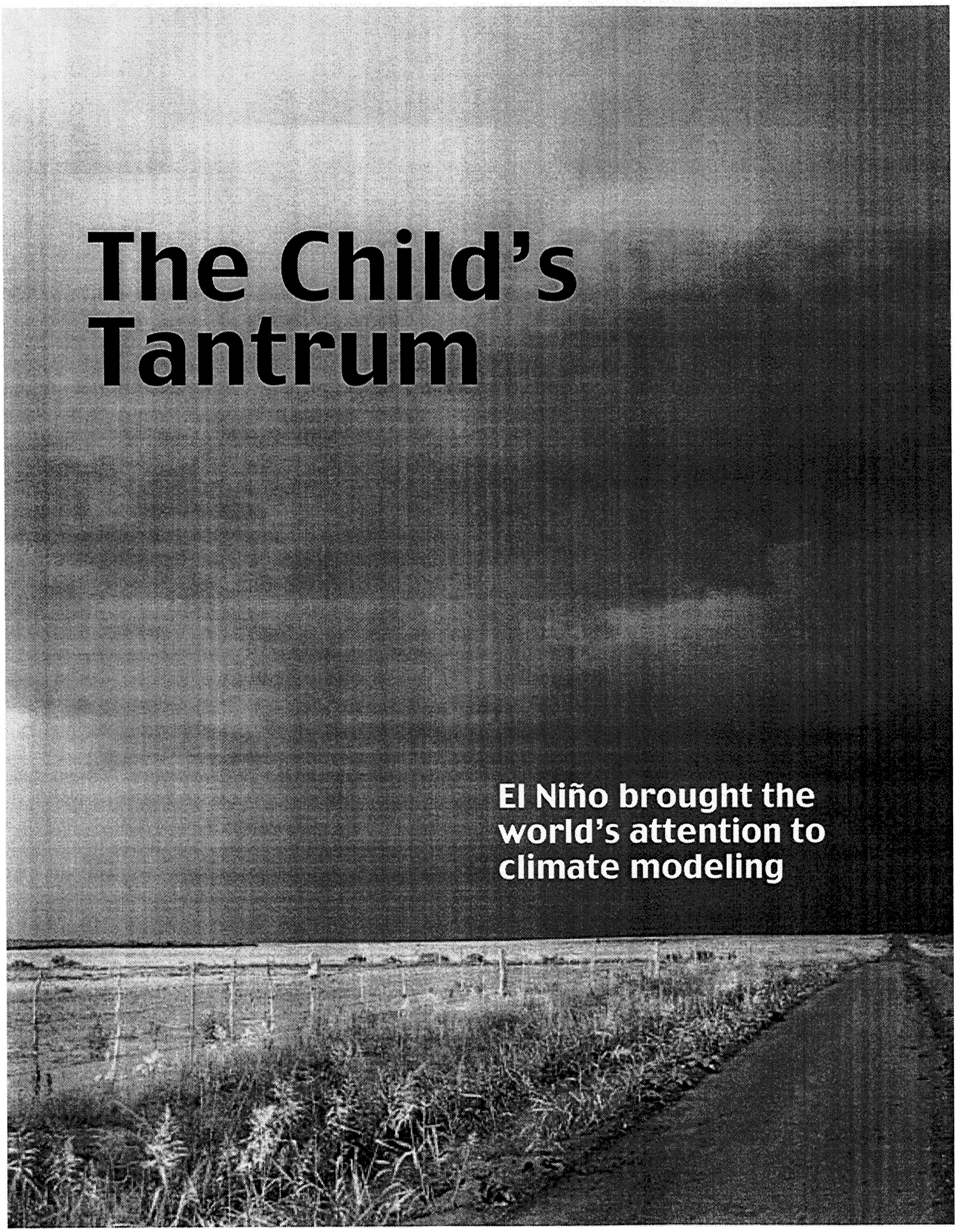
The Child's Tantrum

El Niño brought the world's attention to climate modeling



El Niño

In 1997, a child's tantrums caught the world's attention. These tantrums took the form not of crying and foot stamping, but of droughts and floods. Obviously, this was no ordinary child. It was, in fact, The Child, or *El Niño*, as it was named in the late 1800s by South American observers, who noted that its timing coincided with the Christmas holiday.

