U.S. Weather and the Equatorial Connection

Warm water in the equatorial Pacific can mean brutal winters for the United States, but forecasters see some hope for prediction

You are standing at your bus stop on an agonizingly cold Monday morning in Duluth. The whole winter has been like this, it seems—unusually frigid. Your thoughts wander to soft sand on the beach of a tropical Pacific island, warm ocean water lapping at your feet. Unknowingly, you may be dabbling your toes in the cause of your misery.

How could warm ocean water, 6000 kilometers away, cause such extreme cold in Duluth? The link appears to be an atmospheric teleconnection, in this case a long-distance path over which the warm water sends a signal. On arrival in temperate latitudes, the signal alters the weather patterns there and around the globe. By tracing this and other teleconnections, research meteorologists are learning more about how the atmosphere operates on a global scale. Forecasters have a more practical interest in teleconnections. If they can anticipate the sending of the teleconnection signal, they should be able to improve long-range predictions. Even the modest improvement apparently offered by known teleconnections would be welcome, they say, in the difficult field of long-range forecasting.

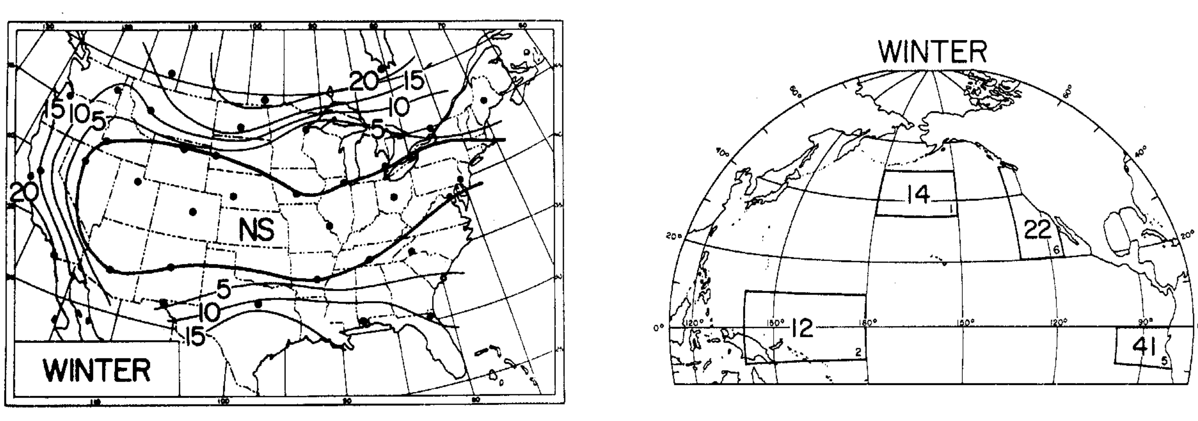
Meteorologists have long known of teleconnections, but only recently has the study of them flourished. In the 1930's, Sir Gilbert Walker traced a number of atmospheric teleconnections, the most famous being the Southern Oscillation. It is a seesawing of atmospheric pressure limited to the tropical and subtropical Pacific, the two ends of the seesaw typically being over Darwin, on the north coast of Australia, and Tahiti, in the central South Pacific. When atmospheric pressure is higher than normal at Darwin, it tends to be lower than normal at Tahiti, and vice versa. A complete oscillation from one extreme to the other and back takes from 2 to 10 years. As shown by Walker and others, the rest of the atmosphere is not isolated from the equator or from the sloshing back and forth of the atmosphere represented by the pressure changes of the Southern Oscillation. Studies have shown that even remote parts of the atmosphere as well as the ocean are part of a single web of teleconnections that includes the Southern Oscillation.

Harry van Loon and Roland Madden of the National Center for Atmospheric Research in Boulder, Colorado, have provided the most recent evidence indicating that Darwin has a teleconnection with Duluth, among other places. They used the time-honored method of statistical correlation to reveal a connection during the past 100 years between the pressure at Darwin and the pressure and temperature in the middle latitudes. For example, when average winter pressure is abnormally high at Darwin, winter temperatures along the southern United States tend to be below normal, and temperatures in California, the north-central United States (including Duluth), and western Canada tend to be higher than normal. They also found areas of consistent correlation with Darwin pressure in the eastern North Atlantic, over the Caspian Sea, in India, in Japan, and in part of Siberia. Thus, in spite of the great distances and the general west-to-east movement of weather in the middle latitudes, a network of teleconnections links the equatorial Southern Oscillation and weather far to the north.

