently under way in Ventura and San Diego counties with locally reared *F. orizabensis*.

Economic impacts on production

Economic losses to growers experiencing an avocado thrips infestation arise from a reduction in fruit quality due to scarring and from increased pest control costs. Scarred Grade A quality fruit are reduced to standard grade or are culled entirely, while some packinghouses have papacado grades for heavily scarred fruit. With lower prices for standards, grower revenues decrease as a larger share of fruit falls into this category. Using packinghouse data, the amount of fruit downgraded due to an untreated thrips infestation can be as high as 95%. On average, losses due to thrips damage reduced revenues by 12% in 1998 (CAC 1998).

In an attempt to prevent large losses in revenue, growers may treat groves with one of the three insecticides recommended for use against avocado thrips. During 2001, abamectin was the most commonly used insecticide, followed by spinosad, then sabadilla. Usually, growers used only one application of an insecticide to control avocado thrips. If they made more than one application, it was typically different from the first insecticide sprayed. As recommended by IPM professionals, insecticides are alternated to prevent the development of pesticide resistance in avocado thrips.

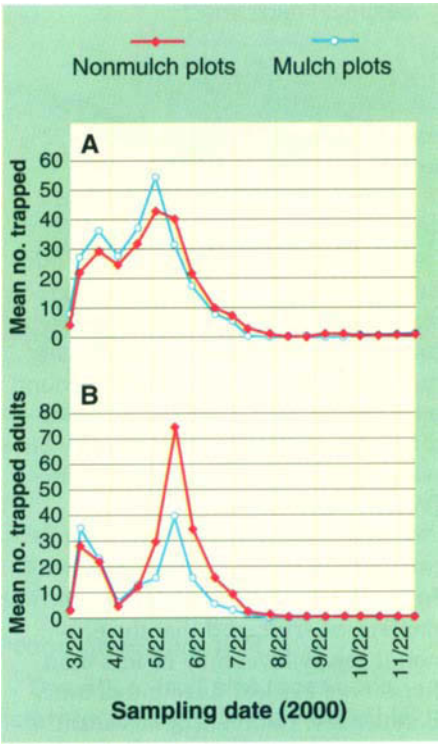

Fig. 2. Mean numbers of (A) avocado thrips larvae trapped on tops of clear sticky panels in thrips emergence boxes, after they fall out of tree canopy to pupate, and (B) mean numbers of adult thrips trapped on undersides of clear sticky panels in thrips emergence boxes, following emergence from composted mulch or leaf duff.

The control costs reported in this study were those incurred by a typical California avocado grower in 2001. Individual costs vary depending on the grower's situation. Abamectin was usually applied to avocados by helicopter with 1% to 2% NR-415 oil added to move the insecticide into the leaf. The total cost of the insecticide, oil and application was approximately $180 per acre per treatment. Treating avocado thrips eliminates economic damage for some growers, but only reduces the level of severity for others. With insecticide treatments, revenue losses from reduced fruit quality were approximately 3% (CAC 1998). Using a 3-year (1994 through 1997) average for grower revenues before avocado thrips infestations occurred, downgrading reduced revenues by an estimated $145 per acre after the pest became established in California. The total increase in grower costs was

"The establishment of exotic species in California agro-ecosystems weakens implemented IPM programs . . ."

equal to treatment costs ($180 per acre) plus losses associated with downgrading ($145 per acre), for a total of $325 per acre. Based on budgets developed by UC Cooperative Extension and the California Avocado Commission, grower costs increased by about 8% with avocado thrips populations that required management (USDA 1999).

The impact on the avocado industry depends on the extent of the thrips infestation and grower adjustments to the infestation over time. Not all growers will have an avocado thrips infestation that causes economic losses. Growers within 10 miles of the coast were more likely to suffer problems than growers farther inland, where the marine influence does not moderate the hot summer temperatures that cause pest population crashes. To the extent that higher costs are passed on to consumers, growers without an infestation of avocado thrips are better off, because they receive higher prices without incurring higher production costs.

