increased, thus increasing the computing power per chip. Because the basic cost of manufacturing the microchip has not dramatically increased over these four decades, the cost per functional unit, and the cost of computing power, has gone down exponentially. It is this economic argument, the cost of silicon real estate, that drives Moore's Law.

For the past decade, however, the size of the microchip has remained roughly constant, so that factors (i) and (iii) have become more important. Today, as pointed out above, we are approaching the atomic limit on critical size. We are left, therefore, with the conclusion that it is factor (iii) that will have to provide the continuity to Moore's Law. What does this say about the role of nanowires?

Although transistors have very short gate lengths (the critical dimensions mentioned above), they have much larger widths in order to provide the current necessary to make the circuits work. If we are to replace the current planar transistor with nanowires, we will have to use a great many such devices in parallel to provide this current. But, we must satisfy the above economic driving forces, and effectively use the overall silicon real estate. This leads to a geometric argument that says that nanowires in the plane will not effectively compete with novel transistors such as the "fin" field effect transistor, or "finFET," Basically, the finFET is a vertically oriented Si "fin" in which transistor structures can be placed on both sides (*8*, *9*), and even on the top (*10*), of this fin. A properly configured finFET more effectively uses silicon real estate. Consequently, there does not seem to be much of a role for nanowires laid horizontally on the Si surface (*11, 12*). However, nanowires can be grown vertically, and this growth can be initiated on a wide variety of substrates (*4*).

As mentioned, currently the transistors are placed in a planar array, but they are overlaid with a great many metal lines, with nine or more levels of metal (worse than any freeway interchange). These metal lines provide power, clock signals to synchronize the switching of the transistors, and various interconnections between the different functional blocks of the chip. Connections from these metal lines to the transistors are made by downwardly reaching metal fingers called "vias." When we can no longer reduce the transistor size, we enhance the use of Si real estate by moving vertically.

Our third Moore's Law factor—cleverness—can be increased by replacing some of these vias with vertical nanowire transistors (*13*) (see the figure). These vertical transistors can reach from the silicon to a metal wire or even between different levels of metal wire. Moreover, we can begin to think about creating reconfigurable architectures in which the connections between different functional blocks are changed by switching just a few of these vertical transistors. Thus, we begin to create real three-dimensional architectures in a different manner from the traditional approach of stacking chips (*14*).

If we are to use these vertical transistors for more effective architectures, then we have to change how we go about microchip design. Today, this chip design is done with automated transistor layout programs that optimize the planar design placing of the various functional blocks and minimize the necessary interconnections (in the metal layers). To change to reconfigurable architectures, we need switchable interconnections based on vertical transistors, and device physicists will have to work with circuit designers to achieve this. These new opportunities for nanowires to extend Moore's Law may well force this paradigm shift.

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CLIMATE

Food Security Under Climate Change

Food insecurity is likely to increase under climate change, unless early warning systems and development programs are used more effectively.

Molly E. Brown and Christopher C. Funk

Some of the most profound and direct impacts of climate change over the next few decades will be on agricultural and food systems. On page 607 of this issue, Lobell *et al.* (*1*) show that increasing temperatures and declining precipitation over semiarid regions are likely to reduce yields for corn, wheat, rice, and other primary crops in the next two decades. These changes could have a substantial impact on global food security.

Since the 1990s, rising commodity prices and declining per capita cultivated area have led to decreases in food production, eroding food security in many communities (*2*). Many regions that lack food security rely on local agricultural production to meet their food needs. Primarily tropical and subtropical, these regions are substantially affected by both global climate variations and global commodity price fluctuations. Warming in the Indian Ocean (*3*) and an increasingly "El Nino–like" climate (*4*) could reduce main-season precipitation across parts of the Americas, Africa, and Asia (see the figure).

In food-insecure regions, many farmers both consume their product and sell it in local markets. This exposes farmers to climate variations, because when they produce less their income goes down while their costs go up to maintain basic consumption. Large-scale hunger can ensue, even when there is sufficient food in the market that has been imported from elsewhere.