The signal traveling along these teleconnections is often weak. Van Loon and Madden found correlation coefficients of up to .5. If during every winter that Darwin had abnormally high pressure the north central United States had warmer than normal temperatures, the correlation coefficient would be 1. A correlation coefficient of .5 means that a teleconnection can account for only 25 percent of the variance observed at the distant site. Still, once such a teleconnection is identified, meteorologists can delve deeper to determine how the teleconnection is formed.

Forecasters have perhaps a more difficult problem. Correlations like those of van Loon and Madden relate events of the same season. In order for teleconnections to help the prediction of Duluth's weather, researchers must find a relation between weather there and the previous autumn's or summer's weather elsewhere.

Tim Barnett of Scripps Institution of Oceanography has identified such a lag correlation that may eventually aid forecasters in preparing long-range predictions. He constructed a mathematical



Teleconnection predictability

(Left) Contours are the percent of air temperature variance accounted for by a statistical model that makes U.S. predictions solely on the basis of the previous season's Pacific sea surface temperatures. NS *indicates the region for which no significant prediction could be made. (Right) Relative predictive importance of individual sea surface temperature regions. [From T. P. Barnett,* Monthly Weather Review ***109****, 1021 (1981). © American Meteorological Society, 1981]*

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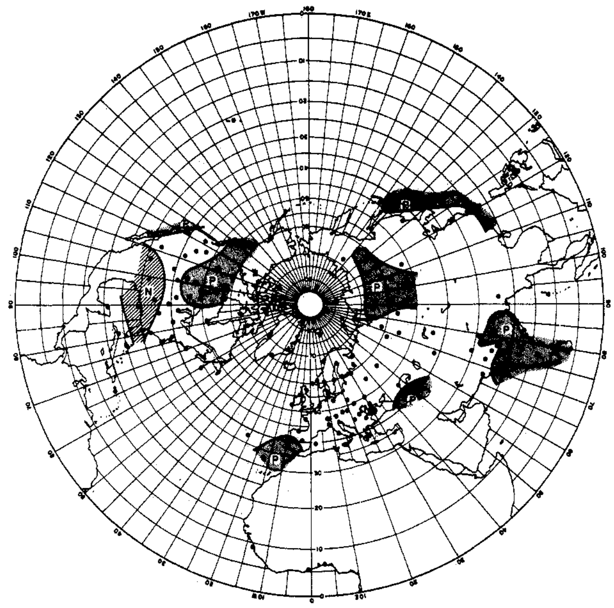
model that relates air temperature over the United States between 1902 and 1979 and the temperature of surface ocean water in the Pacific during the previous season.

Barnett chose to average sea surface temperature (SST) over four specific regions of the Pacific that he suspected might influence U.S. weather. Of these four areas, Jerome Namias of Scripps has emphasized the importance of the area south of the Aleutian Islands. Positioned upstream from the United States beneath the eastward flow of weather systems, the warm SST anomalies can influence the weather to the east, Namias suggests. Barnett's eastern equatorial region off Ecuador and Peru is where El Niño, an occasional anomalous warming of surface water, first strikes. When it does, the warming disrupts the anchovy fishery near the coast and spreads westward along the equator. Researchers believe that this band of warm water also helps drive the Southern Oscillation into the next stage of its cycle. Jacob Bjerknes suggested in the 1960's that such a warming could also affect weather in the middle latitudes.

Barnett found that Pacific SST can indeed be used to predict U.S. air temperatures a season ahead, but SST predictive power varied by season and location. Although Pacific SST of the season before could account for over 20 percent of air temperature variance around much of the periphery of the country, the model could make no prediction within a broad band running from the Rocky Mountains to the East Coast. Winter predictions were more accurate than those for spring and fall; summer predictions were least accurate.

Barnett also found that the predictive power of SST's in the four Pacific regions differed markedly. The eastern El Niño region on the equator appeared to be most important, the California region showed distinctly less predictive power, and the northern Pacific and western equatorial regions showed the least.

The apparent dominance of the El Niño region may be due to its equatorial location. Peter Webster of the Commonwealth Scientific and Industrial Research Organization in Aspendale, Australia—he is temporarily at the Naval Postgraduate School, Monterey—argues that the first link in the teleconnection chain is strongest when the SST anomaly is in the tropics. This first link is the conversion of potential energy to kinetic energy in the atmosphere over the anomaly. In the tropics, the winds are relatively light and the Coriolis effect is weak. As a result, a strong vertical circulation can develop as heat released by the condensation of water vapor accelerates the ascent of air already warmed by the anomaly. In middle and high latitudes, Webster says, the stronger horizontal winds, common in most seasons, suppress this vertical development.



