the cloud-shrouded planet using imaging radar maps from their own Venera 15 and 16 spacecraft of the early 1980s and from NASA's Magellan spacecraft, which is now en route to Venus. A Soviet mission in about 1998 would then place penetrators in eight to ten of the most promising sites, while dropping landers that could obtain panoramic views of the Venusian terrain on the way down.

■ **A Mercury lander.** Even Barsukov admitted that this mission is tentative. But Mercury's scientific appeal is clear: it is the planet closest to the sun; its surface is a unique study in the extremes of daytime heat and nighttime cold; and it is the only one of the inner planets whose surface has not been probed by a landing craft. So the Soviets would like to launch a Mercury probe just after the turn of the century.

How real was all this? No one really knows—perhaps not even the Soviets. U.S. participants at the conference noted that the Soviets' language seemed much more tentative than it had been in the past. Barsukov clearly cast his talk in terms of "Here's some things we might like to do if we have the money and political support."

In addition, Barsukov made no secret of the fact that he and his colleagues are following, not leading. In drawing up their plans they have first looked at what their Western counterparts are up to and then looked for unoccupied niches that can be filled by Soviet capabilities. As expected, for example, his planetary plan continued the Soviet focus on the inner solar system (Mercury, Venus, the moon, and Mars), leaving the distant outer solar system (Jupiter, Saturn, Uranus, Neptune, and Pluto) to U.S. and European missions; Soviet spacecraft have simply not demonstrated the longevity required to reach those planets.

Barsukov was even more explicit when he talked of a possible Mars Sample Return mission, which the Soviets had previously billed as the centerpiece of their whole planetary program, and which is widely considered to be an essential precursor for any manned Mars expedition. Today the Soviets cannot even put a date on the multibillion-dollar effort, admitted Barsukov, because they know they cannot do it without help: "We should plan for the same date as the Americans do."

Still, Barsukov also made it clear that he and his colleagues have not stopped dreaming: "In the next century," he said, "we start collaboration for manned flights to the moon . . . [as] an intermediate step to manned flights to Mars. Who knows when—the middle of the next century? It is something to leave to our children to do."

■ **M. Mitchell Waldrop**

An Astrophysical Guide to the Weather on Earth

A mathematical method for modeling fluid flow in outer space has down-to-earth applications as well

Supernovas, solar flares, and the nuclear brew of stars may seem pretty far removed from the earthbound world of meteorology. But a mathematical technique that was developed to model the violent processes of stellar convection and supersonic jets may now do the same for the seeming chaos of ordinary weather.

Known as the Piecewise Parabolic Method (PPM), the technique involves "a radically different way" of representing numerical weather data, according to Kelvin Droegemeier, a professor of meteorology at the University of Oklahoma in Norman. Unlike standard numerical methods, PPM "builds into [a weather] problem some knowledge of physics and an understanding of fluid flows," Droegemeier says.

PPM is the brainchild of Paul Woodward, an astrophysicist at the University of Minnesota and the Minnesota Supercomputing Center, and Phillip Colella, an applied mathematician at the University of California at Berkeley. Based on work of S. K. Godunov in Russia and Bram van Leer in Holland, PPM was developed just this decade as a numerical technique for handling the shock discontinuities that arise in supersonic fluid flow problems.

Shock waves are not of concern in meteorology, of course, but it turns out that PPM is generally good at handling problems with steep gradients—and anyone who has ever seen tornado damage can tell you how dramatically conditions can vary in less than a city block.

Droegemeier and Woodward met at a conference on algorithm development at the University of Illinois Supercomputer Center in 1986. The meteorologist was impressed with the way PPM modeled fluid flow. "He [Woodward] showed some videotapes of some astrophysical simulations," Droegemeier recalls. "They looked remarkably like what we were doing in the atmosphere, except his solutions looked a heck of a lot better."

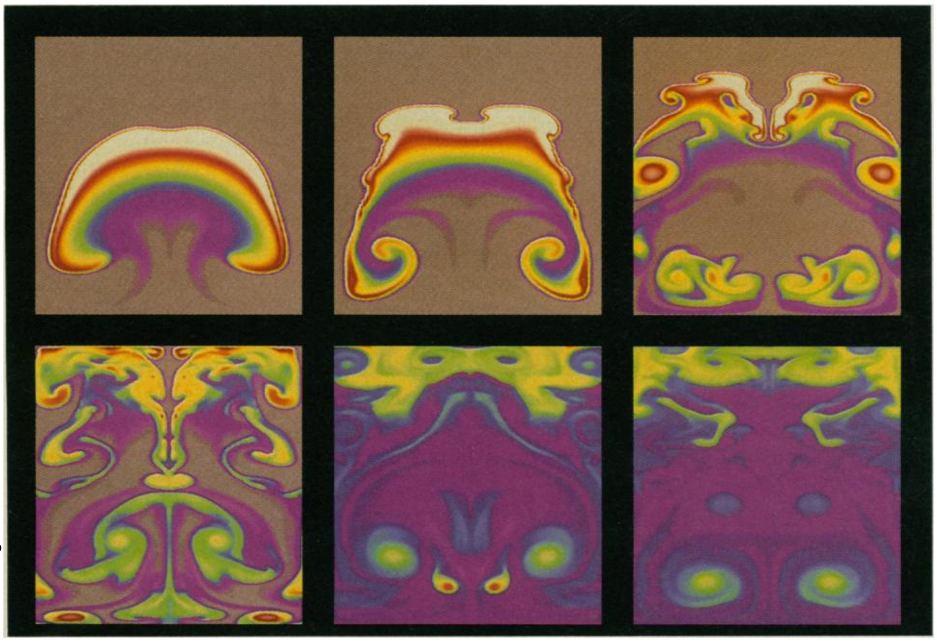
Later that year, Droegemeier introduced PPM to graduate student Richard Carpenter of the Cooperative Institute for Mesoscale Meteorological Studies. Along with Carl Hane at the National Severe Storms Laboratory, Carpenter, Droegemeier, and Woodward have collaborated to develop a meteorological version of PPM. "We weren't sure if it would be appropriate for atmospheric flows, where shock waves are of no consequence and their sister sound waves serve only as a nuisance by severely limiting the time step of the calculation and thus the total computation time," Droegemeier says. "It turns out that PPM works beautifully for atmospheric flows."

