Introduction

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In 1984, a workshop was held on "climatic variability of the eastern North Pacific and western North America." From it has emerged an annual series of workshops held each spring at the Asilomar Conference Center, Monterey Peninsula, California (Mooers and others, 1986). These annual gatherings have come to be called PACLIM (Pacific Climate) Workshops, reflecting broad interests in the climatologies associated with the Pacific Ocean. Participants in the six workshops that have convened since 1984 have included atmospheric scientists, hydrologists, geologists, glaciologists, oceanographers, limnologists, and both marine and terrestrial biologists. A collective goal of PACLIM is to connect these various interests with common targets. One such target is the climate system associated with El Niño-Southern Oscillation (ENSO) and its physical and biological manifestations. Another is the behavior of this system on the scale of decades, centuries, and millennia, as recorded in high-resolution proxy data (i.e., annual ice layers, corals, sediment varves, and tree rings). Multidisciplinary collaborations fostered by previous PACLIM workshops are illustrated in Peterson (1989).

PACLIM Workshops have been sponsored largely by the U.S. Geological Survey (USGS) in cooperation with other federal and state agencies, as well as private institutions. PACLIM 89, which led to publication of this proceedings, was sponsored by USGS, the Monterey Bay Aquarium Research Institute (MBARI), the National Oceanic and Atmospheric Administration (NOAA-Geophysical Data Center), the Environmental Protection Agency (EPA-Global Change Program), and the California Department of Water Resources (CDWR). On behalf of the sponsors, we extend our gratitude to the various individuals responsible for the organization and planning of PACLIM 89. In particular, we thank Dave Peterson, USGS, and Dick Barber, MBARI, for co-chairing the workshop and Lucenia Thomas and Martha Nichols, USGS, for logistical and office support. We also thank Randy Brown, California Department of Water Resources, for arranging publication of this proceedings in the Technical Report Series of the Interagency Ecological Studies Program.

Papers in the proceedings are organized from the general to the specific, from observations based on instrumental data to inferences from the fossil record. The papers by Elsaesser, Sellers, and Namias represent the keynote addresses for PACLIM 89. Elsaesser's (this volume) skepticism about the magnitude of warming projected for doubled CO_2 stirred much debate at the workshop. He feels that too much is being expected of radiation transport theory in large-scale modeling of the CO_2 problem. For summer, general circulation models (GCMs) overestimate continental precipitation amounts and temperature variability. Miscalculations in radiation may also explain misplacement of continental heat lows during summer (i.e., in the eastern rather than southwestern United States). This problem is addressed later in the proceedings by Neilson and others, who show that the GCMs distort actual rainfall seasonalities across the southern United States. Mesoscale models, such as the one constructed by Craig and Stamm (this volume) for the southwestern United States, could improve simulations of seasonality only if the general boundary conditions borrowed from GCM output are fundamentally correct. Elsaesser (this volume) also draws from Angell's (1988) synthesis of upper-air sounding data to show that cooling occurred in the polar zones, where the GCMs simulate maximum warming. In a similar light, Sellers (this volume) analyzes radiosonde data since 1957 for over 500 stations and suggests how temperature patterns in the lower stratosphere and upper troposphere might relate to the solar flux, ENSO, the quasi-biennial oscillation (QBO) and atmospheric CO_2.

Extreme droughts over the Great Plains in 1988 (Namias, this volume) and over northern California since the 1987 water year (Roos, this volume) raise some interesting questions. Though these droughts may have little connection to greenhouse effects, they bring to mind the societal impacts of more frequent droughts projected in some CO_2-climate scenarios. As usual, Namias' thoughtful relations to the oral presentations at PACLIM were worth the price of admission. In his paper, he again warns us against generalizations about El Niño and La Niña teleconnections (see earlier admonitions in Namias and Cayan, 1984). Rather than just the byproduct of La Niña conditions (Trenberth and others, 1988), the 1988 Great Plains drought resulted from evolution and development of the classical three upper-level anticyclonic anomalies over the north Pacific Ocean, north Atlantic Ocean, and continental United States, to interacting sea surface temperature (SST) patterns, and to very dry antecedent soil conditions.