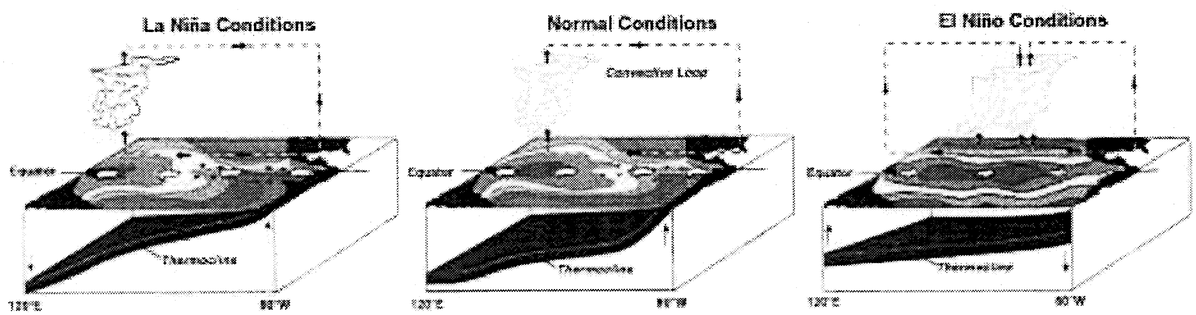
El Niño is a reversal in sea surface temperature (SST) distributions that occurs once every few years in the tropical Pacific. When it coincides with a cyclical shift in air pressure, known as the *Southern Oscillation*, normal weather patterns are drastically altered. The combined phenomenon is known as *El Niño-Southern Oscillation* (ENSO).

Although ENSO is a regular phenomenon, it was unusually strong in 1997. It produced heavy rainfall and floods in California and bestowed spring-like temperatures on the Midwest during the winter. These drastic changes in normal weather patterns captured the public's imagination, from news reports to jokes on late-night talk shows.

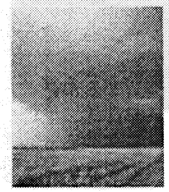
Naturally, people wanted to know as much about El Niño as possible. Fortunately, scientists had at their disposal new satellites and ocean sensors that provided an unprecedented level of information. Consequently, not only was the 1997 ENSO the strongest in recent memory, but it was also the most thoroughly studied. Prominent groups such as the NASA Seasonal-to-Interannual Prediction Project (NSIPP) combined numerous aspects of climate modeling into a single, predictive endeavor.

What happens during El Niño?

Ocean surface temperatures rise and fall throughout the year. Normally, the Pacific waters remain warmer in the west than in the east. Heavier amounts of rainfall are associated with



The El Niño phenomenon pushes cold ocean water away from the surface in the eastern Pacific. In contrast, the La Niña phase brings the cold water up farther than usual near the South American coastline. These changes are evident in the shifting of the thermocline, the depth at which ocean water reaches its maximum temperature gradient. *Image credit: National Oceanic and Atmospheric Administration (NOAA)/Pacific Marine Environmental Laboratory (PMEL)/Tropical Atmosphere Ocean (TAO) Project*



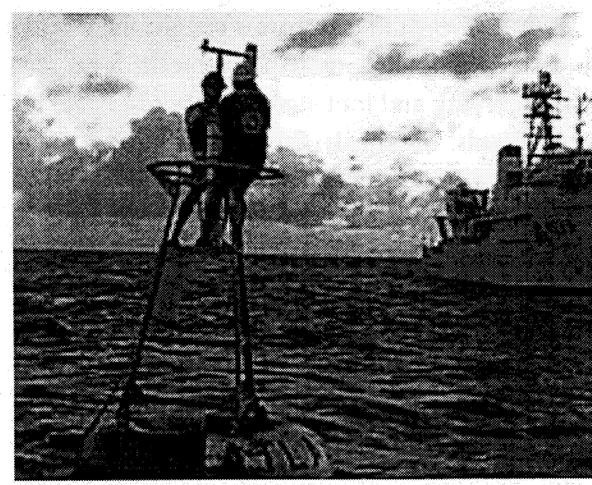
higher SSTs. Furthermore, air pressure over the eastern Pacific is normally higher than it is over the other side of the ocean during the winter months. This increased pressure keeps easterly winds (which start in the east and move west) close to the surface. The low air currents help push warm surface waters toward the west.

