play a role. "We are somewhat baffled why the regression model used by India has not produced a forecast in the past 13 years that is very different from normal," he says. The final product is vetted by the prime minister's office because of the monsoon's tremendous impact on the Indian economy, which has prompted whispers that the forecast could be manipulated for political reasons. But Kalsi vehemently denies that speculation.

The IMD model isn't the only one that has trouble foretelling complex phenomena, says Muthuvel Chelliah of the U.S. Climate Prediction Center in Camp Springs, Maryland. "The farther ahead in time one wants to forecast the weather in a particular place, the more one needs to know, at the present time, about a larger and larger region surrounding that place," he explains. No country, including the United States, has the capability to make monsoon predictions accurately, Chelliah adds.

Knowing which data to collect is a major challenge. The more parameters, say scientists, the more likely they will cancel each other out. "IMD uses too many parameters in their statistical model," says Chelliah, and Shukla says that "no more than three predictors should be used," although he admits that nobody really knows which ones are most appropriate.

The IMD model also depends heavily on data gathered over land. But most scientists believe that the use of general circulation models that couple constantly changing ocean and atmospheric conditions with terrestrial events are essential for understanding large-scale phenomena such as the monsoon. "Prediction of the monsoon will remain a challenging task unless atmospheric data over the oceanic regions surrounding the Indian subcontinent is collected and analyzed," says Shukla.

More extensive field observations might help. Such observations began with the Monsoon Trough Boundary Layer Experiment in 1990 and continued with the Bay of Bengal Monsoon Experiment in 1999 and the Arabian Sea Monsoon Experiment in 2002. "The analysis of data from such experiments will ultimately lead to an improvement in the long-range forecast of the monsoon," says Jayaraman Srinivasan, chair of the Indian Institute of Science's Center for Atmospheric and Oceanic Sciences in Bangalore.

There's also the need to put what is now being collected to better use. "It is almost a national tragedy that the INSAT [India's national weather satellite] data, collected at such huge cost, is underutilized," says Shukla. Officials defend their restrictive policies on the grounds of national security and the need to assist scientists who lack the computational facilities to handle large amounts of raw data.

Despite their disappointment that this year's prediction was wide of the mark, Indian officials say they don't know where else to turn. "I would be willing to prostrate myself in front" of anyone who can do better than IMD has done, says Valangiman Subramanian Ramamurthy, secretary of the Department of Science and Technology, which oversees IMD. Even better models won't help farmers, adds India's minister of agriculture, Ajit Singh: "All the supercomputers and satellites now in use are no substitute for the rain god."

–PALLAVA BAGLA

PLANT GENETICS

Surviving the Long Nights: How Plants Keep Their Cool

Researchers are exploring plants' hidden strategies for surviving the cold months—such as the Douglas fir that remains green but stops photosynthesis

When winter creeps in, casting a mottled sky and raw wind, most of Earth's residents take cover. But plants are stuck outside. With nowhere to turn, the plant kingdom has developed its own strategies for surviving—and even using—the cruel cold season. At the recent American Society of Plant Biologists (ASPB) meeting in Denver, scientists reported new research showing just how complex those strategies can be.

"What happens when plants acclimate to winter?" asked University of Colorado (UC), Boulder, ecophysiologist Barbara Demmig-Adams at the meeting. Her answer: It depends on the plant. Demmig-Adams described a new study in which she, fellow UC Boulder ecophysiologist and husband William Adams, and their colleagues compared winter survival strategies among more than a dozen plant species growing in Colorado's Flatiron Mountains.

The changes induced by cold ranged from slight to severe. During the study, for instance, the researchers documented a montane Douglas fir and a weed, *Malva*, growing side by side and sharing the same frigid days—but reacting in very different ways. Despite being an evergreen, or a plant that keeps sunlight-absorbing green chlorophyll year-round, the Douglas fir actually shut down photosynthesis during winter to stop growing. At the same time, the fir up-

Under the weather. With nowhere to go, plants have evolved creative ways to survive winter.

