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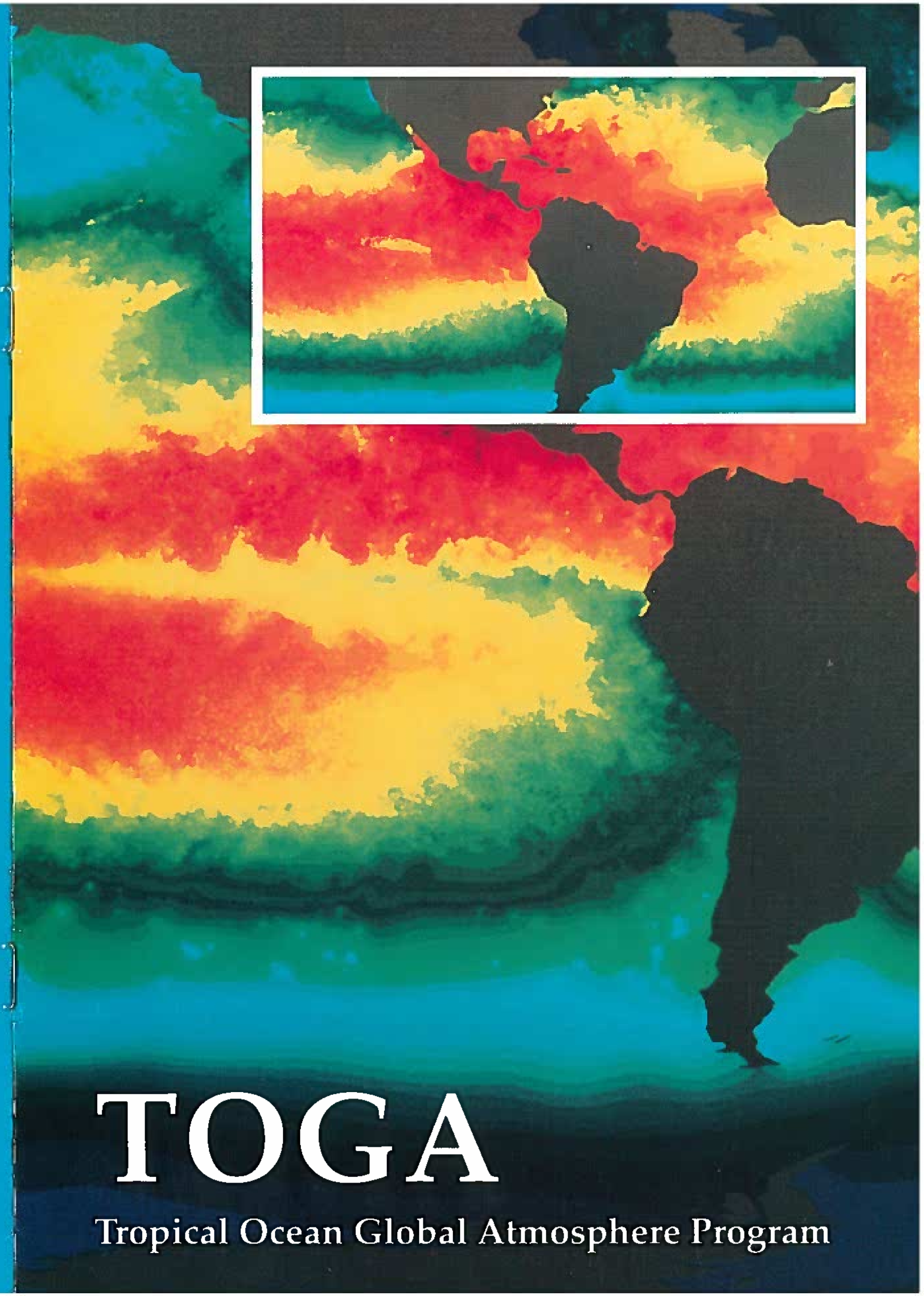
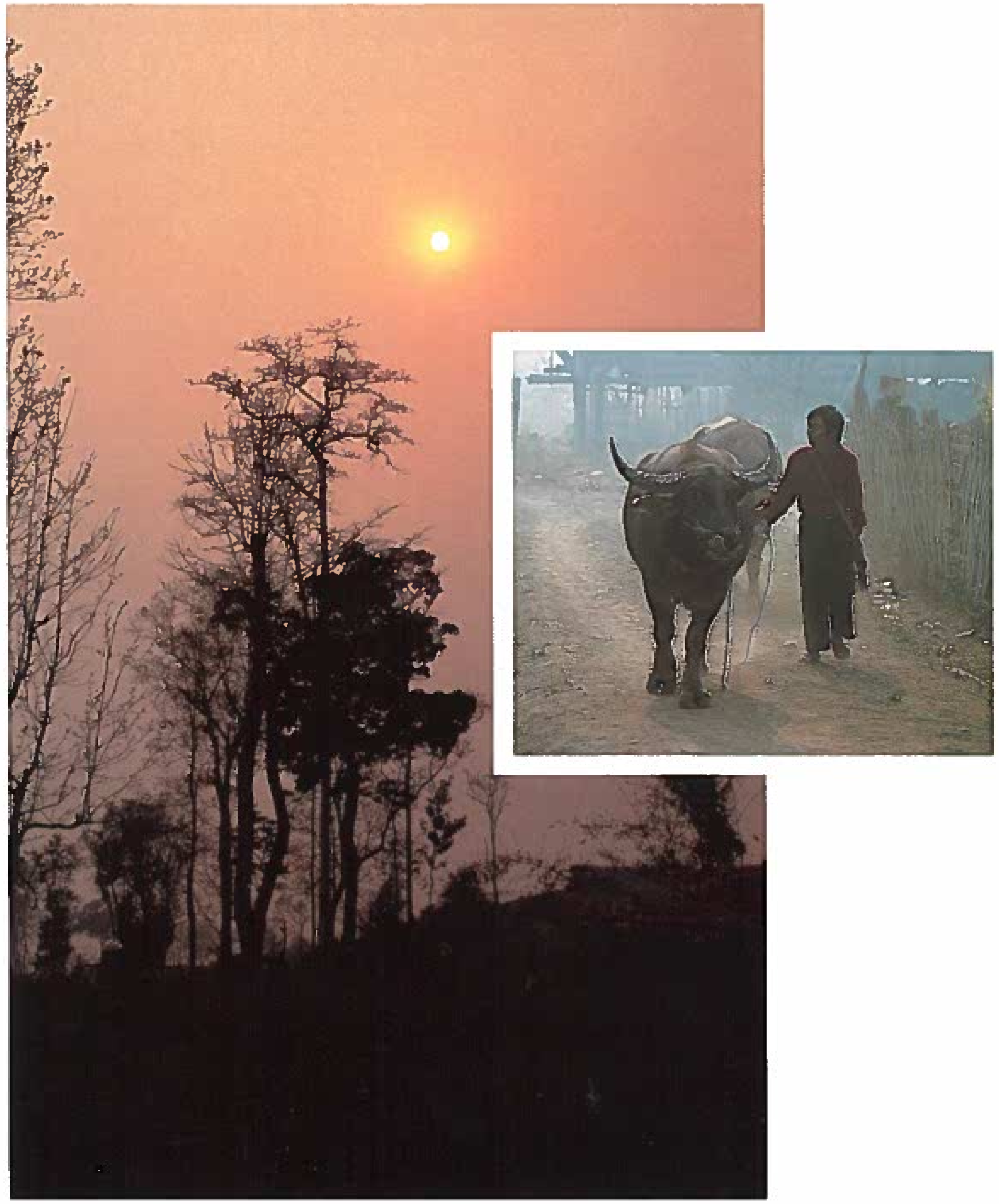