National revenue can also be affected by large-scale droughts, which restrict the ability of countries with small budgets to purchase grain on the international market. Thus, recent large increases in grain prices reduce access to food for the poor, for example, in Tanzania, who compete for corn with ethanol producers and hog farmers in the United States. Finally, up to half of all malnutrition is driven by nonfood factors through diseases such as HIV/AIDS and malaria; the latter disease is

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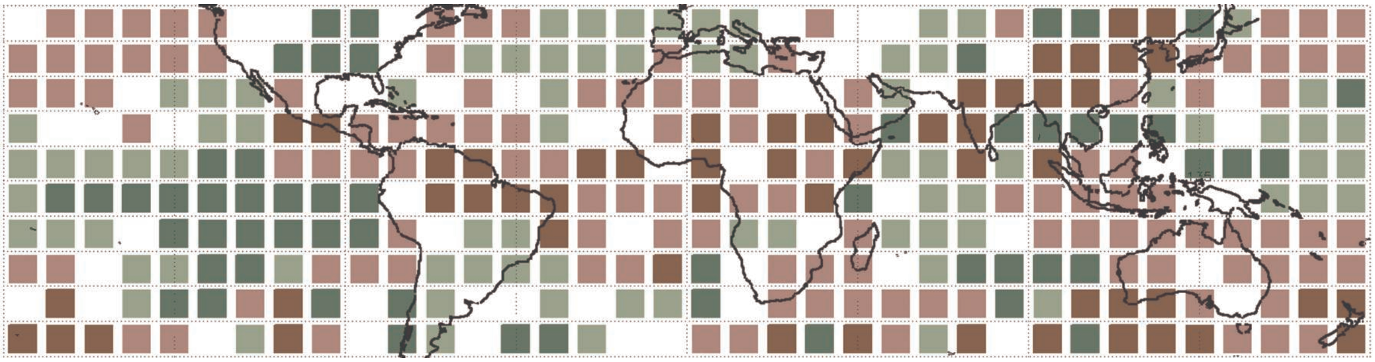

Upcoming change. Each 10° grid cell in this map shows the anticipated impact of warming in the Indian (*3*) and eastern Pacific (*4*) Oceans, expressed as a shift in standardized precipitation, ΔP, in the dominant 3-month season (*8*). σ is the standard deviation. Several regions where precipitation is likely to change over the next 50 years—such as eastern and southern Africa—already face significant food security problems.

likely to become more severe and widespread with warming temperatures.

Lobell *et al.* use crop models to calculate changes in agricultural production to 2030. The results show that climate change is likely to reduce agricultural production, thus reducing food availability. Identifying the impact of this reduced production will, however, be complicated by other changes. The latter include rising oil prices, the globalization of the grain market, and a structural change in demand for key food supplies due to increasing demand for biofuels and rising per-capita consumption in India and China. These changes have pushed up supply costs for staple foods by 40% or more in many food-insecure areas. Decoupling these effects to implement mitigation and adaptation programs will be difficult.

Climate change impacts on farmers will vary by region, depending on their use of technology. Technological sophistication determines a farm's productivity far more than its climatic and agricultural endowments. Food insecurity, therefore, is not solely a product of "climatic determinism" and can be addressed by improvements in economic, political, and agricultural policies at local and global scales. In currently food-insecure regions, farming is typically conducted manually, using a hoe and planting stick with few inputs. The difference between the productivity of these farms and those using petroleum-based fertilizer and pesticides, biotechnology-enhanced plant varieties, and mechanization is extreme (*5*). Not only will climate change have a differential effect on ecosystems in the tropics due to their already warmer climates, but also poor farmers in the tropics will be less able to cope with changes in climate because they have far fewer options in their agricultural system to begin with. These handicaps can be exacerbated by macro-economic policies that create disincentives for agricultural development, such as agricultural subsidies in the United States and Europe and poorly implemented cash transfer programs (*6*).

The study by Lobell *et al.* suggests that communities can cope with climate change, for example, by switching from producing corn to producing sorghum, whose lower water requirements and higher temperature tolerances are better suited to a warmer and drier climate. However, this adaptation measure may be impossible to implement in many parts of the developing world. For example, it assumes markets for millet in regions where only maize is eaten, and technology and know-how about how to process and consume sorghum in maize zones. Communities may nevertheless be forced, as they are today, to consume what they produce regardless of cultural preferences.

