PERSPECTIVES: CLIMATE VARIABILITY

Do the Tropics Rule?

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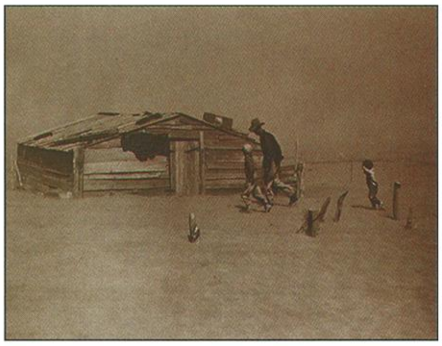
The haunting images of dust bowl refugees left to us by artists such as Walker Evans, Dorothea Lange, Woody Guthrie, John Steinbeck, and John Ford testify to the suffering inflicted by prolonged droughts and other decadal climate changes (see the first figure). We know that one decade's climate will not be like the last one, but we do not know why. We barely even know what happened in the past: Our picture of global decadal to centennial climate variations is fuzzy at best.



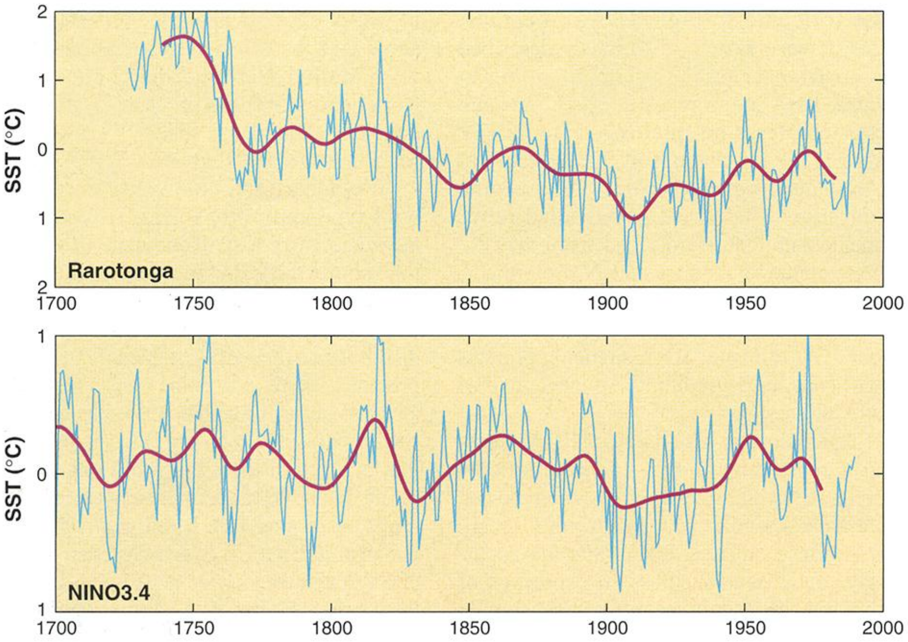
The dust bowl years. During the 1930s, drought conditions in the southwestern Great Plains region of the United States persisted for almost a decade. Millions of people migrated from the drought areas, often heading west in search of work. Photo taken in 1936 in Cimarron County, Oklahoma.

On page 1145 of this issue, Linsley *et al.* (*1*) report an important step toward some answers by presenting a proxy temperature record extending back almost three centuries. Lack of data is the primary reason for our poor knowledge of decadal climate variability. If you were not too fussy and were willing to avert your gaze from almost everywhere south of 30°S, you would have about 130 years of instrumental data providing something like global coverage. That would give you five or six periods of variation of 20 to 30 years each. To put this in perspective, consider recent advances in understanding the El Niño phenomenon, which varies on an interannual, not a decadal time scale. Progress might well have stalled if we had had only the last five or six events to work with. To understand decadal change, we clearly need information on longer time scales than our instrumental records can provide.

Researchers studying modern climate are accustomed to the luxury of instrumental data and typically react to the paleoclimatologist's necessary list of caveats by not buying any of their proxy data. However, proxies are the only source of records long enough to understand variations on time scales of decades and longer. By going to the South Pacific, where even now instrumental data are almost nonexistent, Linsley *et al.* have wisely followed the dictum of Wee Willie Keeler (*2*) to "hit 'em where they ain't." Although not problem free, the Sr/Ca ratio in corals they use is a true proxy thermometer, unlike δ^{18}O, which responds to both temperature and salinity. Their temperature record is persuasive. It is worth noting that generating so many Sr/Ca measurements relatively quickly and cheaply depends on an important technical advance (*3*).