TOGA

Tropical Ocean Global Atmosphere Program



Drought and fires affected Southeast Asia during the El Niño of 1982-83.

Cover: *Sea-surface temperature from satellite during normal conditions (June 1984). Inset shows the sea-surface temperature during an El Niño (June 1983). Note the changes in the eastern equatorial Pacific, and along the coast of South America.*

INTRODUCTION

Consider the following situation. You are an advisor for agricultural interests in northeast Brazil. The amount of rainfall in this region varies substantially from year to year, and a great deal of benefit would result if you could provide reliable forecasts for precipitation during the upcoming season. You know that forecast models are predicting that a significant warming of the sea surface temperature will occur in the central and eastern tropical Pacific, an event termed "El Niño." Measurements in the tropical Pacific also confirm that the sea-surface temperatures are beginning to rise, and that measurements of ocean currents, low-level winds, and sea-level pressure indicate a continued increase. On many occasions in this century, El Niños have been accompanied by droughts in northeast Brazil, but you know that the short-term climate in your region also seems to be influenced strongly by the sea-surface temperatures in the tropical Atlantic Ocean, and that the association between the local climate and El Niño is complex. Should you recommend action in anticipation of drought for the next growing season?

The preceding scenario is fictional but not fanciful. It illustrates our increasing , but still inadequate, understanding of the tropical atmosphere-ocean system, and our growing ability to monitor and predict changes in this system. It also illustrates that we cannot yet totally specify all of the important effects that the tropical oceans have on the world climate. However, three different experimental prediction models have demonstrated our ability to forecast a real event, the 1986-87 El Niño. We were also able to observe the evolution of this event as it developed, in 'real-time.' In addition, there were global climate anomalies during the winter of 1986-87, such as drought in the southwestern United States and unusually wet weather in the southeastern United States, but these anomalies cannot necessarily be attributed to conditions in the tropical Pacific.