Heeding Namias' warming, Ropelewski and Halpert (this volume) exercise great caution in uncovering North American temperature and precipitation patterns associated with extreme phases of the Southern Oscillation (SO). The consistent patterns are confined to the northwestern and southeastern parts of the continent. In the Pacific Northwest, precipitation patterns apparently depend on the precise evolution of each high or low SO-phase event and the prevailing atmospheric pressure patterns in the north Pacific Ocean, as gaged by the Pacific-North American (PNA) index (Ebbesmeyer and Coomes, this volume). Positive values of the PNA index, corresponding to an amplified wave pattern of 500 mb height with the Aleutian Low shifted eastward and an intensified sea level pressure gradient, are associated frequently, but not always, with the low-SO phase of El Niño. In Arizona, wet summers tend to follow the positive phase of the PNA-teleconnection pattern and/ or low SO-phase of the antecedent winter (Carleton and others, this volume).

On a decadal scale, differences in the PNA and SO indices are reflected by hydrologic fluctuations. With the positive PNA-phase, streamflow into Puget Sound is reduced, the density difference across the entrance sill at Admiralty Inlet increases, and the fastest inflow in the Sound deepens toward the bottom (Ebbesmeyer and Coomes, this volume). On the larger streams of southern Arizona, the seasonality and magnitude of annual floods shift with the prevailing flow pattern of the upper-air westerlies and the frequency and intensity of ENSO events (Webb and Betancourt, this volume). Such climatic effects also are evident in biological productivity. Along the northern California coast, Lehman (this volume) notes that chlorophyll concentrations and populations of phytoplankton, zooplankton, and fish declined in the period 1977-1987, a decade bereft of La Niña conditions (Bradley and others, 1987) and with a consistently positive PNA index (Ebbesmeyer and Coomes, this volume). At Southern California ports, landings of swordfish increased after 1976, while those for other species decreased. Though these changes parallel warmer SSTs at the Scripps pier, they could also be attributed to developments in market and technology (Sund and Norton, this volume).

The second half of the proceedings volume is devoted to studies spanning centuries to millennia. Anderson's (this volume) contribution breaks new ground by exploring associations between solar and ENSO activities in the past four centuries. Of particular value is the pre-instrumental record of ENSO reconstructed from archives by Quinn and others (1987). Anderson attributes the reciprocal relation between ENSO frequency and sunspot number to modulation of a linear oscillator (ENSO; see Graham and White, 1988) by the changing amplitude of the 11-year solar cycle. During the Maunder Minimum, for example, ENSO might have approached the frequency of the quasi-biennial oscillation (QBO). Anderson suggests that the ocean's mixed layer should be sensitive to solar modulation of ENSO; a signal should be evident in the marine stratigraphic record.

On the continental slope off the coast of Northern California, Linsley and others (this volume) report alternating cycles of varved and bioturbated sediments between 45,000 and 12,000 YBP (years before present). These cyclic alternations indicate dramatic changes in wind-driven upwelling. Varved intervals reflect more upwelling and anoxic conditions in bottom waters of the oxygen minimum zone that discourage bioturbation by macrobenthos and thus help preserve varves. Linsley and others (this volume) suggest a connection between the rapid transitions in the cycles and climatic "jumps" identified for the same time in the Greenland ice cores (Broecker and others, 1988). These jumps are comparable in magnitude and duration to the Younger Dryas cold snap that, from evidence in the ice cores, apparently terminated abruptly (within 20 years) at ca. 10,700 YBP (Dansgaard and others, 1989). Continued development of marine varved chronologies will be critical to determine whether or not the Pacific Ocean responded as swiftly as the Atlantic, and to what extent the transition involved ENSO.

Casey and others (this volume) report on Neogene, Pleistocene, and Holocene varved sediments off the California coast. Interruptions in the varved series, representing bioturbation, are attributed to ENSO conditions, first identified ca. 5.5 MYA (million years ago). Radiolarian number and flux are used to indicate ENSO, calibrated from plankton tows and analysis of 20th century sediments in the Santa Barbara Basin. In the spirit of calibration, Soutar and others (this volume) propose methods for monitoring particle flux at coastal sites, partly to help understand varve formation. Based on the pioneering study by Soutar and Crill (1972), Schimmelmann and others (this volume) extend the absolute chronology of laminated sediments in the Santa Barbara Basin to AD 1650. Their skillful dating of varves is essential in developing a precise history of the California El Niño that can be compared with other Pacific records of interannual resolution, such as marine varves from the Gulf of California (Juillet-Le Clerc and Schrader, 1987; Baumgartner and others, 1989a).