CREDIT: DAVID MUENCH/CORBIS

regulated carotenoid pigments—such as zeaxanthin and lutein—to help shed any absorbed sunlight as heat. By contrast, the scrappy *Malva* kept right on growing through winter, using every above-freezing chance to photosynthesize at full blast.

The fir's radical strategy is an adaptation to lower temperatures, which impede normal metabolic processes. "Shutting down seems to be the way to go to preserve green leaves in the most extreme winter conditions," remarks William Adams. Whereas short-lived plants such as *Malva* and winter cereals can survive at intermediate elevations during winter, only conifers succeed at higher altitudes. By revving up a photoprotective system, the trees avoid accumulating radical oxygen compounds that could build up in winter and damage them.

In fact, entire evergreen forests appear to wait out winter. This hunkering down is reflected in the rate of CO_2 uptake and release, shown in a study of subalpine forest in the Rockies, published this spring in *Global Change Biology* by UC Boulder ecologist Russell Monson and his colleagues.

Over 2 years, Monson's group found that CO_2 uptake by the forest plummeted as winter set in. "Even on days when it was quite warm, with the temperature approaching 15° to 20°C, the forest stayed locked down," Monson says. But as soon as spring hit in late April or early May, the forest jumped to life almost overnight, becoming a huge carbon sponge. "I think this is the true advantage of being an evergreen: not photosynthesizing year-round, as some researchers have assumed, but instead being able to ramp up quickly in spring, to obtain a lot of seasonal carbon and grow," Monson says.

Biennial plants even welcome a winter break, speakers at the ASPB meeting said. Biennials—including many crops, garden favorites, and weeds—bloom only in their second season, after exposure to prolonged cold. Getting this reproductive timing right is critical so that flowers can attract pollinators and best disperse seeds.

In one talk, Richard Amasino, a biochemist at the University of Wisconsin, Madison, described the emerging molecular mechanics behind "vernalization": a biennial plant's use of the cold season as a time-out, a transition from growing leaves and shoots to preparing for a burst of spring flowering. "These plants have evolved a way to measure winter and wait until it's been cold enough, long enough, to signify spring," Amasino says.

In the past few years, Amasino; Caroline Dean, associate research director at the John Innes Centre in Norwich, U.K.; and others have been unraveling the biochemistry that causes *Arabidopsis* to overwinter and delay flowering. The researchers have found that as cold sets in, a gene dubbed *FRIGIDA* promotes the buildup of the flowering locus C (FLC) transcript, a repressor protein that blocks genes for flowering. After a period of cold, the plant's FLC levels drop, allowing flowers to emerge when temperatures warm.

By creating *Arabidopsis* mutants that flower off schedule, the team has found a handful of additional vernalization genes. Dean's lab last month reported finding the gene *VRN1*, which helps shut down FLC so spring flowers can bloom (*Science*, 12 July, p. 243).

Dean says that *Arabidopsis* likely bears a key set of floral genes that, when activated, switch on flowering. Vernalization proteins represent just one biochemical pathway that can activate those flowering genes, she says. Other pathways, lined with proteins that sense the day's length (photoperiod), for instance, or developmental changes can also trigger those same genes. "My view is these sets of pathways have somewhat overlapping functions to reinforce each other," Dean says. "So the plant says, 'I've had longer days and enough cold, so I'm doubly sure it's O.K.—it's spring, it's time to flower.' "

The emerging research could help plant breeders improve yields of biennial crops such as alfalfa and sugar beets, adds Jan Zeevaart, a botanist at Michigan State University in East Lansing. With molecular tools in hand, the science should blossom.