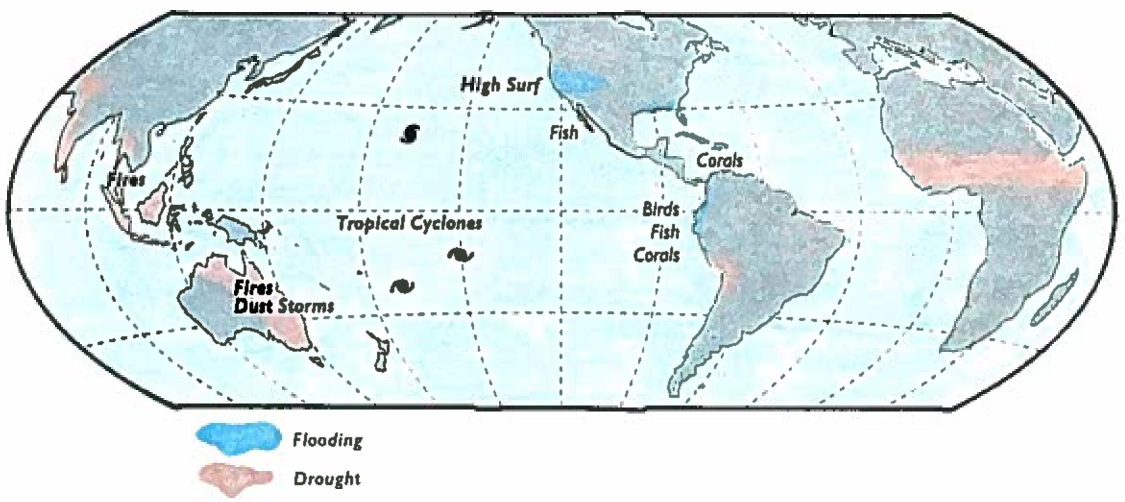
Dramatic climate effects were experienced world-wide in 1982-83 during the strongest El Niño of this century. These effects were not limited to the weather. The marine ecosystem in the central and eastern equatorial Pacific experienced the most direct consequences of the El Niño, such as the migration southward of the coastal fisheries to avoid the warm water. This resulted in a transfer of economic strength from Peru to Chile.

One of the most dramatic earlier consequences was the catastrophic collapse of anchovy stocks off the coast of Peru due to the El Niño of 1972-73. The resulting overfishing caused repercussions throughout world commodities markets.

Important indirect or secondary effects have been noted in other locations world-wide. For instance, during the 1982-83 El Niño, there were huge drought-related fires in Borneo and Australia, drought-related eradication of sea-bird populations on islands in the Pacific, drought-related famines in India and east Africa, and flooding on the east coast of equatorial South America, in the Rocky Mountain region of the United States, and in Brazil south of the equator.

In many parts of the world, the disruption of normal climate can have tragic consequences. Unfortunately, the regions in the tropics that appear to be most sensitive to these climate changes, such as the Sahel in Africa and the regions of Asia dependent on monsoon rainfall, have economic and social infrastructures insufficiently resilient to withstand these stresses. Better predictions will help us compensate for, and alleviate, some of these effects.

The Effects of the El Niño of 1982-83



Vegetation on normally-bare lava in the Galapagos Islands during the El Niño of 1982-83, due to increased rainfall.

Rare tropical cyclone damage in Tahiti due to redirected storm-tracks.

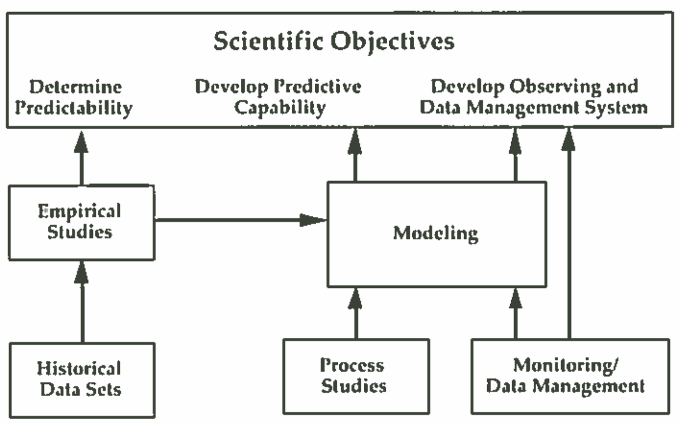
High river runoff in the central United States during an El Niño event.

The TOGA Program

In order to understand better the tropical ocean/atmosphere system and its effect on the climate at higher latitudes, the *T*ropical *O*cean and *G*lobal *A*tmosphere (TOGA) Program was initiated in 1985 by the United Nations' World Meteorological Organization (WMO), with contributions from 16 nations. TOGA, a major component of the WMO'S World Climate Research Programme, has been effective in bringing together the international scientific research community to work on problems of global significance. In addition, the national weather services and national ocean services of the participating countries have been heavily involved in the implementation of TOGA.

TOGA has four major objectives:

- To collect and catalog observations of the tropical atmosphere and ocean,
- to assess the evolution of the tropical atmosphere/ocean system in real-time,
- to promote the development of short-term climate-prediction computer models for the tropics, and
- to study the influence of the tropical atmosphere/ocean system on the climate at higher latitudes.