The meteorological PPM model is currently restricted to a two-dimensional setting, but in a paper to appear in the *Monthly Weather Review*, Droegemeier and colleagues show that PPM successfully models the turbulent structure of a buoyant convective thermal—the sort of event that leads to the formation of storm systems. They have also used their model for a density current simulation, which is a type of flow that can produce low-level windshears that are hazardous to aircraft.

In a way it's no surprise that astrophysics and meteorology should get together. The two subjects share a common mathematical core in the equations of fluid dynamics. "The same fluid flow equations describe weather on the earth, . . . jets from the nuclei of galaxies, [and] motions of fluids in stars," Woodward explains.

As a consequence, the two subjects also share many of the same mathematical headaches. The most chronic is that the equations of fluid dynamics cannot, in general, be solved exactly. Instead, researchers rely on numerical approximations to tell them what happens when, for instance, a hot plasma shoots through a denser, cooler gas, or when a tongue of cold air plunges down in front of a thunderstorm.

Standard numerical techniques try to approximate solutions by keeping track of variables such as temperature and pressure at a finite set of grid points and updating their values in discrete time steps according to formulas obtained from the fluid equations. The standard techniques run into trouble when there's a shock or sharp gradient: they typically wind up exhibiting spurious oscillations, as if the model suddenly got the jitters. This can be controlled by introducing



A sharper view of the life of a plume. *These six snapshots of a rising plume of warm air demonstrate how the breakdown and resulting turbulence at the leading edge of the plume can be simulated by the Piecewise Parabolic Method without the spurious oscillations inherent in other techniques.*

artificial viscosity or dissipative techniques, but then the gradients get smeared out and potentially significant small-scale fluid structures are lost.

An obvious way to get more accuracy in a numerical solution is to use a finer grid and take tinier time steps. Doing so, however, quickly overwhelms the capacity of even the largest computers: halving everything in a three-dimensional model increases the amount of computation by a factor of 16; an additional decimal place in each direction ups the ante by a factor of 10,000.

PPM takes a different approach. Instead of keeping track of, say, the temperature at each grid point, PPM keeps track of certain averages of the temperature over each grid *cell*. In effect, PPM represents the temperature variation within each separate cell as a unique parabola—hence the name. Because it uses a different parabola in each cell, PPM allows for small—or large—discontinuities. In a sense, PPM believes there are discontinuities *everywhere* in the fluid.

When applied to this collection of parabolas, the fluid flow equations are cast into characteristic form and make use of something called a Riemann problem, which can be solved exactly—for one time step—to obtain the nonlinear flux of quantities between neighboring zones. The solution, however, no longer looks like a bunch of parabolas, so before taking another time step, it is necessary first to re-average within each cell to smooth the data back into parabolic shape. PPM also uses a "monotonicity switch" to ward off the jitters—the spurious oscillations that plague standard techniques.

The clear separation of the approximation step from the exact solution step appeals to physicists, Woodward says, because it makes it clear how to add other physics to the problem. In meteorology, for instance, modelers can include effects such as cloud nucleus condensation.

But why parabolas? Mathematically it's a natural step. Godunov's original method used constant values within each grid cell. Van Leer advanced to linear approximations, in addition to introducing the monotonicity switch. Quadratic approximations—namely parabolas—are the sensible next step. It's entirely possible that a Piecewise Cubic, Quartic, or Quintic Method is somewhere down the road. For now, though, parabolas—the epitome of what-goes-up-must-come-down physics—seem well suited to the diverse interests of modelers, from the formation of storms on Earth to the course of galactic explosions.

■ **Barry A. Cipra**

Barry A. Cipra is a mathematician and writer based in Northfield, Minnesota.

Neptune's Triton Spews a Plume

Voyager scientists who took dark streaks on the icy surface of Neptune's moon Triton as signs of ongoing volcanism now have solid proof that their bold speculations were well founded. After a month examining the 8000 images returned during Voyager 2's encounter with the Neptune system, scientists find that a few clearly show a volcano-like plume of fine dust particles. It rises an impressive 8 kilometers into Triton's thin atmosphere and streams 150 kilometers downwind.

The discovery nonetheless leaves researchers with a daunting conundrum. It takes heat energy to turn ice to gas that can drive dust particles out the throat of a volcano, like bullets shot from a gun, or even to loft volcanic dust on a warm plume of buoyant gas. How could anything so cold as Triton, which has a surface temperature of just 40°C above absolute zero, drive such an energetic, towering plume?

Internal heat of the kind that drives Earth's volcanism largely faded away millions, if not billions, of years ago on Triton. Nor does Neptune warm Triton any longer by gravitationally squeezing it, the way Jupiter warms its moon Io, the solar system's only other known volcanically active moon.

A sign of an active Triton. *An 8-kilometer-tall dark plume (between arrowheads on left) drifts downwind to right.*

So that leaves sunlight as everyone's favorite suspect. For example, David Stevenson of the California Institute of Technology suggests that the preferential absorption of solar energy by a surface layer of darkened methane ice may warm underlying nitrogen ice and turn some of it to gas. If so, it would mean that the solar system's three known types of active volcanism are all powered by different types of energy sources.

■ **Richard A. Kerr**