On one side, the ground was cracked and stalks of winter wheat lay limp beneath a hot, dry wind. On the other, people made their way gingerly through flood waters that coursed across fields and highways. The contrasts in moisture during the spring of 2002 were written in bold type across the southern Great Plains, where a record drought played out next to heavy rainfall.

A massive field experiment orchestrated by NCAR and UOP was in just the right place at the right time. Moisture—more specifically, water vapor—was at the heart of the International H₂O Project (IHOP2002). Over 200 scientists, technicians, and other staff converged on southern Kansas, northern Texas, and most of Oklahoma for six weeks. On hand was the biggest, most varied collection of instruments ever assembled to profile water vapor in the atmosphere. Six aircraft canvassed the region at heights from 200 to over 45,000 feet, while over a dozen vehicles crisscrossed the plains with radars and other sensors in tow or on the roof.

Even in normal times, the IHOP region shows a dramatic climate contrast. Semiarid conditions prevail across the High Plains, while the prairie to the east gets more rain on average than do London or Paris. The IHOP researchers, led by NCAR’s Tammy Weckwerth and David Parsons, took advantage of this natural transition zone, while leveraging a wealth of other sensors already in place. These included over 100 state-sponsored automated weather stations across Oklahoma and a radiation-measuring array installed by the U.S. Department of Energy (DOE).

This eclectic armada found pockets of water vapor and tracked their three-dimensional edges, sculpted by wind and landscape moment by moment. It’s hoped this portrait will help improve predictions of rainfall—still a formidable challenge, especially during the summer months when flood risk is at its highest. “Right now the lead time for flash-flood forecasts is under an hour,” notes Parsons. “If you can extend forecasts of heavy rainfall out a few hours, you’re doing great.”

Making the unseen visible

Wispy and skin-softening, water vapor doesn’t seem like a heavy hitter. It’s the sheer amount of water vapor in the air that gives it such heft. Even without a cloud in the sky, the air on a humid day may hold the equivalent of more than an inch (2.5 centimeters) of rainfall.

Weather like this—clear yet moist—was ideal for IHOP. The project relied heavily on lidar, or laser-based radar. Four of these devices were placed at ground level (including three from NASA teamed for the first time), while four others were mounted on aircraft. Lidars use a much smaller wavelength than the microwaves used in Doppler radars. The result is a tool that’s more sensitive than radar, but covers less than 10 kilometers (6 miles) in range—even less when clouds are around.

Like lidar, the other tools commonly used for measuring water vapor each have their Achilles’ heels. Balloon-borne radiosondes provide most of the...
Fixing a dry bias

Five years of teamwork from NCAR and Vaisala, a Finnish maker of radiosondes, has fixed a set of biases that painted an overly dry picture of the global atmosphere. Thousands of readings were taken by balloon-borne Vaisala radiosondes in the western Pacific during the Tropical Ocean and Global Atmosphere Program’s Coupled Ocean-Atmosphere Response Experiment (1992–93). These data showed moisture levels in the lower atmosphere a few percentage points lower than expected from independent surface readings. The radiosonde data implied that large stretches of the western Pacific shouldn’t have been experiencing clouds and storms when they actually were. NCAR’s Junhong Wang, Kathryn Beierle, David Carlson, Harold Cole, and Erik Miller worked with Vaisala engineers Ari Paukkunen and Tapani Laine to identify and correct several distinct problems. These ranged from an imperfect temperature-humidity equation to a water-blocking chemical in the packaging that seeped onto sensors stored for months or years. More than 8,000 soundings from the Pacific project were corrected one by one. This, says Wang, produced “one of the most-examined and highest-quality radiosonde data sets ever collected.” At IHOP2002, Wang and colleagues launched about 20 high-end reference radiosondes. Each one carried three humidity sensors, including an extra-precise Swiss device with a chilled mirror on which moisture condenses. This device performed well against its companions, making it a promising standard for future research. The ongoing work is part of NCAR’s strategic initiative on the water cycle.

The innovative Proteus was one of six aircraft on hand for IHOP.

On the moist edge

Thunderstorms crackled across the plains off and on throughout the IHOP study period. Tornadoes and other severe weather weren’t the direct focus, but researchers were keen to see whether the wealth of instruments could do a better job than usual of predicting where thunderstorms and heavy rains might develop.

Each morning, a team of researchers and forecasters based in Norman, Oklahoma, at NOAA’s Storm Prediction Center and the National Weather Service (NWS) outlined the areas of potential storm formation. By midday, IHOP scientists had often spotted only a few weeks before IHOP. LEANDRE pointed upward, downward, and laterally within the sweep of ELDORA’s dual-Doppler beams.