More records of this length and quality would go a long way toward clarifying our picture of the modes of decadal variability. Fewer than 100 comparable records should be enough to fill in the big picture. Most of the variance in the climate record on time scales of less than a century seems to be captured in a handful of preferred modes of climate variability (*4*), many of which have names (and, invariably, abbreviations). For example, the North Atlantic Oscillation (NAO), most often defined by means of the sea level pressure difference between Iceland and the Azores, has variability at several periods; investigators have singled out the biennial and decadal bands (*5*). The NAO correlates with climate variations in Europe, the Middle East, and the eastern part of North America. The Pacific Decadal Oscillation (PDO), defined in terms of sea surface temperature (SST) in the North Pacific, is related to similar climate variations over North America (*6*).

There is no widely accepted theory for decadal variability. Perhaps the most interesting idea (*7*) invokes unstable ocean-atmosphere interactions at mid-latitudes, with the decadal time scale determined by the oceanic gyre circulation. Observational data have yet to confirm or contradict this theory, but the prevailing evidence is that the atmospheric response to mid-latitude SST perturbations is too weak to sustain long-term modes (*8*). Furthermore, the climate system varies at every frequency anyone has ever looked at, from the seasonal to the millennial and beyond. It is by



Evidence for a tropical source. (Top) Annual proxy SST record from Rarotonga (21.5°S, 159.5°W) from (*1*). **(Bottom)** Annual proxy NINO3.4 index (SST anomalies in the area from 150°W to 170°E, 5°S to 5°N) derived from tree ring data from the Americas (*13*). With a 12-year Hanning window filter, the correlation between the tree ring–based NINO3.4 index and the Rarotonga SST record (red lines) is –0.52 over the common interval 1739–1978. With an estimated 18 degrees of freedom, this correlation is significant at about the 98% level. The correlation and its significance are stable for Hanning windows of 9 to 20 years.

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no means established that "decadal variability" is sui generis, created by mechanisms that single out the decadal band for special treatment (*9*). If not, then the hunt for the decadal time setter will prove fruitless. The climate physics behind all of the variability must work in other ways. One clue is that many dynamical systems with nonlinearities or very large dimension also vary at all possible frequencies.

Both the PDO and the NAO extend into the tropics. It has been suggested that decadal variability in the tropical Pacific is induced from mid-latitudes through oceanic pathways, but this has now been convincingly ruled out by studies showing that observed variability in the tropical ocean is accounted for by low-latitude winds (*10*). It remains possible that the low-latitude wind changes are triggered from mid-latitudes, but the evidence for this is not strong. On the other hand, the same coupled ocean-atmosphere physics that generates the interannual El Niño cycle can generate variability at periods longer than interannual (*11*). Furthermore, the El Niño example, supported by much theoretical work and model experiments, demonstrates that variations in the tropics can generate variations at all latitudes. Linsley *et al.* (*1*) observe that the low-frequency variability in their Rarotonga record is related to variations in the North Pacific. This points to a tropical source, a suggestion made in some earlier studies of the shorter instrumental record (*12*). The time series shown in the second figure strengthens their case. A proxy record for SST anomalies in the central equatorial Pacific constructed from tree ring data in the Americas (*13*) correlates at the 98% significance level with the Rarotonga record over the common period 1739–1978 (see the second figure).

It would be impossible to establish statistical significance with the short records derived solely from instrumental data. With a number of well-placed, reliable proxy records several centuries in length and with annual resolution or better, progress in understanding decadal variability will accelerate. Even then, however, there is no guarantee that useful predictions will prove to be possible.

References and Notes

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5. Y. Kushnir, *J. Clim.* **7**, 141 (1994).
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8. J. J. Barsugli and D. S. Battisti [*J. Atmos. Sci.* **55**, 477 (1998)] explain correlations between the atmosphere and SST patterns as a consequence of these SST patterns thermally damping the atmosphere less than others. This "do the least harm" idea appears to explain the few studies that indicate an atmospheric model response to mid-latitude anomalies, most prominently the NAO simulations of M. J. Rodwell *et al.* [*Nature* **398**, 320 (1999)].
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11. M. A. Cane, S. E. Zebiak, *Science* **228**, 1085 (1985).
12. See especially (*12*) of (*1*), but also their (*3*) and (*13*).
13. M. N. Evans, A. Kaplan, M. A. Cane, R. Villalba, in *Present and Past Inter-Hemispheric Climate Linkages in the Americas and Their Societal Effects*, V. Markgraf, Ed. (Cambridge Univ. Press, Cambridge, in press).