Most of the work with biological indicators in varves from the Santa Barbara Basin and Gulf of California has been with marine organisms. Charcoal counts from the Santa Barbara Basin varves have been used to reconstruct wildfire history in the coastal ranges of Southern California (Byrne and others, 1977). Orvis and others (this volume) and Byrne and others (this volume) now report pollen and dinoflagellate stratigraphies from the Gulf of California. Pollen influx bears directly on the processes of sediment transport and accumulation on the Guaymas slope. Pollen influx has remained the same over the past 200 years, despite artificial damming of rivers that flow into the Gulf (Orvis and others, this volume). This corroborates the claim by Baumgartner and others (1988b) that terrigenic flux in the Gulf is mostly eolian. Byrne and others (this volume) show the great potential awaiting full analysis of cores DSDP 479 and 480, which Glomar Challenger took in 1978 as part of the Deep Sea Drilling Project. Together these cores provide a complete sweep of the last million years in the Gulf of California, much of it laminated. Dating of these cores is still in question; calcareous foraminifera are not abundant enough in the Gulf sediment for development of an oxygen isotope chronology equivalent to stratigraphies now available from the deeper oceans.

Four papers in the proceedings draw from another high-resolution proxy record — tree rings in conifers from the western United States and northern Mexico. Hughes and others (this volume) resume earlier work on giant sequoia by tree-ring pioneer A.E. Douglass, and raise hopes for a 2,000-year chronology from the west slope of the Sierra Nevada. The surest climatic signal in the sequoia rings is the infrequent, severe drought. Severe drought frequencies comparable to those of the 20th century also happened during the 1500s and 1700s. Graumlich (this volume) uses response surfaces to show synergistic interactions of winter precipitation and summer temperature in producing tree rings of foxtail pines and western juniper in sub-alpine environments of the eastern Sierra Nevada. She proposes that response surfaces from multiple species may be necessary to derive quantitative reconstructions of climate from tree rings. Response surfaces also may be useful in attaching climatic significance to large-scale changes in plant distribution. Such regression techniques have been used to simulate past vegetation from GCM output in the eastern United States (Bartlein and others, 1986). A similar approach could be taken to investigate climatic changes responsible for late Holocene expansion of Douglas fir into northeastern California (West, this volume).

Meko (this volume) uses tree rings to infer and compare low-frequency variations in runoff for the northern, central, and southern parts of the semi-arid interior of the western United States. These low-frequency variations seem to respond to both annual precipitation and evapotranspiration during the warm season. He also notes that downward trends in streamflow over the first half of this century are at least 250-year extremes and that asynchroneity between north and south occurs most commonly during ENSO events. In ponderosa pine forests of Arizona and New Mexico, fire activity is much reduced during ENSO events, primarily because of wetter winters and springs. Swetnam and Betancourt (this volume) identified ENSO effects in both fire statistics (1909-present) and fire-scar chronologies (1700-1900). Because teleconnections for fire climatologies are lagged one or two seasons, successful forecasting of extreme phases of the SO could improve fire readiness and scheduling of prescribed burning.

Two of the papers in the proceedings extract climatic meaning from rare and infrequent flood events evident in the fossil record. Enzel and others (this volume) link perennial lakes in the Mojave Desert at ca. 3600 and 400 years ago to a persistent, southward displacement of the North Pacific storm track. As climatic analogs, they use historical flooding that led to formation of ephemeral lakes lasting several months to more than a year. On the hyperarid, northern coast of Peru, most evidence of catastrophic flooding during the Holocene, such as in 1982-1983, is believed to have resulted from ENSO (Wells, this volume). At present, however, the alluvial stratigraphic record is much too coarse and fragmentary for use in reconstructing past El Niño events (DeVries, 1987).

Finally, Holdsworth (this volume) presents a spectacular, interannual record of snow accumulation on Mt. Logan, Yukon, since AD 1700. Because of its location, this record is on equal par with ice core records from the Quelccaya ice cap in Peru (e.g., Thompson and others, 1984), which attracted much attention at early PACLIM workshops (Mooers and others, 1986). At 5340 m above sea level, Mt. Logan is located in the middle troposphere, near the limits of the circumpolar vortex, and along the preferred tracks of Rossby waves and major cyclones. It is thus not surprising, though still impressive, that net snow accumulation on Mt. Logan explains about 40 percent of the variance of precipitation in the northern Great Plains, the steppe of the Soviet Union, and Japan. Like the Quelccaya ice cap and marine varves from the Santa Barbara Basin and Gulf of California, the Mt. Logan record shows that Pacific climate changed dramatically at the end of the Little Ice Age. In many respects, twentieth century climate may be without analog in the past few centuries.

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