Southern Oscillation teleconnections

Shaded areas denote stable positive and hachured areas stable negative correlations between winter atmospheric pressure at Darwin and air temperatures in the areas marked. [From H. van Loon and R. A. Madden, Monthly Weather Review ***109****, 1150 (1981). © American Meteorological Society, 1981]*

Once this equatorial heat engine gets going, it apparently reaches into the upper troposphere (10 to 15 kilometers above the surface) and makes itself felt thousands of kilometers to the north. This upper troposphere link in the teleconnection may be a Rossby wave, as suggested by Brian Hoskins and David Karoly of the University of Reading, England. This is the same sort of atmospheric disturbance that appears as broad waves in the prevailing high-altitude winds—the westerlies—over the United States. Hoskins and Karoly have calculated how high-altitude winds might bend and redirect Rossby waves generated by a heat source near the equator, much as changes in density bend light waves. John Horel and John Wallace of the University of Washington have noted that once such Rossby waves reach the middle latitudes, they could distort the wave pattern in the westerlies so that extreme weather would be steered into North America.

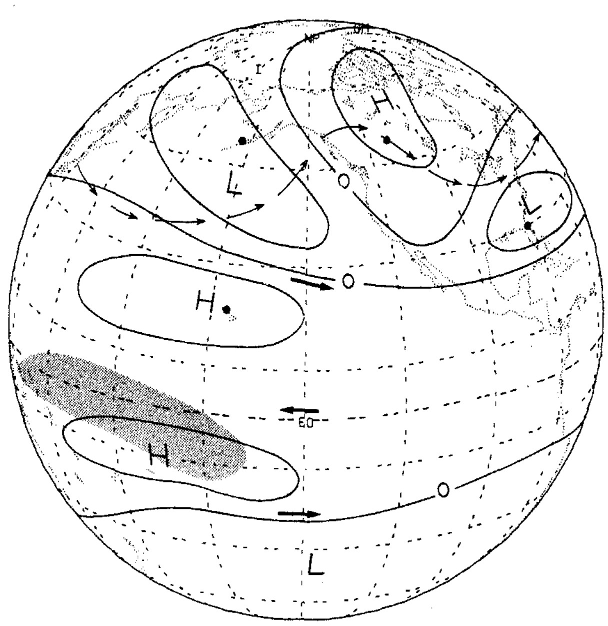
Horel and Wallace have found some evidence in the middle and upper troposphere that a Rossby wave could provide the central link in the tropical Pacific–North America teleconnection. They have shown that warm SST anomalies in the equatorial Pacific tend to be accompanied by a train of high-altitude pressure anomalies arcing into the Northern Hemisphere. This train includes regions of anomalously low pressure over the far North Pacific and the southeastern United States, and a high over western Canada.

The pattern bears a strong resemblance, Horel and Wallace say, to the theoretical Rossby wave patterns calculated by Hoskins and Karoly and by Webster. It also resembles the pattern of highs and lows, called a blocking pattern, that funnels unusually warm air into Alaska and sends frigid air into the lower 48 states. Like Barnett's observed teleconnection, this pattern would be strongest during the winter half of the year, Webster notes, when the westerlies dip far enough toward the equator to overlie any SST anomaly. The consistency between theory and observation has convinced most researchers that tropical SST anomalies have the greatest influence on weather in the mid-latitudes. The SST anomalies of the central North Pacific appear to be more often passive reflections of those in the tropics than a primary driving force behind weather changes.

Although the equatorial teleconnection appears to be real enough, its usefulness in long-range prediction will be limited to those occasions when the signal from the tropics rises above other influences on North American weather. Madden has compared the amount of climate noise, the background of day-to-day weather variations that cannot be predicted far in advance, with the Southern Oscillation signal evident in U.S. temperature records. Even in New Orleans, where the signal-to-noise ratio was highest, Madden found that the Southern Oscillation signal would only rise far enough above the noise to be useful in prediction about 10 percent of the time.

