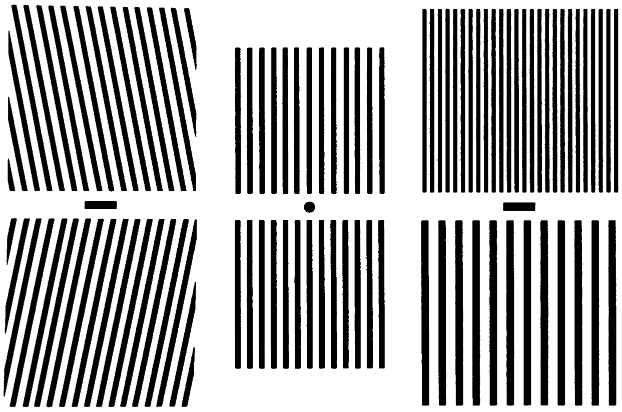

Adapt your cortical cells. First, look at the dot between the central gratings and confirm that they are both vertical and have the same spacing. Then, place the figure about 30 cm in front of you and fix your eyes for 30 s on the black strip between the left gratings, moving them along the strip but not outside it. Next, transfer your gaze to the central dot and compare the upper and lower gratings; for a brief period the upper grating should appear tilted to the right and the lower one to the left. To produce an illusion of size, repeat the procedure by adapting to the right pair of gratings. [Adapted from (*6*)]

As expected, movement of a grating over the portion of the visual field that excites a neuron causes a modulated stream of action potentials that diminish in number during adaptation. The new result is that the stimulus-induced responses of the intracellular potential are barely attenuated by adaptation; instead, the reduction in the number of action potentials is caused by a slowly developing and persistent increase in the negative intracellular potential of the cell, so that a diminished fraction of each cycle of modulation rises above the cell's firing threshold, and fewer impulses occur with each cycle as adaptation progresses. They obtained no direct evidence about the cause of this hyperpolarization, but it was not accompanied by any significant change in the membrane resistance of the cell.

The biophysical mechanisms underlying this phenomenon are likely to be the subject of further experiment and argument, but the existence of a factor that slowly changes the membrane potential of a cortical neuron may tie in with other recent developments.

The increase in the cortical response that occurs when an animal is attending to a particular stimulus could be accomplished by such a tonic process that depolarizes the neuron (*2*). Although in the opposite direction, this could work through the same mechanism as the hyperpolarization of adaptation. There are also dramatic changes in the receptive fields of neurons in the primary visual cortex when regions outside the receptive field are stimulated, which could result from a change in the neurons' responsiveness (*3*). If so, this plasticity could also use the same mechanism. There is little evidence to decide whether such a common modulatory system would work through tonic excitation that is increased by attention or surround stimulation and decreased by adaptation, or through tonic inhibition with the directions of change reversed.

Glutamate released into the synaptic cleft of hippocampal neurons can leak back to metabotropic glutamate receptors on the synaptic terminals, thereby inhibiting further release (*4*). Such negative feedback looks at first like a promising mechanism for adaptation, but if it were operative in Carandini and Ferster's experiment it would have decreased the modulated response and would only cause a persistent hyperpolarization if a high proportion of the neuron's tonic input were presynaptically inhibited; hence, it cannot explain adaptation at these neurons, but serves as a warning that adaptation in the cortex is a not a simple affair.

There are other adaptation experiments in the pipeline (*5*) showing that cortical neurons adapt and respond to the joint presentation of two patterned stimuli in a manner that cannot be accounted for by their adaptation to the stimuli presented separately, suggesting that a component of their adaptation is contingent on their joint presence during adaptation. The cerebral cortex, a part of the brain that first appeared in mammals and is largest in primates and humans, is thought to give its owner the power to adapt its behavioral responses in accordance with variations in enviromental circumstances. This in turn requires it to take account of the observable statistical contingencies and associations, for it is these that necessitate something beyond a stupid, invariant response. Neurophysiology has so far told us very little about how the cortex does this, so this ability to adapt to contingencies is particularly interesting, and the elucidation of adaptation mechanisms may ultimately give us insight into these broader problems of cortical function.

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CLIMATE CHANGE

Are We Seeing Global Warming?

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The measured increase in global mean surface temperature since the last century is about 0.5°C. This value is consistent with the predictions of state-of-the-art climate models (see figure, top), but an order of magnitude smaller than the climate variations experienced year for year in any given region of the Earth (*1*). Regional climate fluctuations are largely due to shifts in air masses and tend to cancel when averaged over the globe or over a longer time period. Thus, attempts to detect anthropogenic global warming have focused on global scales and long-term trends. Despite considerable progress, the question of whether the observed gradual increase in global mean temperature over the last century is indeed caused by human activities or is simply an expression of natural climate variability on larger spatial and temporal scales remains a controversial issue.

To answer this question we need to (i) predict the anthropogenic climate change signal, (ii) determine the natural climate variability noise, and (iii) compute the signal-to-noise ratio and test whether the ratio exceeds some predefined statistical detection threshold. The last problem is the easiest one. It can be solved by generalizing standard signal analysis methods developed for

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the detection of time-dependent signals in noisy time series to the space-time–dependent case (*2*). A space-time filter, or fingerprint, is used to enhance the less noise–contaminated components.