An upwelling of cold water from the eastern depths rises in response to this displacement. Meanwhile, the accumulation of heated waters in the west warms the atmosphere above. This heat affects the major jet streams that influence global weather.

Once every few years, however, air pressure decreases over the eastern Pacific and increases over the western Pacific. This change in air pressure reverses the direction of the Pacific winds, and warm water that normally would migrate westward remains near the coast of South America. Consequently, SSTs in the eastern Pacific are higher than usual. This reversal is the El Niño effect, and it normally lasts throughout the winter months.

During El Niño, heavy rainfall shifts from the Indian Ocean to the Atlantic. As a result, weather in Australia and Indonesia is drier than usual, whereas South America and the Gulf Coast of the United States get drenched.

A few years after the El Niño warming period, a cyclical cooling of the eastern Pacific waters follows. This event, known as *La Niña*, brings the SST of the eastern Pacific down below its normal levels. The combined El Niño/ La Niña cycle typically spans 2 to 4 years.

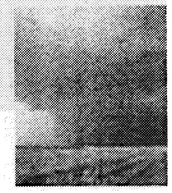


Sensors located on the buoys of the TAO array help keep track of the ocean's temperature. *Image credit: NOAA/PMEL/TAO Project*

How do we study El Niño?

The Tropical Ocean Global Atmosphere (TOGA) program has provided much of our ability to study El Niño. Begun in 1985, TOGA was an international effort to create instant observations and models of the ocean and atmosphere. TOGA used satellites to record the speed and direction of ocean and wind currents, the level of the ocean, and SSTs.

Another important component of TOGA was the Tropical Atmosphere Ocean (TAO) array, a set of 70 moorings that were positioned along the Equator across much of the Pacific. These moorings provided *in situ* (at-the-site) tempera-



ture recordings from the ocean surface to a depth of 500 meters. With these instruments, scientists were better able to detect the onset of El Niño.

Once scientists have collected the measurement data on the El Niño phenomenon, they must study and analyze this vast amount of information to make sense of it. NSIPP, a leader in this effort, focuses on studying climate patterns that span several months to a few years, such as ENSO.

NSIPP developed the Poseidon ocean general circulation model (GCM) as well as a number of ocean data assimilation systems. By combining these with an atmospheric GCM, NSIPP can use ocean measurement data to forecast future movement of warm and cool waters in the Pacific.

The NCCS has provided critical support that enabled NSIPP to piece together the El Niño puzzle. In 1997, the NCCS purchased a Cray T3E supercomputer and dedicated it to NSIPP's use. "Working with the NCCS to configure the T3E has really helped us." said Michele Rienecker, NSIPP's principal investigator.

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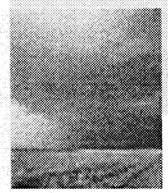


Research Profile: The Origin of the El Niño-Southern Oscillation

Investigators:
Joel Picaut, Institute for Research and Development (IRD), Laboratory for the Space-Based Study of Geophysics and Oceanography (LEGOS); Eric Hackert, Antonio Busalacchi, and Ragu Murtugudde, Earth System Science Interdisciplinary Center (ESSIC), University of Maryland; Gary Lagerloef, Earth and Space Research

Using the resources of the NCCS, this cooperative research project analyzed data sets for the 1997-1998 El Niño event. The NCCS computers performed complex calculations in single-processor mode to draw recognizable patterns from an enormous amount of data. From this examination, the researchers described the preconditioning, onset, and growth of the El Niño event, as well as its faster-than-usual transition to the La Niña phase. By comparing these observations with current theories on the origin and operation of ENSO, the researchers produced new insight into this global weather phenomenon.

Gary Lagerloef, from the Earth and Space Research organization, provided the statistical model that calculated the ocean currents. Lagerloef's model used wind data from satellite-based microwave sensors as well as ocean-level recordings from the TOPEX/POSEIDON satellite array to determine how the sea level and winds shape the movement of the seas.