In fact, the equator–North America teleconnection has been quite fickle. Re-

An equatorial teleconnection



A schematic illustration of the middle and upper tropospheric pressure anomalies that might link warm sea surface temperatures near the equator with abnormally cold winters in the lower 48 states. A Rossby wave generated by the sea surface warming of an El Niño propagates into the Northern Hemisphere, creating a train of centers of anomalously high and low pressure (solid lines). The light arrows show how flow in the mid-troposphere would be distorted by the anomalies. In turn these high-altitude winds would steer unusually warm air into Alaska and abnormally frigid air into the eastern United States. [From J. D. Horel and J. M. Wallace, Monthly Weather Review ***109****, 825 (1981). © American Meteorological Society, 1981*]

searchers agree that only one of the five El Niño episodes of the past 30 years had a dramatic effect on U.S. weather. That was the 1976–1977 El Niño that brought record cold to the United States during the winter of 1977. Why one signal should get through and another not is unclear. Horel has compared the strong 1972–1973 El Niño, which had no obvious effect at middle latitudes, and the 1976–1977 episode. The only difference between the two was a displacement of the SST pattern to the east in 1972–1973, which may have somehow prevented the formation of a teleconnection to North America. This inconsistent behavior emphasizes the ease with which things can go wrong along the complex chain linking the equator with the middle latitudes, Horel says. In addition, blocking patterns can form without a known teleconnection. The winters of 1978 and 1979 were both exceptionally cold, but the equatorial Pacific had near normal temperatures.

Because of the intermittent nature of the equatorial teleconnection, most meteorologists are cautious about its potential in long-range forecasting. But, as Donald Gilman, head of the National Weather Service's long-range prediction group in Camp Springs, Maryland, notes, even a small improvement would be welcome. Their greatest success, seasonal prediction of winter temperature, has been a modest one. Forecasters have accurately predicted when winter temperatures would be above or below normal about 65 percent of the time. If predictions were based on the toss of a coin, they would be correct 50 percent of the time. For the year as a whole, temperature predictions are accurate 60 percent of the time. Precipitation forecasts have a success rate of only 55 percent.

Gilman and his group have been watching the Southern Oscillation for more than a year now with no luck—nothing unusual has been happening in the equatorial Pacific. "I have my fingers crossed," Gilman says, "that [the teleconnection] will help us when the Southern Oscillation gets stronger. In this business, anything that's valid, even if it's weak, is going to help. We've been saying for a long time that you have to look at the whole globe, but we weren't able to do anything before." The need now, he says, is for a greater understanding of the physical processes that form the teleconnection. Other researchers note that prediction might also be improved by the pinpointing of other teleconnections that influence weather.

While long-range forecasters await the next strong signal from the eastern tropical Pacific, some researchers are looking far to the west. They suspect that an even earlier signal, the very earliest stirrings of El Niño, may be detected there. The ultimate cause of El Niño is much disputed, but the only well-defined mechanism is the oceanic Kelvin wave proposed by Klaus Wyrtki of the University of Hawaii. He has suggested that in the year before El Niño the winds blowing along the equator from the east (the easterlies) subside, creating a deepening of the warm ocean surface layer that propagates along the equator toward South America as a Kelvin wave. Arriving at the coast, it would cut off the upwelling of deeper, cold water and create the SST anomaly.

Recent studies suggest that the Kelvin wave may start its leisurely trip across the Pacific much farther to the west than was thought; if so, this might allow more time to anticipate the formation of the teleconnection. Eugene Rasmusson and Thomas Carpenter of the National Weather Service in Camp Springs have compiled SST and wind data associated with El Niño. They confirmed earlier work indicating that the early weakening of the easterlies occurs in October and November in the far western Pacific near New Guinea, not in the central Pacific as had been assumed.

Antonio Busalacchi and James O'Brien of Florida State University have used the observed equatorial winds of the 1960's to create El Niños in a computer model of the ocean-atmosphere system. Weakening of the easterlies in the far western Pacific preceded both the 1965 and the 1969 El Niños that appeared in the real ocean as well as in the model. Only the minor El Niño of 1963 seems to have been triggered by wind changes to the east of the dateline, they say. Busalacchi and O'Brien contend that the most likely link between wind changes on one edge of the Pacific and an ocean warming on the other is a Kelvin wave, a long wave having a speed of 250 kilometers per day. Starting in October, it would arrive at the Peruvian coast 2.5 months later in time to initiate an El Niño.

Although regarded as the most complete theory, the Kelvin wave model still has its problems. George Philander of the Geophysical Fluid Dynamics Laboratory in Princeton points out that the winds in the far western Pacific weaken even more in the year after the start of an El Niño, but no effect at all is seen in the eastern Pacific. He notes also that no one has yet detected a wave propagating from west to east along the equator, only the east to west progression of El Niño.

The equatorial forerunners of El Niño may extend even farther west into the Indian Ocean and thus farther back in time. In a preliminary study, Barnett found that an anomalous pattern in the summer monsoon winds over the Indian Ocean moved toward the east before the 1972 El Niño. The anomaly reached the trade winds of the Pacific in November or December. That could have been in time to produce a Kelvin wave and the subsequent El Niño.

—RICHARD A. KERR