JPL's TOPEX/POSEIDON STUDIES THE OCEAN

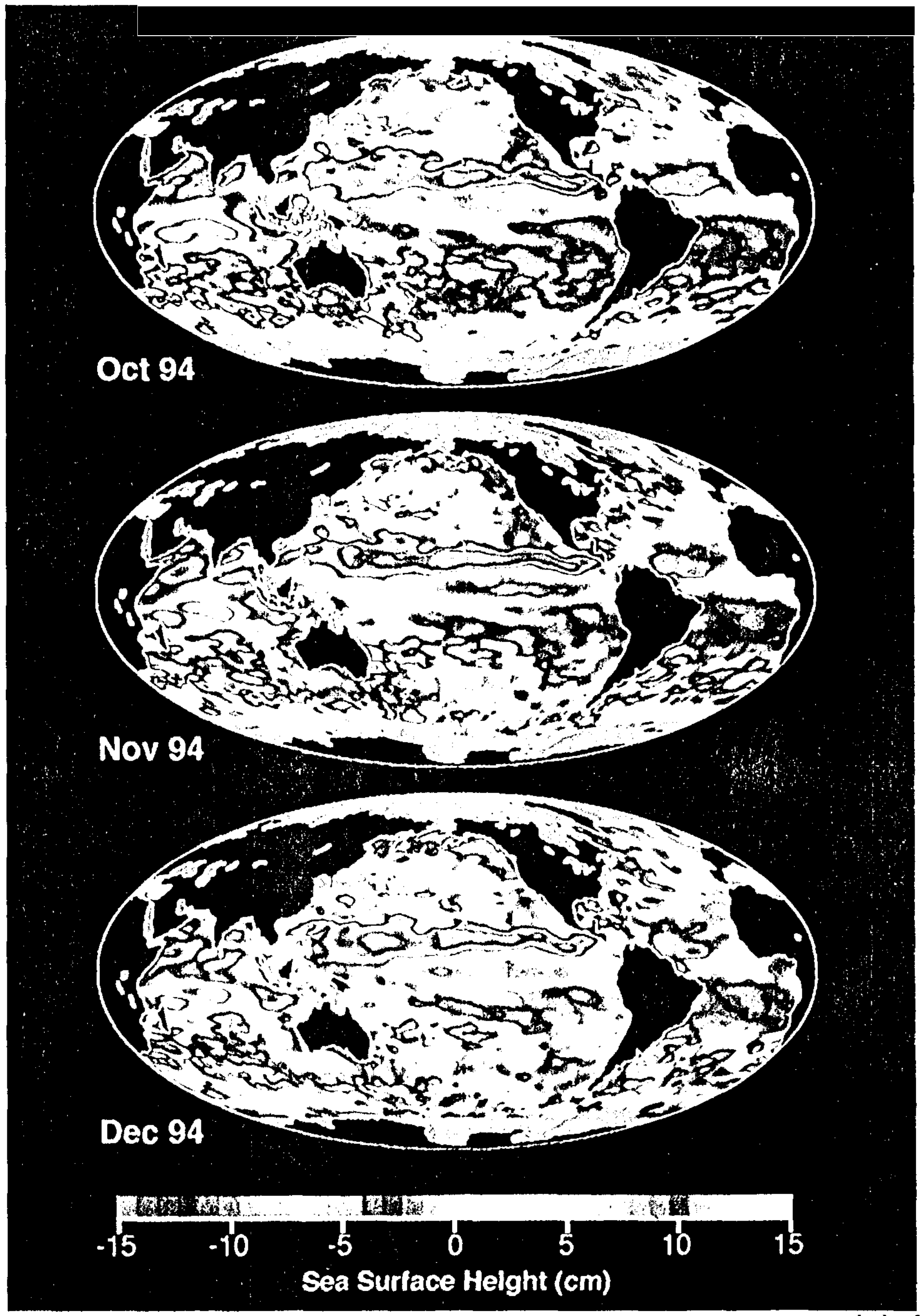
(And may help explain the rain)

by Kent Frewing

La Cañada Flintridge's Jet Propulsion Laboratory (JPL) is best known for exploring planets in our solar system hundreds of millions or even billions of miles from Earth. But a little-known joint JPL/French satellite called Topex/Poseidon, in orbit around our own planet, is producing just as exciting information about how Earth's oceans behave, what their effects are on our climate, and what the long-term impact of human activity on our planet might be. Even though it is studying our own planet instead of a mysterious distant one, the science from Topex/Poseidon is exciting, the engineering that enables it to detect ocean height changes of one-eighth inch per year is revolutionary, and the practical consequences of its results for us, our children and grandchildren are enormous.