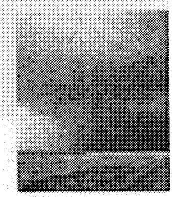
The movement of an imaginary marker called a *hypothetical drifter is* tracked through the use of currents. The drifter highlights strong Pacific currents that pushed the eastern end of the warm pool during the 1997 El Niño. Tracing these temperature disparities enables researchers to see the influence of El Niño on the Pacific.

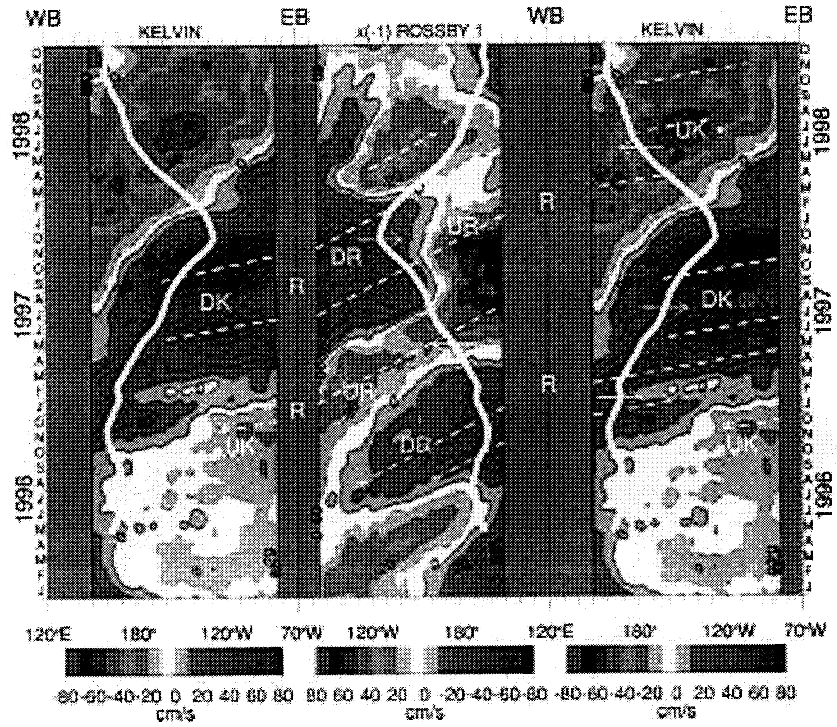
Once the research team determined the movement of wind and water, their next task was to detect patterns out of that massive collection of data. They accomplished this task through a *multivariate empirical orthogonal function* (MEOF), a complex mathematical analysis.

The first MEOF analysis grouped 19 percent of total data variance in a pattern that corresponded with the mature phase of ENSO. The second MEOF analysis drew out the onset of ENSO and accounted for 17 percent of total data variance. With these patterns of related data, the study shed light on several theories about how El Niño emerges and develops into La Niña.

The *recharge theory* states that for El Niño to start, warm water must accumulate in the western Pacific equatorial basin. The study confirmed this prerequisite feature.

Convergence zone theory explains that the shift between ENSO's warm and cold phases is related to the movement of the eastern edge of the western Pacific warm pool. As this edge





