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The Tropical Pacific Ocean—Back in the Driver's Seat?

Amy Clement and Pedro DiNezio

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ing the evolution of the surface morphology of a specimen and then analyzing the result by means of the Navier-Stokes equation (*5*, *10*) or an equivalent model of fluid flow (*7*). The basic idea is that any nonflat surface structure (artificially or spontaneously created) produces pressure gradients that then drive the specimen to flow. In the lubrication approximation (usually applicable to thin-film specimens with thickness less than ~100 nm), the flow is planar and on average parallel to the pressure gradient. The current (or flow of fluid) per unit width is proportional to the pressure gradient and the film mobility, which can be used to determine the viscosity (*5*).

In one example study, the dynamics for the Brownian height fluctuations of an equilibrated film was monitored and modeled against that of overdamped surface capillary waves (*10*). In two others, surface structures, either shorter (*5*) or taller (*7*) than equilibrium, were created and the dissipative dynamics toward equilibrium (equivalent to that of the former example by the fluctuation-dissipation theorem) was monitored. To discern any anomalous surface mobility, the Navier-Stokes equation was solved for a bilayer film comprising a mobile layer on top of a bulk-like layer. The solution predicts that a crossover from bulk flow to surface flow can occur by either decreasing the thickness or lowering the temperature. The former has been verified by systematically decreasing the thickness from 86 to 2 nm (*5*).

Chai *et al.* measured the flattening dynamics of a step edge created on the surface of polymer films with an average thickness around 100 nm. Upon cooling the films, they observed an analogous flow transition at T_g. A previous experiment (*7*) studying the flattening of surface gratings imprinted on micrometer-thick films of an organic glass also observed a transition from bulk diffusion [a mechanism only feasible in thick films (*2*)] to surface diffusion at T_g + 12 K upon cooling the films. All these findings reinforce the conclusion that surface diffusion is directly tied to the phenomenon of enhanced surface mobility of glasses. Indeed, it becomes the dominant transport process upon lowering the temperature or thinning the specimen.

It remains unknown whether surface diffusion is possible for long-chain polymers, particularly for those with radii of gyration exceeding several nanometers [the thickness of the surface mobile region as derived from surface relaxation time studies (*4*, *6*), which can reveal local motions besides surface flow]. Efforts to understand the dynamics of these materials will have to incorporate material viscoelasticity in the data analysis, which has hitherto been treated sparingly (*11*–*13*).

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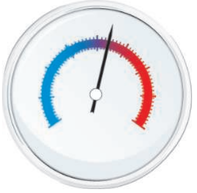
CLIMATE CHANGE

The Tropical Pacific Ocean— Back in the Driver's Seat?

Persistent cool conditions in the eastern tropical Pacific may explain the current global warming "hiatus."

Amy Clement[1] and Pedro DiNezio[2]

Average temperatures at Earth's surface are now higher than they were in the mid-19th century, but the rate of warming has not been steady. A pause in surface warming in the mid-20th century coincided with increases in the atmospheric concentrations of sulfate aerosols, which are generally understood to cool the planet. Surface warming resumed in the 1970s, when strong pollution controls were implemented in developed countries. Thus, a balance of warming by greenhouse gases and cooling by aerosols may explain the variable rates of surface warming in the past century. A pause in global warming since 2000—a global warming "hiatus"—has opened up new questions about natural and human activity-driven (anthropogenic) effects on global mean trends in surface temperature. Recent studies point to the importance of the tropical Pacific in driving these changes.



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A range of factors may have contributed to the current pause in global warming, including changes in stratospheric water vapor, aerosol concentrations (*1*), and reductions in the Sun's output (*2*). The quantitative influence of these factors is still uncertain. However, what is striking about the current hiatus is that while many regions of the globe have continued to warm, the tropical Pacific has been colder than it was during the latter part of the 20th century.