–KATHRYN BROWN

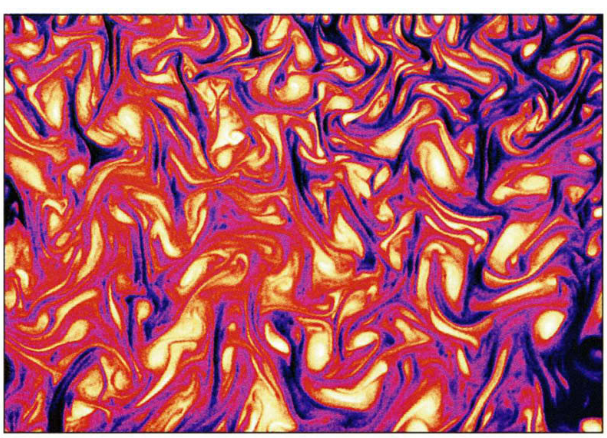
STATISTICAL PHYSICS

A Fresh Take on Disorder, Or Disorderly Science?

For nearly 80 years the definition of entropy has been literally etched in stone. A few physicists want to carve a new one, but others say the idea is cracked

Near the middle of Vienna's sprawling Central Cemetery stands the imposing tomb of Ludwig Boltzmann, the 19th century Austrian physicist who first connected the motions of atoms and molecules to temperature, pressure, and other properties of macroscopic objects. Carved into the gravestone, a single short equation serves as the great man's epitaph: $S = k \ln W$. No less important than Einstein's $E = mc^2$, the equation provides the mathematical definition of entropy, a measure of disorder that every physical system strives to maximize. The equation serves as the cornerstone of "statistical mechanics," and it has helped scientists decipher phenomena ranging from the various states of matter to the behavior of black holes to the chemistry of life.

But roll over, Boltzmann. A maverick physicist has proposed a new definition of entropy, and his idea has split the small and already contentious community of statistical physicists like a cue ball opening a game of pool. Supporters say the new definition extends the reach of statistical mechanics to important new classes of problems. Skeptics counter that the new theory amounts to little more than fiddling with a fudge factor.



Into the mix. Proponents hope a new entropy will help physicists untangle tortuous subjects such as turbulence.

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The new definition gives insight into the myriad physical systems that verge on a kind of not-quite-random unpredictability called "chaos," says Constantino Tsallis of the Brazilian Center for Research in Physics in Rio de Janeiro. Tsallis proposed the definition in 1988, and since then researchers have applied it to subjects from the locomotion of microorganisms to the collisions of subatomic particles, and from the motions of stars to the swings in stock prices. The new definition appears to account for subtleties in the data exceedingly well, Tsallis says. It also probes a gap in Boltzmann's reasoning that Einstein spotted nearly a century ago.

But many physicists remain highly skeptical. So-called Tsallis entropy simply adds another mathematical parameter that physicists can twiddle to make their formulae better match the data, says Itamar Procaccia of the Weizmann Institute of Science in Rehovot, Israel. "It's just mindless curve-fitting," he says. Joel Lebowitz of Rutgers University in Piscataway, New Jersey, says that researchers crank out papers on the new entropy by the dozen (Tsallis lists nearly 1000 of them on his Web page, tsallis.cat.cbpf.br) but that most contain few physical insights. "The ratio of papers to ideas has gone to infinity," he says.

Several well-respected physicists, however, say that the skeptics have closed their minds to a potentially fruitful innovation. "It's ridiculous to reject this out of hand," says E. G. D. Cohen of Rockefeller University in New York City. Michel Baranger of the Massachusetts Institute of Technology (MIT) in Cambridge says that behind the skepticism lurk more personal misgivings about Tsallis, who traverses the globe stumping for his idea. "He spends an enormous amount of time making sure his work gets recognition," Baranger admits, but that doesn't mean his idea isn't a good one.

Counting the ways. Anyone who has ever touched a hot burner should have an intuitive feel for the concept of entropy. As heat flows from the metal of the burner into the flesh of a finger, it jiggles the atoms and