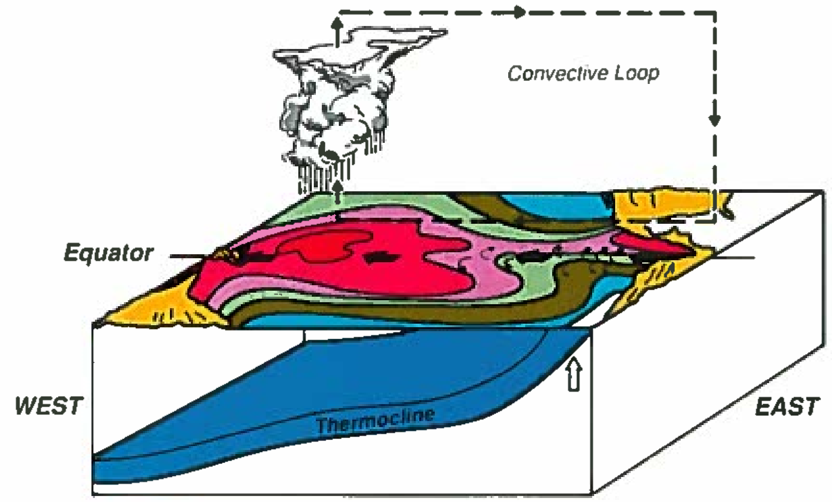


Due in large part to TOGA, we now have an observing system that can monitor important changes in the tropical oceans in real-time, using satellites, island weather stations, and moored and drifting buoys. Because of the importance of the El Niño, the Pacific basin has been emphasized. These observations are crucial for providing the initial and boundary conditions for computer-based model forecasts of the tropical climate system, and for verifying the results of predictions made using those models.

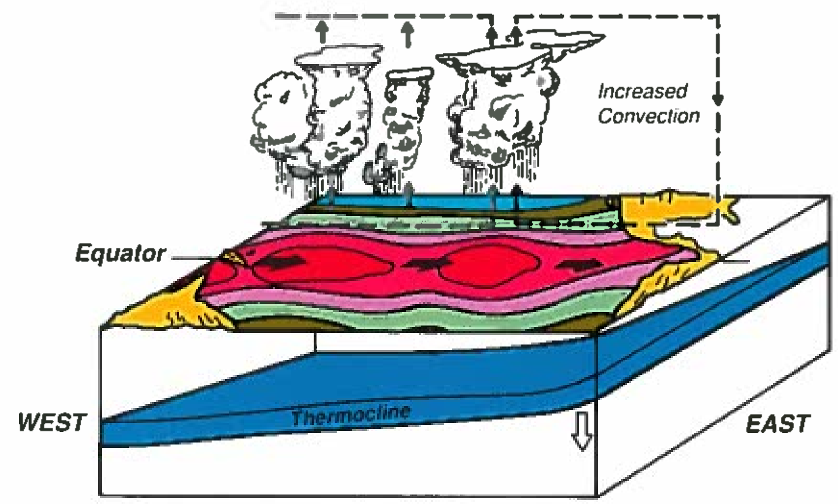
El Niño - Structure and Prediction

Remarkable differences are observed in the tropical Pacific during normal- to-cool conditions as compared with warm El Niño events. In the normal situation, *very* warm sea-surface temperatures are found only in the western Pacific Ocean. The thermocline, a thin boundary-layer separating warm, well-mixed, near-surface water from the colder water below, is shallow in the east and relatively deep in the west. During warm events, this pool of warm water expands into the central Pacific and the thermocline becomes less steeply sloped. Higher-than-normal ocean temperatures also occur in the eastern Pacific and along the coast of South America.