Between December 1992 and September 1994, Topex/Poseidon has detected a one-eighth inch per year increase in average sea level over the entire planet. This is consistent with tide gauge measurements scientists have been making around the world for the last century. Tide gauges, which are subject to inaccuracies caused by their sparseness around the planet, by land elevation changes, and by the constant shifting, of the European and North American land masses by as much as an inch per year, show an increase in sea level of 0.04 to 0.08 inch per year.

in addition, Topex/Poseidon has detected a "Kelvin Wave", which is an indication of an "El Niño" current of warm tropical water across the Pacific Ocean. The El Niño is one of the factors which has shifted the Pacific jet stream south, thereby bringing rain to



"Topex/Poseidon measurements of ocean heights show a "Kelvin Wave" (red color) of higher elevation across the tropical pacific last year, implying an "El Niño" condition of warmer water. "

California instead of to the Pacific Northwest, and causing the temperate winter of the Eastern Seaboard. This winter's El Niño was detected from October through December 1994, is stronger than that of the winter of 1992-1993, and probably dissipated by January or February of this year.

Topex/Poseidon's detection of the sea-level rise thus raises the question of whether this could be caused by a warming Earth causing pol:: ice to melt and increasing the volume of the oceans, or whether this small change is just a random short-term fluctuation. For several years, scientists who model the atmosphere using programs called "general circulation models" (GCMs) on supercomputers, have predicted that the Earth will warm by something between 3 degrees Fahrenheit (deg F) and 8 deg F during the next century because of a doubling of carbon dioxide and an increase in other human-generated "greenhouse" gases dumped into the atmosphere since the industrial revolution. They argue that this could warm the Earth, change the planet's climate, disrupt agriculture, melt the polar ice caps and thereby cause ocean levels to rise, and cause a greater rate of species extinction. Thirty-eight years ago, Roger Revelle and Hans Suess of the Scripps Institution of Oceanography pointed out that we are conducting an unprecedented experiment on the Earth, observing the effects of human activity on the planet over a very short period of time. But this concept is not without controversy. Other scientists and political leaders believe that there is no need to be alarmed, or even to study Earth's environment for signs of adverse effects from human activities. They feel that for billions of years the planet has been able to adapt to major changes in geology, weather and temperature, so why should a few billion humans and our economic activities be able to make any significant long-term changes? Besides, changing our habits would be prohibitively expensive, and would disrupt the economies of all the nations of the world. Many argue that it isn't even necessary to spend a little on "insurance" to develop alternate technologies that could be useful if it turns out that humans are causing adverse changes to the planet.

No one disputes the fact that a greenhouse effect exists. In fact, it is

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what makes our lives on Earth possible. At our distance from the sun, a bare planet would have a temperature of about zero deg F, so it would be a world in deep freeze. Earth's average temperature, however, is just under 60 deg F, and it is a greenhouse effect, caused by gases such as water vapor, carbon dioxide, methane (natural gas), and chlorofluorocarbons (Freon refrigerants and propellants) that causes this warming to a life-permitting temperature. Most of the greenhouse effect is caused by natural gases such as water vapor from evaporation, carbon dioxide from plant and animal respiration, and methane from normal growth and decay. Just like the glass in a greenhouse, these gases permit light near 0.00004 inch in wavelength to penetrate to the Earth's surface and warm the planet. But heat radiated to space from Earth's warm surface is blocked by these same gases because they absorb the heat, which is radiated at much longer wavelengths: about 0.0006 inch. The absorbed heat thus warms the atmosphere in which the absorbing gases are carried.