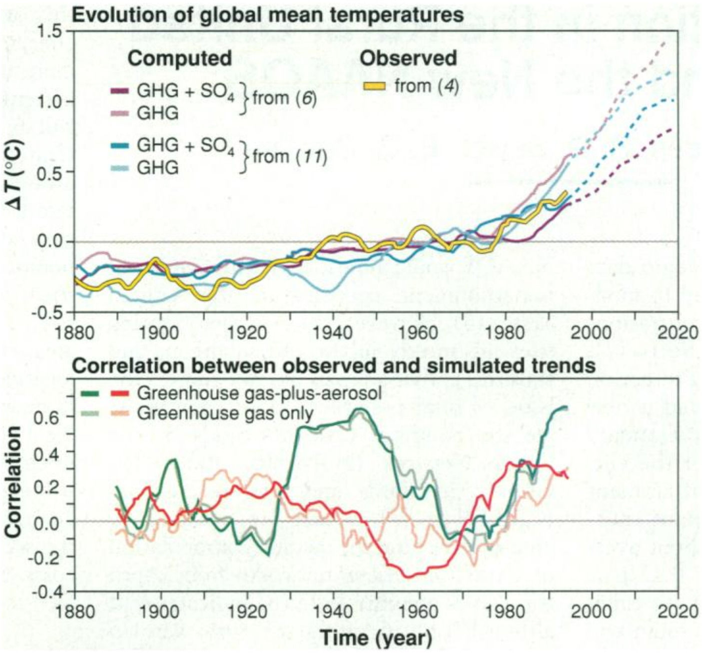
The first two problems are more difficult ones. Are climate models sufficiently reliable to predict the climate change signal that we wish to extract from the natural variability noise? And do we know the space-time structure of natural climate variability well enough to meaningfully apply the fingerprint technique?

Modern climate models consist of coupled ocean-atmosphere general circulation models (CGCMs) that integrate basic fluid dynamical equations. They simulate the time-dependent three-dimensional flow fields and associated transports of mass, heat, and other fluid properties at a resolution of typically a few hundred kilometers. Processes below this resolution (such as clouds and ocean eddies) cannot be represented explicitly and must be parameterized, that is, expressed in terms of the resolved larger scale motions. This is the major source of uncertainty of CGCMs. Advances in supercomputers enabling higher model resolution have helped reduce these uncertainties, and the latest greenhouse warming simulations by different modeling groups show a scatter of only 20% in the predicted global mean temperature, compared with a value of typically 50% a few years ago (*3*). But significant differences still exist in the predicted patterns of temperature change, or in other distributions such as precipitation or sea level rise.

Similar uncertainties apply to the estimation of natural climate variability on the decadal-to-century time scales relevant for anthropogenic climate change detection. The instrumental record for global surface temperatures extends back over little more than a hundred years (*4*), insufficient for useful estimates of climate variability except at short decadal time scales. The instrumental record can be augmented by longer paleoclimatic records from tree rings, corals, or deep-ocean cores (*5*), but such proxy data also have numerous problems of interpretation.

Nevertheless, combining these independent analyses, various groups have produced best-guess estimates of the space-time structure of natural climate variability and have applied fingerprint methods to test whether the global warming pattern predicted by state-of-the-art climate models can be detected in the observed temperature data (*6*–*8*). The general conclusion of these efforts (adorned by numerous caveats), in the cautious words of the Intergovernmental Panel on Climate Change (IPCC), is that "the balance of evidence suggests a discernible human influence on climate" [(*3*), p. 4].

The hesitant reversal of the original negative detection assessment of the first 1990 IPCC report (*9*) was the fruit not only of improved models and the application of more advanced fingerprint techniques, but also a shift of focus from the 100-year temperature trends to shorter 30-year trends, whose noise statistics can be more reliably determined, and which exhibit higher signal-to-noise levels—a consequence of the accelerated warming in recent decades (see figure, top). Another important factor was the availability of new global warming predictions including both greenhouse gases and aerosols, which gave better agreement between the observed and predicted temperature patterns (see figure, bottom). However, the impact of aerosols is still poorly known, and the pattern correlations for the greenhouse gas-plus-aerosol forcing shown in the figure, although generally higher in the last decades than for the greenhouse gas–only case, are still relatively low. A statistically significant climate change signal was nevertheless detected, as this is dominated by the pattern-independent global mean temperature (*6*).



Patterns of climate change. (**Top**) Evolution of observed (*4*) and computed global mean temperatures. Curves GHG (*1*) and GHG + SO_4 (*1*) for greenhouse gas-plus-aerosol forcing are from Hegerl *et al.* (*6*). The corresponding curves GHG (*2*) and GHG + SO_4 (*2*) are from computations with the improved model of Roeckner *et al.* (*11*), see also (*7*). (**Bottom**) Pattern correlation between observed 30-year trends and climate change signal simulated for the greenhouse gas only case and the greenhouse gas-plus-aerosol case (green). Also shown are correlations after subtraction of the spatial mean from the patterns (red). [Adapted from Hasselmann *et al.* (*12*), see also (*7*)]

A reduction in the present uncertainties would significantly improve our confidence not only in the detection of climate change, but also in its attribution to anthropogenic greenhouse warming (*10*). This requires further research not only on the impact of aerosols, but also on the sources of the discrepancies in the global warming patterns predicted by different CGCMs. Foremost among these are the role of clouds, the interactions between the tropical ocean and the global atmospheric circulation, the coupling between the atmosphere, ocean, and sea-ice in high latitudes, and the snow and soil water budget (*3*).

However, the inherent statistical uncertainties in the detection of anthropogenic climate change can be expected to subside only gradually in the next few years while the predicted signal is still slowly emerging from the natural climate variability noise. It would be unfortunate if the current debate over this ultimately transitory issue should distract from the far more serious problem of the long-term evolution of global warming once the signal has been unequivocally detected above the background noise.

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