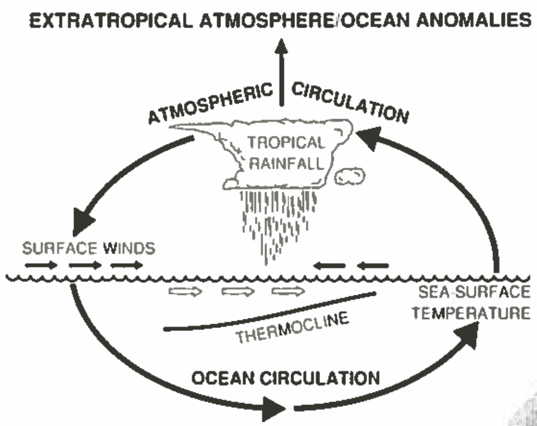
Normal Conditions



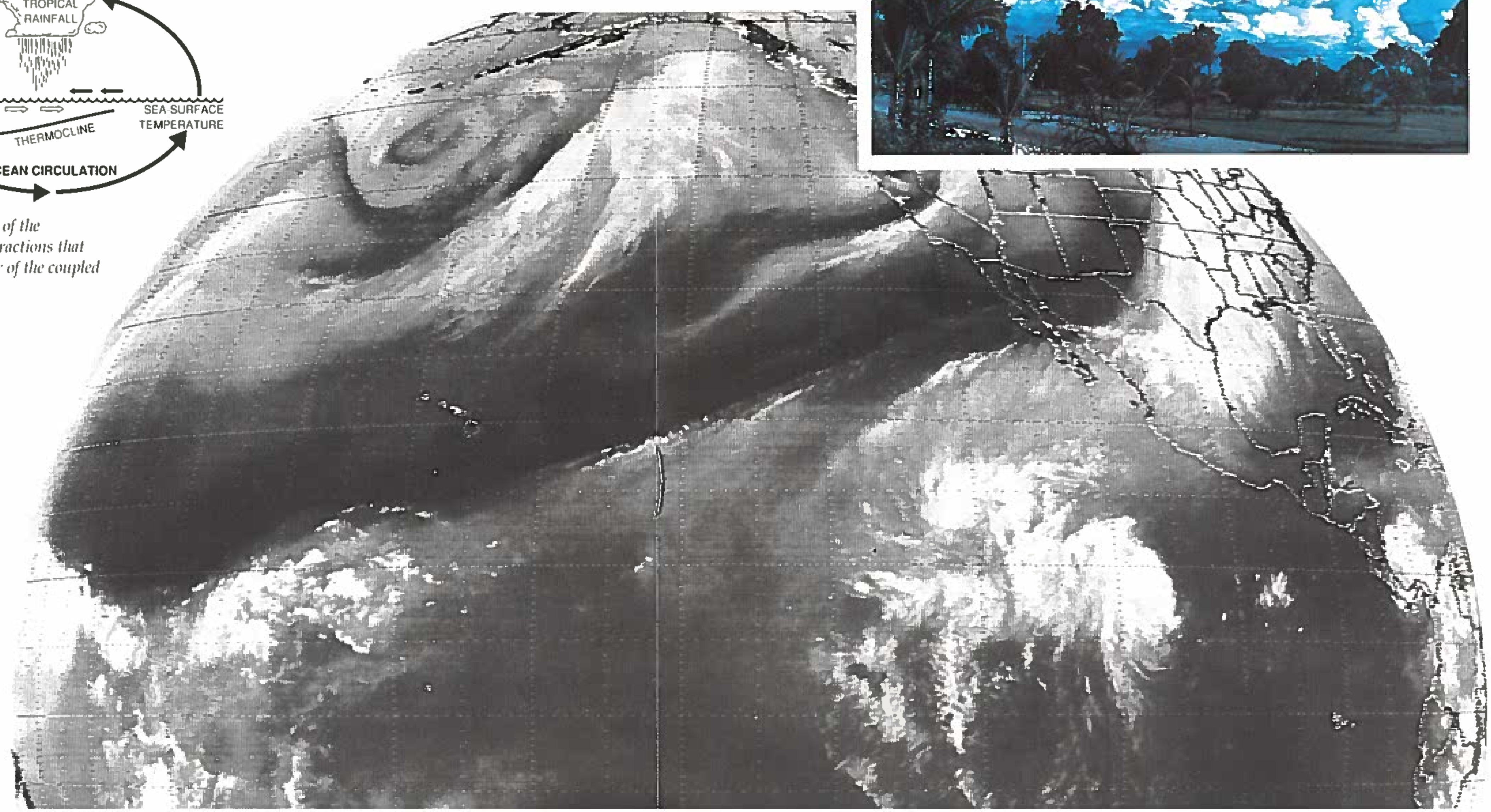
El Niño Conditions

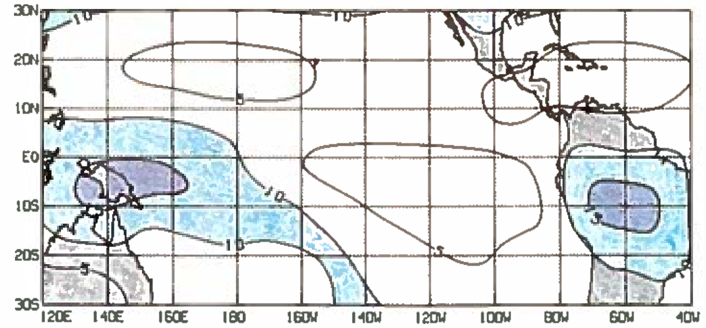


During each regime, the processes occurring within the atmosphere and the upper ocean mutually reinforce one another. Towering thunderheads, cumulus convection, and heavy rainfall are enhanced in regions of warm sea-surface temperature, and low-level winds converge into these regions to maintain the convection. These winds modify the upper-ocean circulation, which in turn affects the sea-surface temperature and the depth of the thermocline. The increased atmospheric fluctuations associated with the enhanced cumulus convection form the connection between the tropical ocean and atmospheric circulation at higher latitudes.