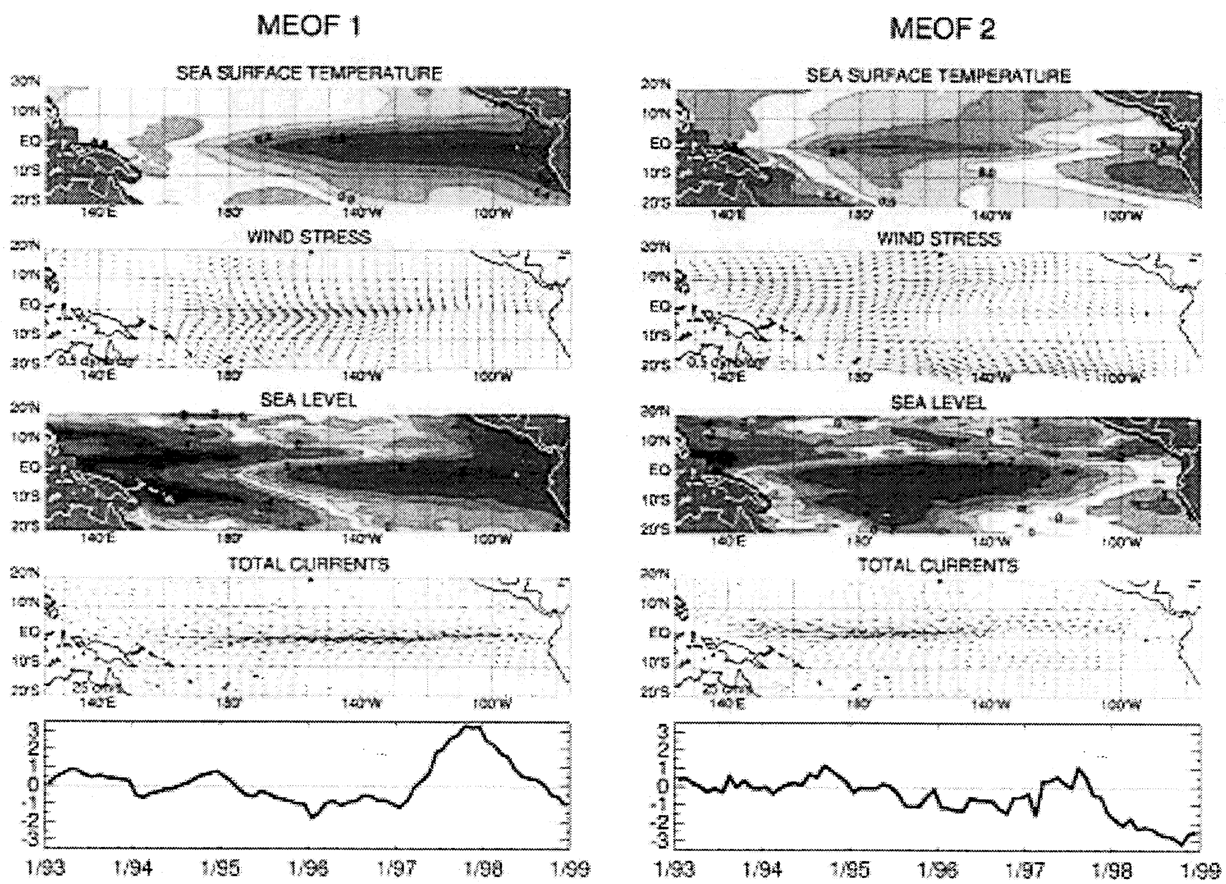
The speed of ocean currents is mapped out for the equatorial region (2 degrees N - 2 degrees S). The currents are divided into Kelvin and Rossby wave components. The path of a hypothetical drifter (shown in white) traces the shifting of the eastern edge of the warm ocean pool.

travels eastward and then westward, El Niño shifts into La Niña.

Although this theory was demonstrated at the beginning of the 1997 ENSO cycle, the return of the warm pool to the west did not seem to change the Pacific SST. Because of the strength of the 1997 El Niño, the SST along the Equator was already nearly constant. An additional source of cold water was required to initiate the move into La Niña.

The *delayed action oscillator theory* can explain this source of cold water. According to this theory, the rise of cold waters from the depths erodes El Niño warming in the east and moves the ENSO cycle into the La Niña phase. Equatorial Rossby waves and Kelvin waves, which are created by wind forcing and wave reflection, provide the mechanism for this transition.