Today, millions of hungry people subsist on what they produce. If climate change reduced production while populations increase, there is likely to be more hunger. However, it may still be possible to reduce world hunger through programs that feed the poor during crises and by investing in agricultural inputs such as fertilizer and improved varieties that can dramatically increase yields (*2*). Improved environmental monitoring and prediction systems can provide more effective early warnings, which may help governments to take action to preserve the thin agriculture production margins by which many make ends meet (*7*). Early warning systems involve extensive climate monitoring and prediction tools that could be used to enhance agricultural development programs. Crop insurance programs that are triggered by remote sensing data products may ensure farmer's livelihoods even in drought years. Investments in improved seeds and varietals and an augmented use of inorganic fertilizer (*2*, *6*) can increase yields. Improved local governance, reduced developed-world agricultural subsidies, and more nuanced food aid policies that protect local markets could together produce rapid improvements in food access and availability, reducing hunger while providing for more people.

30% of farmers in developing countries are food-insecure; the work of Lobell *et al.* suggests that climate change may impact these undernourished communities by decreasing local yields while contributing to a global increase in commodity prices through significant global reduction in the production of corn, wheat, and rice. Despite these challenges, the very low agricultural productivity of food-insecure countries presents a great opportunity. Transform these agricultural systems through improved seed, fertilizer, land use, and governance, and food security may be attained by all.

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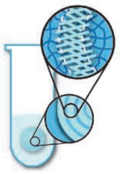

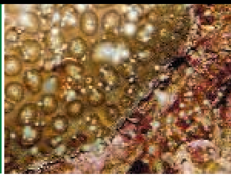

LETTERS

edited by Jennifer Sills

Ensuring Food Security

IN A RECENT PERSPECTIVE, "FOOD SECURITY UNDER CLIMATE CHANGE" (1 February, p. 580), M. E. Brown and C. C. Funk conclude that improved seed, fertilizer, land use, and governance lead to food security. I find these claims highly questionable. The green revolution model (monocultures of improved crops supported through high levels of agrochemical and other inputs) has done much to increase agricultural productivity. It does little, if anything, to increase food security.

Farmers in developed countries raise and sell crops but buy their food in supermarkets. Despite improved seeds and fertilizers, crops sometimes fail. When this happens, Western farmers receive government or other insurance payments. This scenario does not always apply in less developed regions or to subsistence farmers.

Across the wide scope of agriculture, there are plenty of ecologically sound, food-ensuring mechanisms. At the farm level, land modifications, climatically stable agroecosystems, plot landscape positioning, alternative crops or varieties, in-soil vegetative material, and well-placed biodiversity can all play a role in countering unfavorable climatic events.

Organized traditional societies avoid recurrent periods of starvation through multiple and overlapping mechanisms. For example, the Incas used crop varieties, communal irrigation, stone terraces, and plot scattering, along with community food storehouses, to lessen or mitigate famines.

Less organized farmers often rely upon a single mechanism. In wetter regions of West Africa, farmers plant rainfall-demanding rice along with drought-resistant cassava. Early European and traditional African societies placed a greater reliance upon climatically resilient tree crops. In early Europe, the acorn was the bailout crop (*1*). In Africa, there are a number of fruiting tree species that yield even when staple crops are lost (*2*).

Another advantage of alternative agricultural models—always in place, always functioning—is that they do not require monitoring or prediction.

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Incan terraces. Societies throughout history have used a variety of methods to ensure food security. Stone terraces built by the Incas are one example.

Response

WOJTKOWSKI SEEMS TO ASSERT THAT MONItoring and prediction of variations in agricultural productivity are not only unnecessary, but actually a waste of resources for ensuring food security. He also seems to assert that we propose a one-size-fits-all, Western, agribusiness solution. We disagree with both of these assertions. Our suggestions regarding how to ensure adequate food availability in regions chronically food-insecure certainly include many of the food-ensuring approaches mentioned by Wojtkowski, such as land modifications and plot landscape positioning. Our piece also focused on other issues that affect the ability of the poorest and most vulnerable to access food, such as governance and technological transformation. The sources of food insecurity are complex and will require complex solutions (*1*).