In a recent study, Kosaka and Xie (*3*) showed that by prescribing the cold temperatures in this region (which represents less that 10% of Earth's surface), their model can simulate the pause in global mean temperature since 2000, even when greenhouse gases have been increasing. In another climate model study, Meehl *et al.* found that a cold tropical Pacific increases the heat stored below the ocean surface, thus partially offsetting the warming at the surface (*4*). In the latter model, such hiatus periods arise as a result of natural variations in the climate system, implying that future global surface temperatures will be marked by periods of slowed and accelerated warming as a result of naturally occurring cold and warm periods in the tropical Pacific. Together, the two studies (*3*, *4*) make a compelling case for a modulating effect of the Pacific.

Will these results hold up in other models? The answer depends on the Pacific's natural

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[1]Rosenstiel School of Marine and Atmospheric Science, University of Miami, 4600 Rickenbacker Causeway, Miami, FL 33149, USA. [2]School of Ocean and Earth Science and Technology, University of Hawaii at Manoa, Honolulu, HI 96822, USA. E-mail: aclement@rsmas.miami.edu

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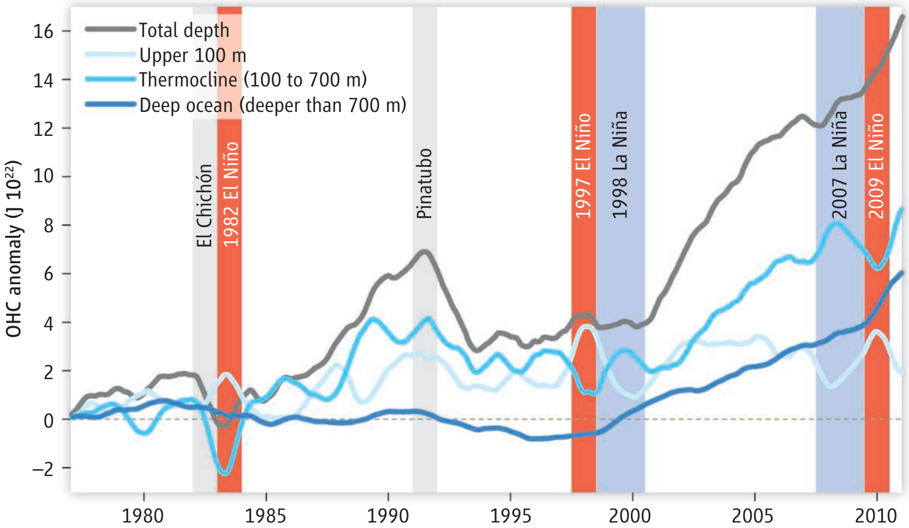

Oceanic heat sink. Evolution of the ocean heat content (OHC) at several depths of the global ocean between 1980 and 2011. Since 2000, the subsurface ocean has warmed much faster than in the preceding two decades; this ocean warming may explain why average atmospheric temperatures have not risen during the past decade. The gray bars show the timing of the El Chichón and Pinatubo volcanic eruptions. The yellow and blue bars show the timing of several key El Niño and La Niña events. Data from the ORAS-4 ocean reanalysis (*10*).

variability, the warming response to greenhouses gases, and the cooling effect of aerosols —a balance of processes that models may not represent accurately. Model-simulated climate sensitivity to anthropogenic greenhouse gases ranges from 2° to 6°C warming, with some models simulating even higher values (*5*). The potential offsetting effects of anthropogenic aerosols are even more uncertain (*6*). The simulation of natural decadal variability is also highly model dependent, with models generally underestimating the magnitude of decadal climate variability in the Pacific (*7*). The interaction among these processes must be represented accurately in a multimodel framework to assess how confident we can be in the attribution of the global warming hiatus.

Examining Earth's energy budget could help to determine whether changes in the tropical Pacific or in aerosols are the main cause of the current hiatus. For instance, there is some observational support for the hypothesis that the missing anthropogenic heat is being stored below the ocean surface (*8*), as proposed by Meehl *et al.* (*4*). Since 2000, the global ocean heat content has increased much faster in the thermocline (between 100 and 700 m) than in the deep ocean (below 700 m), whereas the surface layer (the upper 100 m) has not shown much warming (see the figure) (*9*, *10*). The changes in the thermocline—which is highly responsive to changes in winds—are dominated by the Pacific, where stronger trade winds associated with cold tropical sea-surface temperatures may be instrumental for the penetration of the warming below the ocean surface (*9*, *10*). Although the pathways and rates at which heat is stored in the ocean are still uncertain, these results are consistent with what is expected from a cold tropical Pacific.