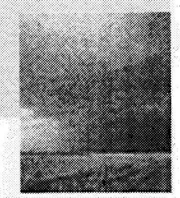
Using space-based data alone, researchers identified the mechanism for the sudden transition of the El Niño to the La Niña. Results of a complex

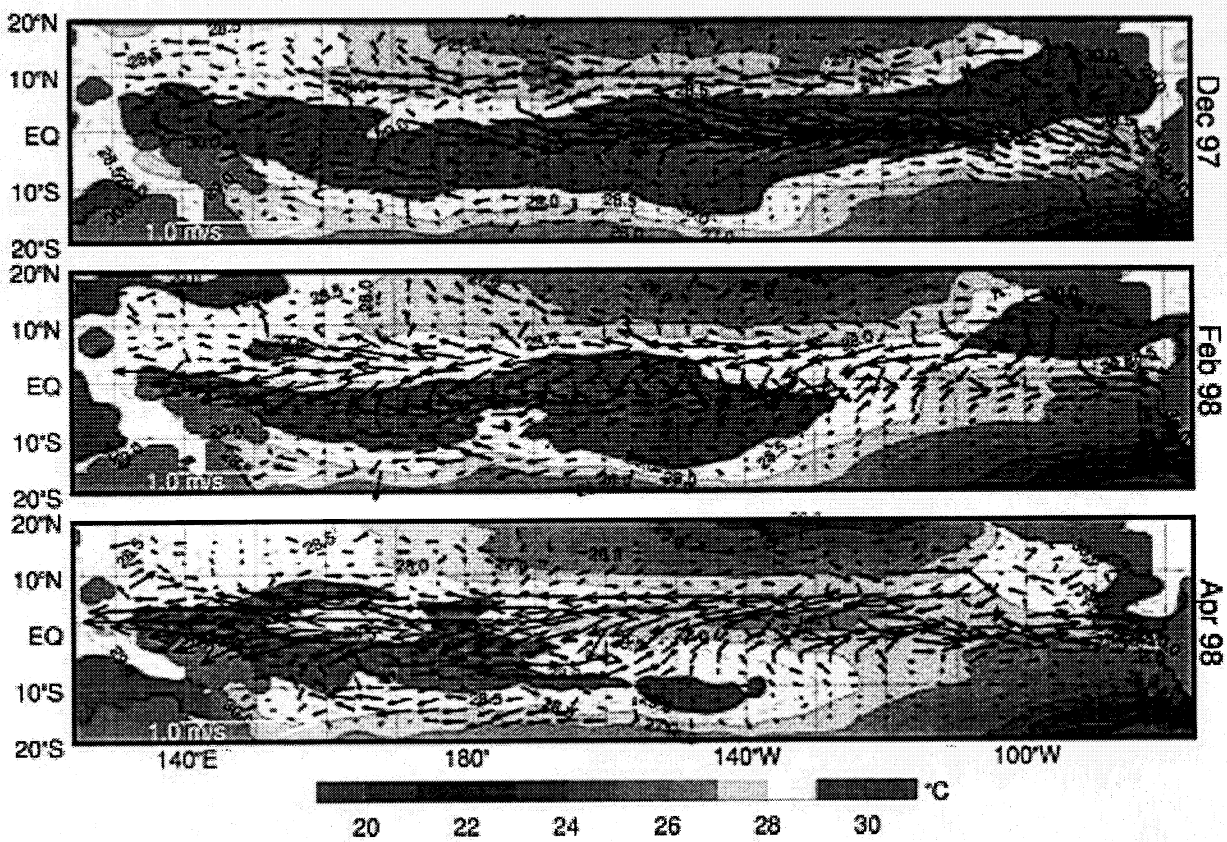


Two MEOF analyses extracted the main trends in the progression of the ENSO. Scientists follow these trends through measurements of SST, wind stress, sea surface height, and currents. The first analysis (left) shows the characteristic peak of the El Niño phase, which accounts for 19 percent of data variance. The second analysis (right) depicts the transition into La Niña, which accounts for 17.4 percent of data variance.

MEOF analysis show how Rossby waves pull currents to the east and Kelvin waves draw surface waters to the west, effectively separating warm surface waters and allowing cold water from below to surface.

This analysis confirmed the western Pacific oscillator conceptual model. This theory attributes the beginning of La Niña to the lowering of the SST in the off-equatorial western Pacific during El Niño. This cold SST anomaly raises sea-level pressure, which, in turn, produces the easterly winds that slow El Niño and turn it into La Niña.





This map shows SST between December 1997 and April 1998. During the peak of El Niño in December, the warm pool stretches across the basin. By April, it mostly returns to the western Pacific Ocean. Some warm water remains in the east, providing the mechanism for a sudden shift to La Niña.