While there is a role for conventional seed, fertilizer, and other technology, many natural resource management techniques mentioned by Wojtkowski have been successfully implemented in the Sahel and can lead to incremental gains that help close the food security gap. Farmers in Africa have always had diverse agroecosystems, and examples abound of those who have increased their agricultural diversity and productivity. An excellent example is Niger, where tree planting and conservation have transformed highly degraded landscapes into productive agroecosystems. Farmers are able to produce more food on less land, more reliably (*2*, *3*). Nevertheless, Niger faces chronic and mounting food-production challenges that will be difficult to meet through improved landscape ecology alone. In Niger, 20 years ago, fertility rates were seven children per woman. Today, fertility rates are 7.2 per woman, and Niger has cultivated 91% of its potentially cultivatable land. Under current population and agricultural expansion rates, Niger will run out of new land to cultivate by 2015 (*4*).

Issues of food security are compounded by the impacts of poor governance on food access and utilization. Governance includes the education of women and children, provision of clean water and health care, and a stable functioning market system. Again, Niger is a good example of the complexity of the food security problem (*4*). There are still incredibly high levels of malnutrition in the country, particularly among children. In the 2004–2005 crisis, chronic malnutrition caused by poor child-feeding habits and an insufficiently diverse diet was exacerbated by declines in food production outside of the

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country and high food prices. These changes in food availability and access caused massive increases in enrollments in child-feeding programs and a large increase in the need for humanitarian assistance.

Ensuring food security for all in the face of climate-caused reductions will require adequate food production through improved seed and fertilizer; better land use policies and good governance; as well as appropriate interventions, safety nets, and investments during crises. Africa's culture, landscape, and challenges are complex, and complex solutions integrating responses from the social, political, economic, and biophysical domains will be required.

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Coarse-Resolution Models Only Partly Cloudy

IN THEIR REPORT, "A MADDEN-JULIAN Oscillation event realistically simulated by a global cloud-resolving model" (14 December 2007, p. 1763), H. Miura *et al.* promote the impression that coarse-resolution climate models cannot simulate the Madden-Julian Oscillation (MJO). We would like to point out that some coarse-resolution climate models, using conventional parameterizations of convection and clouds, can represent the boreal winter and summer MJO with fidelity (*1*–*9*).

In several studies, one coarse-resolution atmospheric model validated the MJO in terms of convection, eddy stream function, and surface evaporation, and it was hypothesized that lack of air-sea interaction contributed to shortcomings in the MJO simulation (*1*). This hypothesis was later borne out, resulting in a more realistic MJO simulation (*2*). Subsequently, the model was used for idealized predictability studies that demonstrated the potential for the MJO to be forecast with lead times of 15 to 30 days (*3*). Using a different set of models, for which more complete model diagnostics were available, important aspects of the MJO were realistically represented, including the relationships between convection and low-level moisture convergence, surface fluxes, the vertical structure of winds and divergence, and air-sea interactions (*4*). None of these relationships, including the spontaneous generation of MJOs, have been adequately demonstrated in Miura *et al.* to justify their claim of a realistic MJO or their inference that high-resolution models may be necessary to represent the MJO.

Other coarse-resolution simulations capture the northward propagating component of boreal summer intraseasonal variability (*5*–*7*). During both summer and winter, a realistic representation of the time-mean climate state is required to produce a realistic MJO (*4*, *8*, *9*). These works provide evidence that coarse-resolution climate models have been successful in understanding mechanisms involved in the propagation of the MJO, and for exploring important applications of MJO variability and predictability.

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CORRECTIONS AND CLARIFICATIONS

Newsmakers: "Thermometer kings" (4 April, p. 29). Richard Porter's thermometer collection did not include an earring thermometer from a 1650 whaling ship.

News of the Week: "China's modern medical minister" by R. Stone (28 March, p. 1748). Chinese minister Wan Gang's name was misspelled.

Random Samples: "Homeward buzz" (March 14, p. 1465). The article referred to a "colony of 750,000" bees. The collection is actually 56 colonies of 14,000 bees each. Each colony has its own queen.