If indeed the tropical Pacific is central to the current hiatus, then it may take a while until the Pacific shifts into a warm state and global surface temperatures resume their upward trend. In the past, warm and cold states have lasted for several decades. The last cold period from 1945 to 1975 was followed by a warm period from 1976 to the end of the 20th century (*11*). Some authors have argued that these decadal changes in the Pacific are driven by changes in ocean circulation (*12*), implying some degree of predictability, but others argue that they can arise in response to random forcing from the atmosphere (*13*), with cloud feedbacks potentially playing a role in how long the cold or warm states linger (*14*). The question of what drives decadal changes in the Pacific, as well as their predictability, takes on new urgency in the context of the current hiatus.

Looking back into the past may help to unravel the role of the Pacific Ocean in modulating changes in global mean surface temperature. For example, the mid-20th-century cooling is generally attributed to large increases in sulfate aerosols (*6*), but the cold state of the tropical Pacific may have played a role as well. It is worth reconsidering the balance of natural and anthropogenic effects during this period. Large ensembles of climate models run with historical changes in greenhouse gases and aerosols, as well as natural climate forcings (solar output and volcanoes) (*15*), will allow this balance to be quantified in models. Proxies for past climatic conditions—for example, from corals or tree rings—can also provide more observations of decadal-scale shifts in the tropical Pacific climate and help to determine how well climate models simulate the range of variability of the preindustrial climate (*7*).

The current pause in global mean surface warming has opened new and exciting research questions about the role of the tropical Pacific. A next step is a full attribution of the effects of natural and anthropogenic influences on the Earth's energy budget. How much of the energy gained at the top of the atmosphere is due to greenhouse gases, and how much is reflected back to space by aerosols and clouds or redistributed through the Earth system, in particular stored in the ocean? Is it possible to accurately determine whether aerosols are having an influence on ocean-warming rates during the current hiatus? Answering these questions will require extensive observations and well-tested models to quantify the relative influence of greenhouse gases, anthropogenic aerosols, and internal variability on the Earth's energy budget.

Although high-quality observations of the radiative fluxes at the top of the atmosphere and in the upper 2000 m of the ocean are available for the period since 2000, their estimates of interannual variations in energy gains do not agree (*16*). This issue needs be solved before an attribution of the relative roles played by internal variability versus anthropogenic aerosols can be made. Determining how these rates compare with prior periods of global warming for which climate-quality observations are limited is even more challenging. Furthermore, models and reanalysis data suggest that the upper 700 m of the ocean play a key role storing the excess energy during hiatus periods, whereas the deep ocean may reflect the longer greenhouse gas-driven warming trend. To increase the accuracy of ocean heat content estimates, it is critical that observational capability in the ocean, including arrays of autonomous profiling floats and tropical moorings, is maintained and expanded.

Greenhouse gases are warming the planet, and will continue to do so. Developing a framework for measuring and attributing subtle variations in the global energy budget—from the top of the atmosphere to the depths of the ocean— is one of the outstanding challenges. This research will lead to a more complete and dynamic view of energy flows within the global Earth system, where perhaps the tropical Pacific is indeed in the driver's seat.

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NEUROSCIENCE

The Neural Code That Makes Us Human

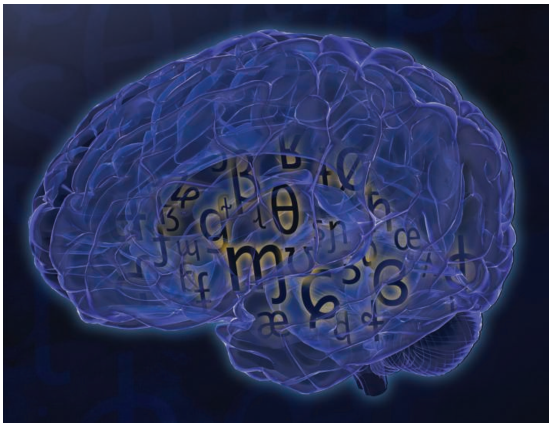
How does a certain pattern of vibration in the air reliably represent a meaningful speech sound?