It takes time for an industry to adjust to a new exotic pest problem. Therefore, short-run losses are greater than losses over the long term, after growers adjust to changes in cost and market prices. In the short run, the annual cost of avocado thrips to the avocado industry is estimated to be $12 million to $14 million. In the long run, it is estimated at $8 million to $11 million per year.

Managing a new exotic pest

The establishment of exotic species in California agro-ecosystems weakens implemented IPM programs and requires agricultural industries to rapidly develop or modify and adopt new IPM programs to manage new invasive pests within the context of existing pest complexes. Our work in developing an IPM program for avocado thrips in California is multifaceted, consisting of several concurrent research programs that have simultaneously investigated biological, cultural and chemical control. Economic analyses have quantified the detrimental fiscal impact of avocado thrips on avocado production in California. The rapid deployment of cooperative research and extension efforts, composed jointly of industry support, UC Agricultural Experiment Station personnel and Cooperative Extension personnel, has allowed the development of an IPM program to meet a new pest challenge facing California's 6,000 avocado growers.

Work is continuing on identifying natural enemies of avocado thrips in its home range for possible importation into California. We will be investigating the effect that pruning schedules and fertilizer applications have on flush and fruit-setting patterns and subsequent thrips damage to developing fruit. Cultural manipulations combined with natural enemies and carefully timed applications of selective insecticides may reduce grower reliance on pesticides for controlling avocado thrips, thereby promoting sustainable avocado production in California.

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The researchers scoured Mexican and Central American avocado orchards for natural predators of avocado thrips. They found the predatory thrips *Franklinothrips orizabensis, left* (larva) and *right* (adult). Also native to California, this predator is now being reared and tested as a possible biological control agent.

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Scientists have recently characterized a disease first seen in 1986. Two Tulare County plum orchards succumbed to bark necrosis and stem pitting; tests confirmed a graft-transmissible agent. Symptoms include chlorotic ring spots, which were induced on 'Shiro' plum.

NEW PESTS and PLANT DISEASES

Graft-transmissible agent causes bark necrosis and stem pitting in plum trees

Diana B. Marini ■ Adib Rowhani ■ Jerry K. Uyemoto

In two Central Valley plum orchards, nearly all the trees started exhibiting copious amounts of dark gumballs on scaffold branches and main trunks. Exposed bark showed extensive tissue necrosis and necrotic stem-pitting on the surface of the woody cylinders. Eventually, both orchards had to be removed and replanted. The symptoms were highly suggestive of a viral or viruslike disease agent. We began studies to characterize the pathogen associated with the failure of these orchards and were successful in associating the disease with a new virus that proved to have an extensive host range in many cultivated Prunus. *Characterization of this virus is under way.*

IN 1986, young 'Black Beaut' plum trees in two orchards in Dinuba (Tulare County) showed bark necrosis and gummosis on scaffold branches and the main trunk, and the woody cylinders were severely pitted. The disease was given the trivial name plum bark necrosis–stem pitting (PBNSP). The infectious nature of PBNSP was confirmed by graft-transmission assays performed at UC Davis (Uyemoto and Teviotdale 1996).

This situation occurred because scions of 'Wickson' plum (used as pollenizers) — that appeared to be healthy, but were in fact infected — had been whip grafted on every second-leafed 'Black Beaut' tree. All the grafts failed, but the disease agent was, nonetheless, transmitted into the trees.

Apparently, 'Wickson' plum is a symptomless host of the disease agent. Several *Prunus* species are grown commercially in California and others are used as virus disease indicators in the California Fruit and Nut Tree Registration and Certification Program (R&C Program). We were interested in determining host responses to this particular disease agent and providing descriptions of the symptoms. The hope is that our work will prevent further occurrences of the disease and provide diagnostic information to growers and advisors.