Reports: "Asphericity in supernova explosions from late-time spectroscopy" by K. Maeda *et al.* (29 February, p. 1220). In author affiliation 16, the name of the institution should have been Institute of Space and Astronautical Science (not Astronomical Science). In ref. 8, the order of author names was incorrect. The reference should read as follows: 8. R. Buras, H.-Th. Janka, M. Rampp, K. Kifonidis, *Astron. Astrophys.* **457**, 281 (2006).

Reports: "Nonadiabatic interactions in the $Cl + H_2$ reaction probed by ClH_2^- and ClD_2^- photoelectron imaging" by E. Garand *et al.* (4 January, p. 72). This research was supported by Air Force Office of Scientific Research grant F49620 03 1 0085 (D.M.N.), NSF grant CHE0413743 (M.H.A.), and Office of Naval Research grant N000140510460 (D.E.M.). E.G. thanks the Natural Science and Engineering Research Council of Canada for a postgraduate scholarship.

TECHNICAL COMMENT ABSTRACTS

COMMENT ON "Long-Lived Giant Number Fluctuations in a Swarming Granular Nematic"

I. S. Aranson, A. Snezhko, J. S. Olafsen, J. S. Urbach

Narayan *et al.* (Reports, 6 July 2007, p. 105) reported giant number fluctuations attributed to curvature-driven active currents specific for nonequilibrium nematic systems. We present data demonstrating that similar results can be found in systems of spherical particles due either to inelastic clustering or persistent density inhomogeneity, suggesting two alternative explanations for their results.

Full text at www.sciencemag.org/cgi/content/full/320/5876/612c

RESPONSE TO COMMENT ON "Long-Lived Giant Number Fluctuations in a Swarming Granular Nematic"

V. Narayan, S. Ramaswamy, N. Menon

On the basis of experiments using monolayers of spherical grains, Aranson *et al.* suggest that the giant number fluctuations we observed in active granular rods may be explained by static inhomogeneity or inelastic clustering. We refute these alternative explanations and underline the evidence that the fluctuations originate in nematic ordering.

Full text at www.sciencemag.org/cgi/content/full/320/5876/612d

Response

WE DEMONSTRATED THAT A GLOBAL CLOUD-resolving model (GCRM) can simulate the realistic evolution of a single Madden-Julian Oscillation (MJO) event, including its internal structures. We did not claim that GCRMs provide a full solution to the MJO problem or that conventional general circulation models (GCMs) cannot simulate the MJO.

The essential mechanisms of the MJO are not yet comprehensively understood, and consequently, whether GCMs and GCRMs can fully simulate the MJO remains undetermined. The MJO simulations in our Report demonstrate that a GCRM can marginally reproduce the internal cloud systems and overall structure of a single MJO event over a period of one month (*1*). Finer internal structures and topographic effects were also better simulated because of the finer horizontal resolution. Contrary to the assertion of Sperber *et al.*, however, we did not claim that either GCRMs or GCMs embedding two-dimensional cloud-resolving models were the only way to produce realistic MJO simulations.

Letters to the Editor

Letters (~300 words) discuss material published in *Science* in the previous 3 months or issues of general interest. They can be submitted through the Web (www.submit2science.org) or by regular mail (1200 New York Ave., NW, Washington, DC 20005, USA). Letters are not acknowledged upon receipt, nor are authors generally consulted before publication. Whether published in full or in part, letters are subject to editing for clarity and space.

Most of the papers cited by Sperber *et al.* stated that air-sea interaction is necessary to simulate the MJO by GCMs. However, we believe that this point is still controversial (*2*, *3*). We have studied this issue and performed a sensitivity test with a 14-km horizontal grid. The time evolution of an MJO event did not differ very much between the simulations with the observational time varying sea surface temperature (SST) and the fixed SST, though the convective activity of the MJO was weaker in the fixed SST run. A GCM embedding a two-dimensional cloud-resolving model also simulated the MJO without feedback from intraseasonal perturbations in SST (*4*). These results support the hypothesis that the MJO is inherently an atmospheric mode, even if it can be modified and perhaps amplified by air-sea interactions (*5*, *6*).

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