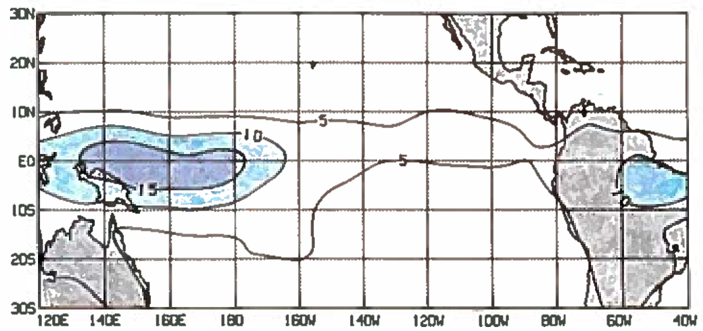


Schematic illustration of the atmosphere/ocean interactions that determine the behavior of the coupled climate system.



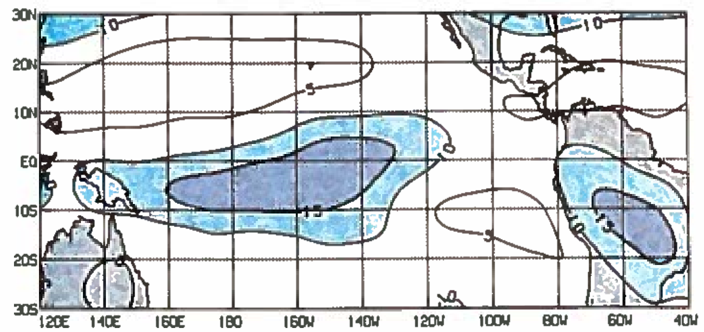


Observed mean June precipitation in mm/day.

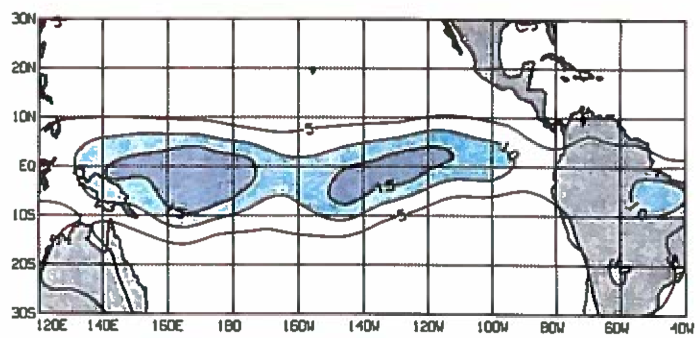


Modeled June precipitation based on average sea-surface temperatures.

Observed June 1983 precipitation (El Niño).

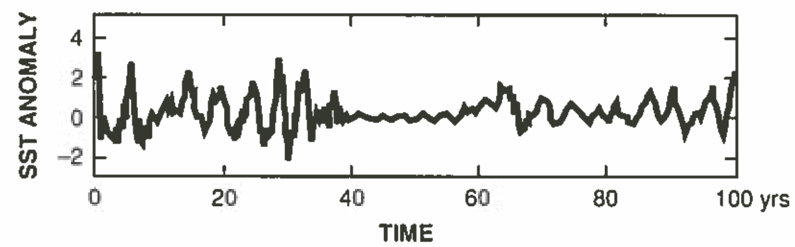


Modeled June 1983 precipitation using observed sea-surface temperatures.