Test plant cultivars included:

- **Fay Elberta and GF 305 peach** *(P. persica)*
- **Bing and Mazzard cherry** *(P. avium)*
- **Colt cherry** *(P. avium x P. pseudocerasus)*
- **Shirofugen flowering cherry** *(P. serrulata)*
- **Mission almond** *(P. dulcis)*
- **French-Improved and Stanley plum** *(P. domestica)*
- **Angeleno, Black Amber, Black Beaut, Casselman, Friar, Laroda and Shiro plum** *(P. salicina)*

The authors tested a variety of plum cultivars for susceptibility to plum bark necrosis–stem pitting disease. A diseased 'Black Beaut' plum tree in bloom, 2 years after infection.

Bark necrosis and gummosis of scaffold branches.

Disease symptoms on tree trunk.

Stem-pitting symptoms. Note remnant of grafting tape used to secure 'Wickson' scion piece. When the whip graft failed, a subtending 'Black Beaut' bud developed a shoot.

At UC Davis, we evaluated the responses of several *Prunus* species and varieties to infections by the PBNSP agent (see box). Two or three trees per variety were graft-inoculated in September 1997, with multiple bark tissues or peach bud chips. Trees that were not grafted served as healthy controls. The source of the PBNSP inoculum was diseased 'Black Beaut' plum trees on 'Nemaguard' peach rootstock, which produced numerous sucker shoots. The tree was located at UC Davis.

Disease symptoms induced

Following a 6-month incubation, chlorotic (yellow) ring spots were evident on young expanded leaves of 'Colt' cherry trees during spring growth. A year later, chronic symptoms consisting predominantly of light green or water-soaked marks developed along the leaf midrib. In other test plants, after 12 months of incubation, leaf symptoms on 'GF 305' peach and 'Casselman', 'Laroda' and 'Shiro' plums included chlorotic rings, chlorotic mottling and line patterns.

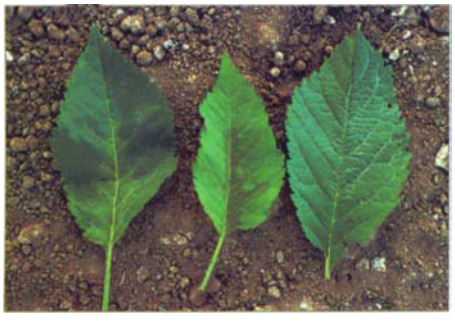
In the plum varieties 'Angeleno', 'Black Beaut' and 'Friar', gummosis (formation of gumballs) and bark necrosis (die-off of bark) begins in the second season after inoculations. Symptoms become more evident and severe in the third year. Wood markings intensified during the third growing season. There were no leaf symptoms on these plum varieties.

In contrast, latent (symptomless) infections occurred in 'Fay Elberta' peach; 'Shirofugen', 'Bing' and 'Mazzard' cherries; and 'Black Amber' and 'Stanley' plums. The trees

Dead 'Wickson' scion (white paint) and bark necrosis on 'Black Beaut' plum.

Several different types of leaf symptoms were identified on diseased trees. Leaf with chlorotic mottle on 'Shiro' plum.

Chlorotic ring spots on a leaf of 'Colt' cherry, after a 6-month incubation.



***Left and center,* Leaves of 'Colt' cherry with light green and water-soaked marks along midrib, second year after inoculation. *Right,* A healthy leaf.**

Leaf with line-pattern symptoms on 'Laroda' plum. Similar symptoms developed on 'Shiro' plum (not pictured).

were found positive by reverse transcriptase–polymerase chain reaction (RT-PCR) assays. 'French Improved' plum was apparently resistant to the causal agent. All healthy controls appeared normal.

With the single exception of 'French Improved' plum trees, virus infections in all of the other graft-inoculated test plants, with and without leaf or bark-stem symptoms, were positive. Healthy plants were found negative in a laboratory assay (such as RT-PCR) developed specifically for the associated disease agent.

Bark scraping from only symptomatic 'Colt' cherry trees yielded purified preparations of double-stranded ribonucleic acid (dsRNA). After electrophoresis in 6% polyacrylamide gels, the dsRNA preparations revealed a banding pattern similar to that reported for members of the *Closterovirus* group. Knowing this, we used purified preparations as templates for RT-PCR using degenerate primers designed specifically to detect the heat shock protein 70 (HSP70), a conserved gene found in *Closterovirus* (Tian et al. 1996).