Although there is no disagreement about the existence of a greenhouse effect, there is considerable dispute about whether human activity can influence it enough to cause dangerous consequences. Some of the questions being asked are:

- How, where, and how much greenhouse gases are generated?
- How much of the greenhouse gases are absorbed by plants and by oceans?
- What effects do clouds have on possible warming, since they reflect the sun's energy and could lower the Earth's temperature?
- How fast will the oceans warm if the atmosphere warms gradually?
- won't volcanic ash and industrial dust particles block some of

the sun's **energy** so that this adds to the planet's cooling?

• Will the polar ice caps start to melt, thereby **exposing** more **dark** absorbing ground and causing even more heating?

• Will thawed polar tundra and warmer temperate anti tropical wetlands produce even more methane, thereby causing an even more accelerated warming?

Recent studies suggest that, over very large geological time periods, greenhouse gas concentrations have varied with temperature in the way scientists' models predict; anti they have changed in about the amounts that the models predict. Furthermore, these same analyses show temperature variations in both directions; that is, when Earth's temperature has increased, greenhouse gas concentrations have also increased; and when temperatures decreased, greenhouse gases decreased. These studies have been conducted both in the Cretaceous, about 100 million years ago when dinosaurs lived, and in the much more recent last ice age., about 18,000 years ago. During the Cretaceous, temperatures were about 18 deg F hotter than today, while during the last ice age temperatures were some 5 deg F to 9 deg F colder, and sea level was sonic 330 feet below (hat of today. These studies don't indicate whether the change in greenhouse gases caused the change in temperature, but they do account for most of the uncertainties surround ing today's models, since the data were generated from a real Earth, with real clouds, oceans and volcanos.

Data taken over the iast century indicate that carbon dioxide has increased about 25% from pre-industrial times: from about 295 parts per million to 370 parts per million. This 25% increase is expected to be followed by a doubling over the next century. Computer models, and the data from past geologic times, imply that, with that doubling, Earth's average temperature

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will increase by something from 5.4 deg F to 7.2 deg F. This is about the same increase that has occurred since the last ice age, but human activities are driving it a hundred times faster.

But how is Topex/Poseidon able to measure an increase in sea level of one-eighth inch per year, or to see the small change in elevation of an "El Niño" ocean current, when everyone knows that waves and breakers can vary five to ten feet or more in elevation in just a few seconds. The answer is that scientists average the data over many orbits (many days or weeks) to get a very accurate average elevation at every point beneath the spacecraft. To determine the oceans' effects on Earth's climate, Topex/Poseidon measures the sea level beneath the spacecraft with respect to the center of mass of the planet. Its six sensors can predict ocean tides to about one inch accuracy. The elevations of Earth's oceans vary by hundreds of feet due to both variations in gravity over the surface of the planet, and due to winds and other forces acting on the large bodies of water. The variation due to gravity alone is about 525 feet in elevation difference. Topex/Poseidon scientists subtract this "gravitational topography" from the total height of the sea surface with respect to the center of mass of the earth to get the "dynamic topography", or the amount of ocean surface height change due to winds and currents. This ocean height due to dynamic effects varies by about six feet in elevation over the entire surface of the planet, with high elevations in the Pacific and Indian oceans, and lows near the poles. For instance, these elevation changes permit scientists to see the Gulf Stream circulating clockwise around the north Atlantic Ocean. They can also infer how much heat is stored

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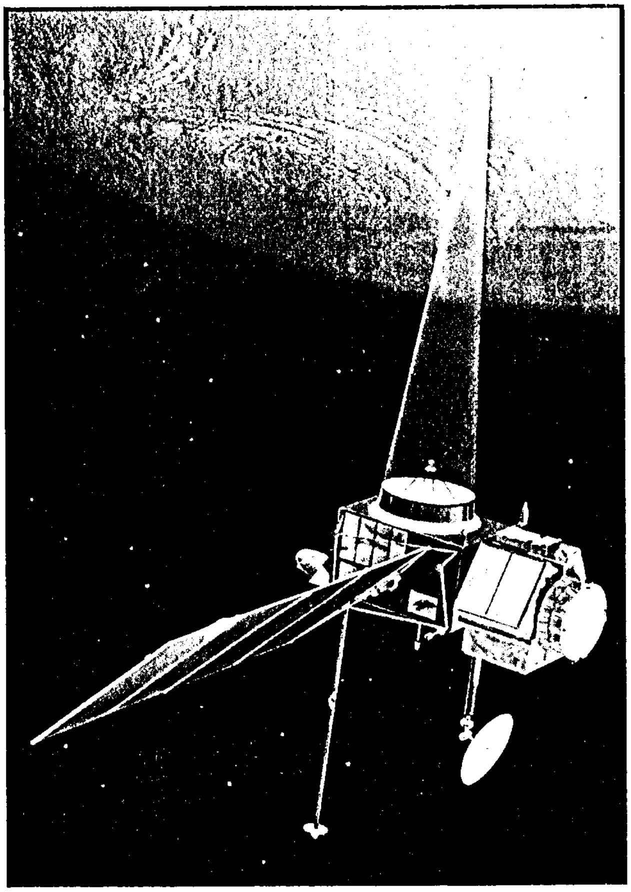
in the upper ocean and the speed and direction of ocean currents by measuring high and low ocean levels, just as weather forecasters predict atmospheric winds by sensing high and low barometric pressures.