Yosef Grodzinsky[1,3] **and Israel Nelken**[2,3]

Speech provides a fascinating window into brain processes. It is understood effortlessly, and despite a huge variability, manifests both within and across speakers. It is also a stable and reliable carrier of linguistic meaning, complex and intricate as it may be. How speech is encoded and decoded has puzzled those seeking to understand how the brain extracts sense from an ambiguous, noisy environment (see the figure). On page 1006 in this issue, Mesgarani *et al.* (*1*) demonstrate the neural basis of speech perception by combining linguistic, electrophysiological, clinical, and computational approaches.

How do brains use the pattern of pressure waves in the air that is speech ("speech-as-sound") and extract meaning ("speech-as-speech") from it reliably, despite huge variability between speakers and background noise? Studies dating as far back as the 1950s showed that natural speech is highly redundant—speech sounds convey their identity by a large number of disparate acoustic cues (*2*). However, to ensure stable cue-to-speech translation by brains, an invariant code—something like a dictionary of speech units—seems necessary. What, then, is the nature of the representation of speech units in the brain, and how do they combine into larger, meaning-bearing pieces?

In the 1930s, linguists Roman Jakobson and Nikolai Trubetzkoy classified consonants and vowels along articulatory dimensions: Their description of the basic units of speech recognition referred to elements such as the place in the oral cavity where air is compressed on its way out ("labial," "dental," "velar," etc.), the manner of air release ("plosive," "sonorant," etc.), and whether the vocal cords vibrate or not ("voiced," "unvoiced") (*3*). For example, the sound /p/ is a composite of features—[+labial, –voiced, +plosive]—distinguishable from /b/ [+labial, +voiced, +plosive] and from /t/ [+alveolar, –voiced, +plosive]. Distinctive features, then, help to characterize the nature of invariance, while systematically grouping speech units in clusters. These features have therefore played a central role in speech recognition research.



Speech perception. How highly variable speech sounds (vowels and consonants) are represented as stable phonetic units in the brain has not been clear. Acoustic-to-phonetic transformation may involve processing in the superior temporal gyrus of the human brain (*1*). The illustration shows phonetic symbols from the International Phonetic Alphabet superimposed on the language regions of the left cerebral hemisphere.

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But what actually happens in human brains during speech perception, and where? It may be that invariance is expressed in terms of articulation-related distinctive features (as proposed by linguists). Invariance may also be reflected already in sensory areas; alternatively, brain processes may achieve invariant representations of speech sounds only outside the auditory system proper. One extreme possibility is that distinctive features correlate with acoustic ones, in which case the invariant coding of sounds may already occur in sensory areas. At the other extreme, as suggested by the influential motor theory of speech perception, speech sounds may well be represented by the articulatory gestures used to produce them (*4*). A recent form of this view actually posits mirror neurons in the brain that do precisely that—map sounds onto motor actions. In that case, the invariant representation of speech would by necessity occur in motor areas, outside of the auditory system (*5*).

Mesgarani *et al.* recorded responses to speech sounds in the brains of human patients who were about to undergo brain surgery for clinical reasons. These recordings give a more detailed view of the electrical activity in the human brain than noninvasive methods such as electroencephalograms or functional magnetic resonance imaging, although they still reflect the average responses of large neuronal populations. Using these electrical signals, the authors demonstrate a high degree of invariance of speech representation as early as in the human auditory cortex by showing that speech sounds of different speakers and

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[1]Department of Linguistics, McGill University, 1085 Dr. Penfield Avenue Montréal, Québec H3A1A7, Canada. [2]Department of Neurobiology, The Alexander Silberman Institute of Life Sciences, Hebrew University, Jerusalem, 91904 Israel. [3]The Edmond and Lily Safra Center for Brain Sciences, The Hebrew University of Jerusalem, Givat Ram, Jerusalem 91904, Israel. E-mail: yosef.grodzinsky@mcgill.ca

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