When the reaction products from RT-PCR assays were evaluated using electrophoresis in 1.5% agarose gel, the presence of two DNAs was evident (Marini et al. 2002). The DNA bands were extracted and purified from the agarose gel and cloned, and desired DNA pieces were sequenced at the DNA Sequencing Facility at UC Davis. The purification and cloning process followed the manufacturer's procedures that were supplied with standard kits.

Based on sequence information obtained, we designed new primers, and the primer combination yielded a specific product (541 bp [base pair]-size DNA) that was used in all RT-PCR assays of test plants.

Likely agents

In a previous publication, the PBNSP-associated virus was designated as PBNSPaV (Marini 1999). Absolute establishment of the causal relationship between PBNSPaV and disease symptoms in 'Black Beaut' plum would require fulfillment of Koch's postulates, often a difficult task in woody perennial plants such as *Prunus;* accordingly, Koch's postulates require the scientist to isolate and identify the agent, back-transmit the agent and produce the same disease on inoculated plants, and reisolate and reidentify the same agent. Nonetheless, the consistent association of the putative agent and PBNSP trees is highly suggestive of cause and effect. These observations suggest that 'Wickson' plum, like 'Black Amber' and 'Stanley' plums, may be regarded as another latent host for PBNSPaV.

At this time, the discovery of the *Closterovirus* PBNSPaV in stone fruit species can be regarded as something of a rarity. In the literature, only three others (*Little cherry virus* [LChV]-1, -2, -3)

Stem-pitting symptoms on 'Black Beaut', *left,* and 'Friar' plums, *third and fourth from left. Second and fifth from left,* Healthy 'Black Beaut' and 'Friar', respectively, third year after inoculation.

have been reported and all were found exclusively in cherry trees in Canada and Germany (Eastwell and Bernardy 2001; Rott and Jelkmann 2001). Sequence comparisons of the HSP70 gene revealed only 44% similarity between PBNSPaV and LChV-1, suggesting that these viruses are distinct and unrelated.

The extent to which PBNSPaV exists in California's stone fruit and nut orchards is not known. Nevertheless, widespread occurrence is not expected because 'Shiro' plum is routinely used as a standard indicator for *Prunus* virus diseases in the R&C Program. The presence of PBNSPaV in source trees destined for propagation purpose would be easily detected and avoided. Our research determined that 'Shiro' plum is a sensitive indicator for the putative agent that causes PBNSPaV disease.

Gummosis on tree of 'Friar' plum, second year after inoculation.

'Shiro' plum is a standard indicator used in the clean stock program; it was originally selected because of its sensitivity to diseased sources infected with line pattern–inducing agents, some of which are identified while others remain unidentified. Several unrelated viruses can cause line-pattern symptoms in 'Shiro'. For example, in addition to American and Danish line-pattern viruses, we have associated line-pattern symptoms with a plum isolate of *Prunus necrotic ring spot virus* (Uyemoto, unpublished data). Nonetheless, in order to minimize serious virus-disease outbreaks in commercial orchards, growers should always request certified propagation materials identified in the R&C Program. This will to help ensure that virus-tested sources are collected and used in their orchards.