Launched on August 10, 1992 from Kouru, French Guiana in South America, Topex/Poseidon is a joint project between NASA and the French space agency, Centre National d'Etudes Spatiales (CNES). Part of NASA's "Mission to Planet Earth", it has been spectacularly successful in meeting its original purpose of gathering data to help determine how ocean circulation affects the Earth's climate. During its flight Topex/Poseidon is monitored by JPL, and is in a circular orbit around Earth at an elevation of 830 miles and at an angle of 66 degrees to the equator. It completes one orbit about the planet every 112 minutes so that it is able to map 95% of the ice-free oceans every 10 days, when it returns over the same spot within an accuracy of about 1 000 yards and starts the 10-day mapping cycle once again. Some 200 scientists from 11 nations comprise the international teams that analyze Topex/Poseidon's data and develop the ocean maps showing changes in elevation, temperature, and currents.

Planning for Topex/Poseidon started in 1983. The spacecraft was build for JPL by the Fairchild Space Corporation of Germantown, Maryland. The French space agency provided two of the six instruments, plus the Ariane launch rocket and all the launch facilities in French Guiana. The spacecraft is about nine feet on an edge, eighteen feet long, and weighs



"Artist's conception of Topex/Poseidon Spacecraft measuring ocean heights"

5500" pounds. A single eleven-foot- - 29-foot solar panel "wing" provides the 21 ()() watts it takes to operate the instruments and communicate the data to ground stations through NASA's "Tracking and Data Relay Satellite System". Topex/Poseidon carries six instruments: four from NASA and two from the French CNES. Two of the instruments do the actual measurement of sea surface elevation, aided by a third which measures atmospheric water vapor to calibrate the elevation-measuring instruments to within 0.4 inch. (Water vapor can interfere with the elevation measurements by affecting the radar signals travelling between the spacecraft and the ocean.) The three position-measuring instruments are: (1) a set of NASA laser reflectors, plus twelve laser ground transmitting and receiving stations which permit locating the spacecraft to an accuracy of 0.8 inch; (2) a NASA demonstration "Global Positioning System" (GPS) receiver which is an experiment in high accuracy satellite location; and, (3) a CNES Doppler tracking receiver, plus 40 to 50 ground transmitting stations, which use the change in radio frequency caused by the satellite's motion with respect to the ground stations to determine its velocity and position, and to calibrate the radar altimeters for effects caused by transmitting through the Earth's ionosphere, which is full of charged particles. The two elevation measuring instruments are two radar altimeters: a two-frequency altimeter from NASA (the two frequencies also help calibrate the instrument for ionospheric charged particle effects) and a single-frequency CNES altimeter.

Topex/Poseidon is scheduled to be a three-year mission, ending in September 1995, with the possibility of an extended mission for another three years. The spacecraft may have enough fuel (attitude control gas to keep the solar panel pointed toward the sun so that its electrical power needs are met) for ten years. Because it will take decades to determine whether human activities are altering the planet's climate in dangerous ways, what is really needed is a series of Topex/Poseidon spacecraft, launched every few years, so that we have continuous data, and can get an early warning, like that provided by a miner's canary, of threatening changes in Earth's atmosphere and oceans that might affect the lives of our descendants and of all other species.