PERSPECTIVES: MOLECULAR BIOLOGY

Unwinding RNA Silencing

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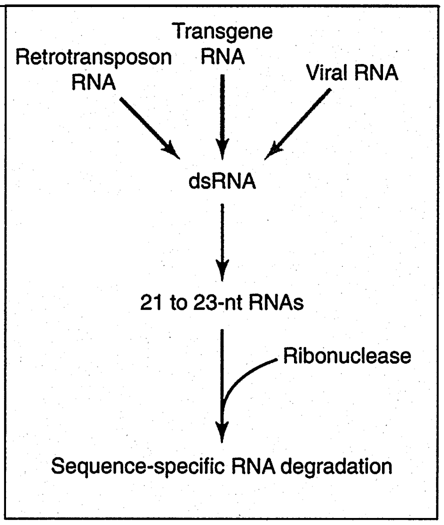
Eukaryotic cells have developed an elegant defense system to eliminate unwelcome foreign RNA molecules. This defense system is variously described as posttranscriptional gene silencing in plants, RNA interference in vertebrates and invertebrates, and quelling in fungi (*1*). Work in the worm and fruit fly suggests that RNA silencing may protect the genome from mobile DNA elements called retrotransposons that are derived from viruses. These elements produce an RNA intermediate that enables them to move about within the genome and to inactivate essential genes (*2*). In plants, RNA silencing protects plant cells by degrading the nucleic acid of RNA viruses (*3*).

The molecular machinery of RNA silencing is remarkable in that it targets not only foreign RNA but also other RNAs in the cell that have a similar sequence to the foreign RNA. Once initiated, RNA silencing apparently continues to suppress the expression of RNA species even after the original foreign RNA has been eliminated. Exactly how foreign RNAs are silenced is still unclear, but a report by Wu-Scharf *et al.* (*4*) on page 1159 of this issue is beginning to shed light on the mystery. These investigators describe a mutant form of the green alga *Chlamydomonas* in which RNA silencing is abrogated. They show that the affected gene in the mutant form, called *Mut6*, normally encodes an RNA helicase that has the capacity to unwind double-stranded RNA (dsRNA) such as that found in many RNA viruses.

Wu-Scharf and colleagues engineered wild-type and *Mut6* forms of *Chlamydomonas* to carry a synthetic gene (transgene) that conferred resistance to the antibiotic spectinomycin. When grown on medium containing this antibiotic, wild-type algae soon died because their RNA silencing mechanism prevented expression of the transgene, whereas *Mut6* algae (in which RNA silencing was shut down) grew robustly. What is more, the loss of RNA silencing in *Mut6* mutant cells resulted in an increase in the movement of the retrotransposons TOC1 and *Gulliver* within the algal genome. This demonstrated that the effect of a mutated *Mut6* gene is similar to the loss of the *Mut7* gene in worms, which is required for silencing of retrotransposon and transgene RNA (*2*).



Silencing RNA. Eukaryotic cells have several RNA silencing mechanisms. These detect and degrade foreign RNAs originating from viruses, retrotransposons, or transgenes (colored arrows). In one mechanism, foreign double-stranded RNAs (dsRNAs) such as those from viruses are processed into short 21- to 23-nucleotide sequences. These short sequences activate ribonuclease enzymes and guide them to the foreign RNA (and cellular RNAs of similar sequence), which is then degraded.

What is the cue for activation of RNA silencing? In some instances, the double-strandedness of RNA may be involved because, in worms and fruit flies, an effective means of activating RNA silencing is to directly introduce dsRNA into the cell (*5*). However, when the foreign nucleic acid is made of DNA, as is the case for retrotransposons and transgenes, it is possible that the cell detects misprocessing or premature termination of the singlestranded RNA transcribed from the foreign DNA. Wu-Scharf *et al.* show that aberrant RNAs—from the spectinomycin-resistance transgene, the TOC1 retrotransposon, and the

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