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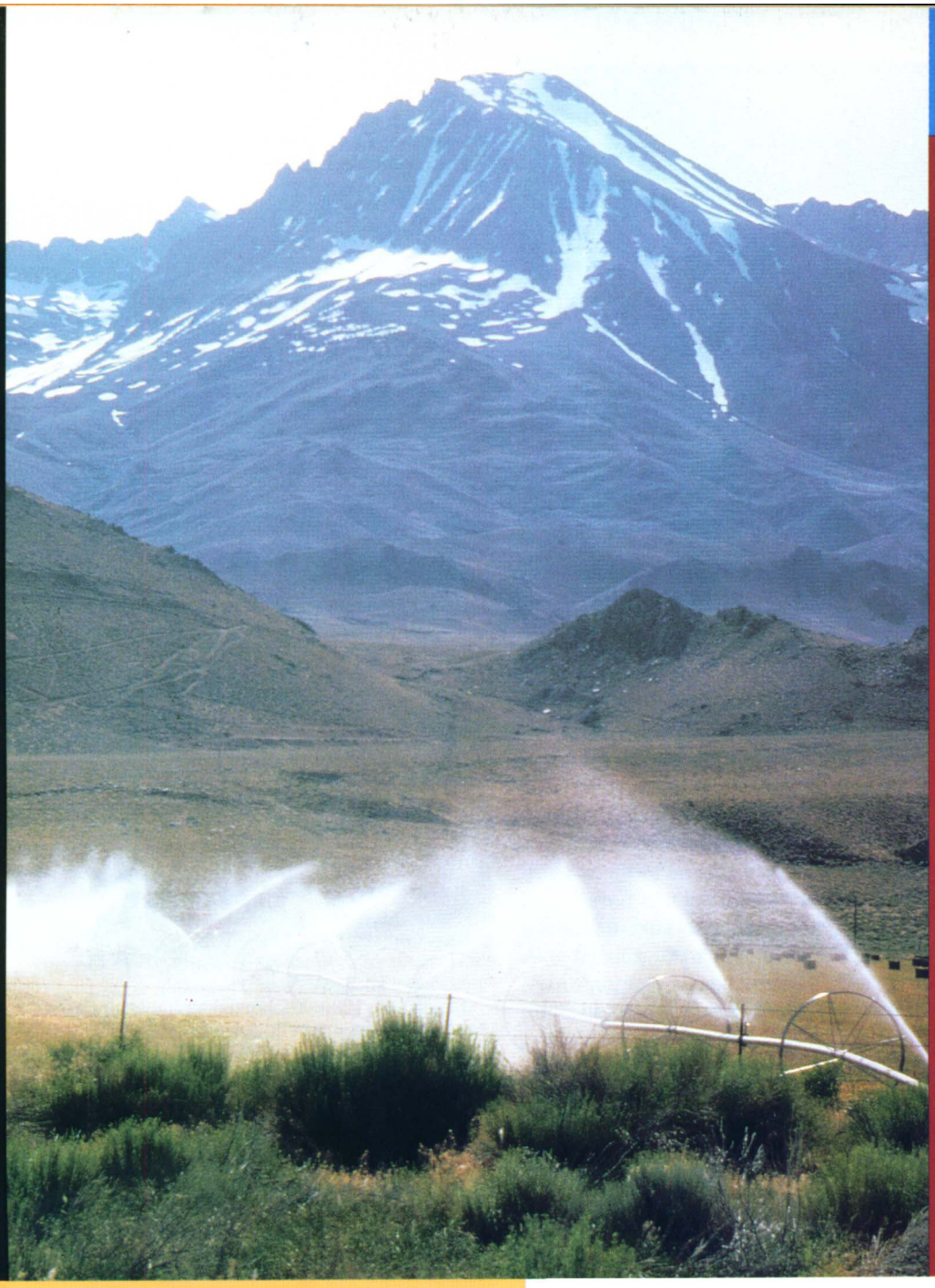

NEXT ISSUE

Improving irrigation efficiency

Agriculture currently uses between 75% and 80% of California's developed water supply, on about 9 million irrigated farmland acres. While irrigation has made California a world agricultural leader, there is perpetual competition for limited water supplies among urban, residential, environmental and agricultural users. California growers face mounting pressure to reduce the proportion of the state's water that they use. In the July-August issue of *California Agriculture*, scientists explore some of the ways that growers and others can improve the efficiency of water use, including using reclaimed irrigation water on landscape plants, irrigating garlic properly, saving energy at pumping plants, and utilizing water management to control pistachio diseases.

Also in the July-August 2002 issue:

African Americans and diabetes

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