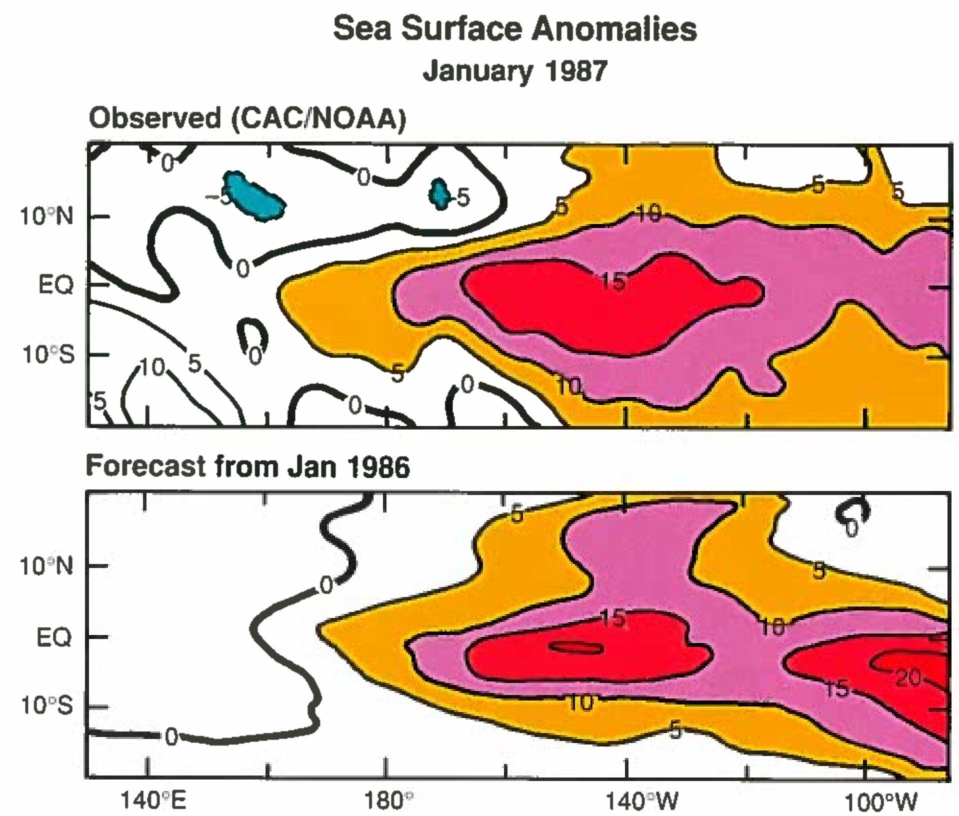


Distributions of precipitation from a sophisticated computer model of the atmosphere correspond well with observed patterns of precipitation in both El Niño (lower diagrams) and normal (upper diagrams) years, especially along the Equator.

A computer simulation of sea-surface temperature in the east-central equatorial Pacific using a simplified model of the atmosphere and ocean predicts a series of typical El Niño events with intervals of about 4 years.



A version of this simplified model also predicted successfully a specific event, the El Niño of 1986-87. These results indicate that major swings in the tropical climate system are predictable about a year in advance. As the following figure shows, distributions of precipitation predicted by a sophisticated computer model of the atmosphere correspond well with observed patterns of precipitation.

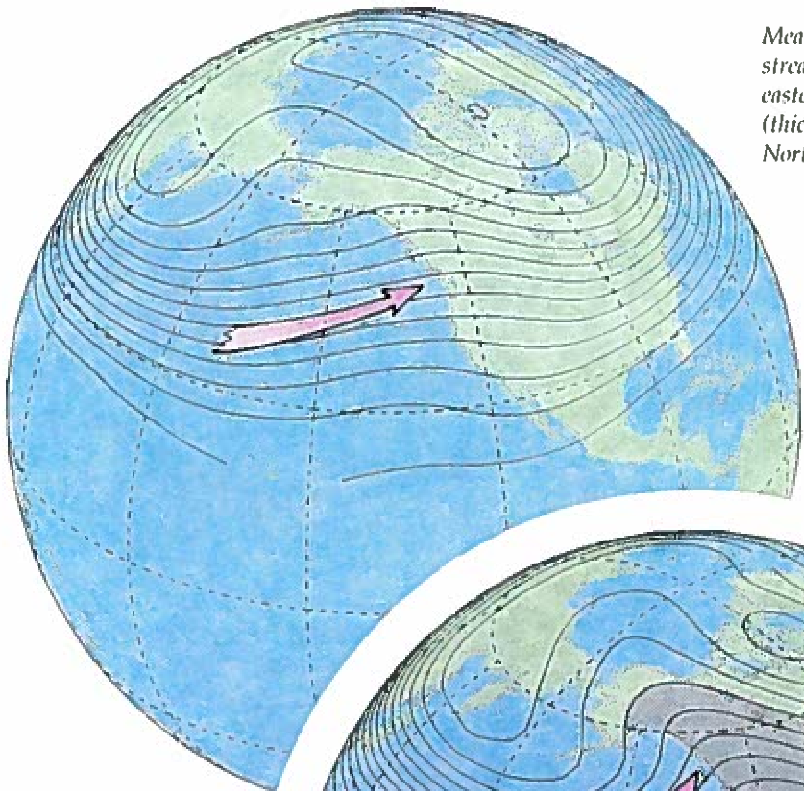


Prediction of El Niño One Year in Advance

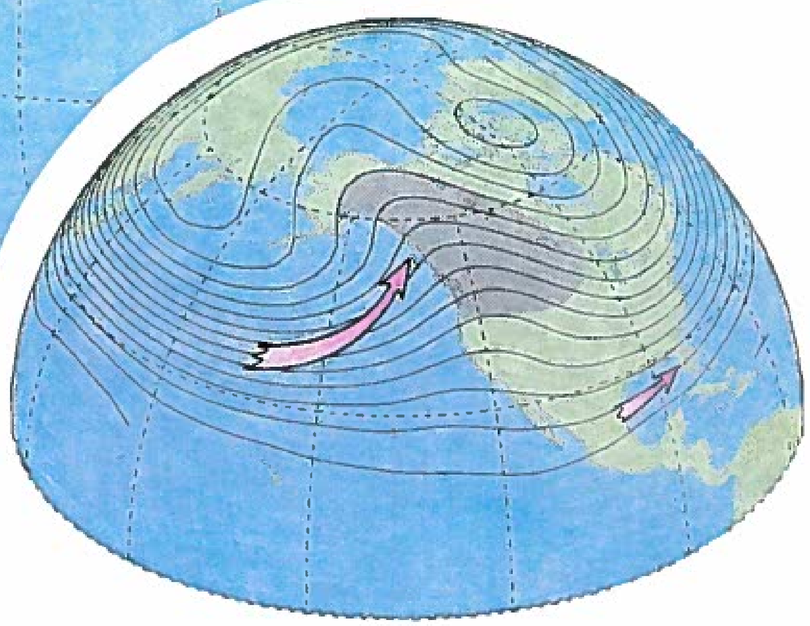
Comparison of observed sea-surface temperature for January 1987 and those predicted a year earlier by the atmosphere-ocean model.

Extratropical Effects of El Niño

Changes in the tropics appear to cause a variety of significant short-term extratropical climate anomalies, but these anomalies do not always recur in a consistent manner. Warm El Niño events appear to have some general consequences for the winter weather in North America. The wind in the upper atmosphere during normal years tends to be from the west, and carries storms into the Pacific Northwest. During a warm event, higher pressure is found over the west coast of North America, and storms are pushed to the north of their usual tracks, bringing above-normal winter temperatures to southeastern Alaska, western Canada, and the Pacific Northwest, and increased storminess to the Gulf Coast states.



Mean middle-atmosphere streamlines (thin lines) and eastern Pacific stormtrack (thick arrow) during a typical Northern Hemisphere winter.



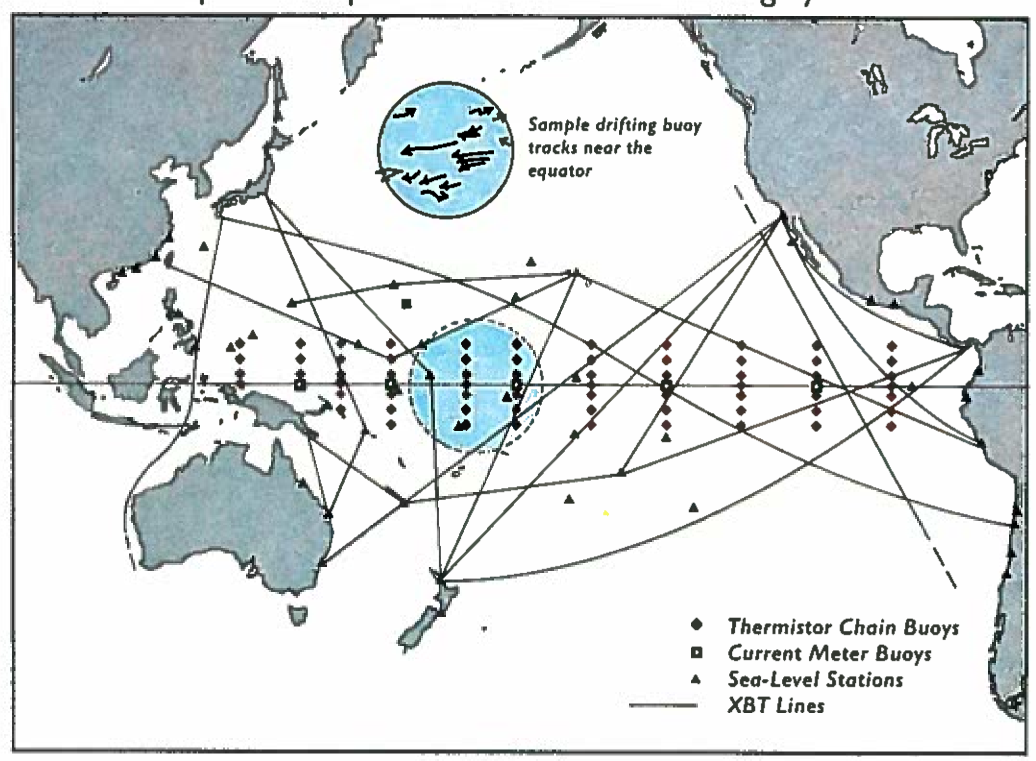
Streamlines and stormtracks in winter during El Niños.

The Future of TOGA

TOGA will continue to study the dynamic processes responsible for significant changes in the tropical oceans and atmosphere. The program emphasizes, but is not limited to, the mechanisms responsible for the initiation of El Niño events. Atmospheric and oceanographic data-collecting networks in the tropics are being upgraded, especially in the western Pacific. Computer modeling of the tropical climate system is also progressing, both for real-time prediction and as an analysis tool. Short-term climate forecasting for the tropics is now an experimental activity; a transition is underway to make these forecasts on an operational basis.

Ongoing studies are investigating how mid-latitude circulation is linked to the tropics, and how this linkage can be exploited to improve monthly and seasonal weather forecasts. This application was a primary motivation for TOGA, and it has a large potential payoff in providing more accurate information, thus improving our policy makers' ability to make the correct strategic decisions in social, economic, and agricultural planning.

Proposed Tropical Pacific Ocean Observing System



By the usual standards of a large scientific program, TOGA has been a success. It has fostered cooperation across national and agency boundaries, and has produced exciting and important scientific results. Improved observing and computing technology and a growing appreciation for the importance of climate research provide solid bases for tackling TOGA-related problems. Reliable predictions of climate variations will allow better management of resources to the clear benefit of society. In this era of increasing concern for the fate of the Earth, understanding the mysteries of Tropical Ocean Global Atmosphere interactions takes on a new urgency.

Deployment of oceanographic equipment in the equatorial Pacific.