“We collected a unique data set,” says Cyrille Flamant (CNRS, France’s National Center for Scientific Research). Flamant specializes in studying the atmosphere’s boundary layer: typically the lowest kilometer or 0.6 mile, but sometimes deeper. The strong moisture contrasts evident in IHOP provided plenty of grist for the mill. “The lidar data showed enhanced moisture patterns and other interesting features we plan to interpret in the framework of a larger 3-D picture,” says Flamant.

That picture is being extended below ground level. The intimate links between earth and atmosphere were analyzed exhaustively in IHOP: Ground-hugging aircraft sampled the low-level air, while research teams probed the earth and flora in diverse ways, such as gauging electrical conductance to infer soil moisture. Instrument-studded towers and satellite images filled out “the most detailed observations of the boundary layer ever available,” says Kenneth Davis (Pennsylvania State University). Within the large-scale, east-west contrasts, Davis and colleagues found a complex web of smaller-scale contrasts in heat and moisture. How these might affect storm formation, and how sharp a model’s resolution must be to capture the most critical detail, are two major outstanding questions, according to Davis.

The task of coordinating IHOP field work fell largely to UCAR’s Joint Office for Science Support. The office has overseen logistics for some of the world’s biggest weather experiments, yet according to JOSS’s James Moore, IHOP was “a challenge as big as anything we’ve ever undertaken.” The office worked closely with collaborators on everything from flight plans that meshed with civilian and military air traffic to an online catalog that furnished data both during and after the project.
the invisible moisture boundaries where showers would kick off. Yet that was only the beginning of the story, according to Kevin Knupp (University of Alabama in Huntsville). “Once a boundary was detected, we found it challenging to forecast its movement and evolution in a one-hour time frame. Analysis of the data should provide insight on why some boundaries move so erratically.”

Some of the most dramatic results came from an NCAR radar mounted on a gentle rise in the eastern Oklahoma Panhandle. Less than a decade old, the S-Pol radar has proven its mettle in using polarized radar signals to distinguish rain from hail. (Unlike the classic teardrop image, raindrops tend to fall as flat discs, while hailstones tumble to produce a more spherical signal.) The polarization technique used in S-Pol will likely be added to NWS radars across the country over the next few years.

S-Pol is now the testbed for another technique that may push the analysis envelope even further. While at NCAR on a postdoctoral appointment, Frédéric Fabry (McGill University) teamed with NCAR’s Charles Frush and McGill colleagues Iztzar Zawadzki and Alamelu Kilambi on a technique that uses ground-based reference points to measure moisture-induced delays in the radar signal. The resulting index of refractivity allows water vapor to be mapped as far as 50 km (30 mi) away. At IHOP, the new technique detected some boundaries even before faint echoes from wind-clumped insects could be seen in Doppler data. “There’s tremendous interest in trying to detect zones of convergence as early as possible,” says Fabry.

Other surprises emerged from high-tech sensors that profiled the atmosphere above a dusty, abandoned homestead a few miles east of S-Pol. Scientists there captured several nocturnal “bores”—undulating boundaries that surf atop ground-level inversions and sometimes trigger storms. IHOP was the first organized attempt at predicting bores, and at least two were successfully forecast, according to Belay Demoz (University of Maryland, Baltimore County; and NASA). Despite a 100-mile diurnal commute, he adds, “We stayed up all night so we would not miss these opportunities.” On other nights, aircraft probed a recurring, moisture-laden jet stream that can howl northward at speeds of hurricane force a mere kilometer (half mile) above the prairie.

The big picture

Another group of sensors at IHOP2002 used the Global Positioning System (GPS) to extract a dense set of data on moisture. Like Doppler radar, most of these sensors track microwave signals, yet they follow the refraction of wave energy in much the same way as Fabry’s S-Pol technique.

Partners ranging from UCAR and NOAA to the University of Oklahoma (OU), several French research groups, and DOE gathered this data. Also in the mix was SuomiNet, a fast-growing university consortium organized by UCAR that uses GPS to improve measurements of water vapor and other atmospheric and geodetic data. Having so many similar yet distinct GPS-based instruments at IHOP led to a smorgasbord of information, says UCAR’s Randolph Ware. “This defines the water-vapor field across the whole region in a way nothing else does.”

One pressing goal is to get these and other new kinds of data into regional-scale computer models. Several groups ran customized models during IHOP. OU’s Kelvin Droegemeier and Ming Xue are in the midst of a three-year, NSF-funded project to see how well retroactive modeling can reproduce IHOP storms with the help of the GPS-based data. “This will provide much-needed education and training for graduate students and postdocs in some increasingly important areas,” says Droegemeier.

Even before IHOP wound up, new complexities had emerged in how water vapor behaves. Rather than forming directly on boundaries, storms often developed 5–10 km (3–5 mi) downstream. In addition, says Weckwerth, “We found that the boundaries were not simple fine lines [as seen on radar] but had multiple band structures.” It will take years for researchers to work through these fresh wrinkles and come up with a new overall picture of how water evolves from innocuous vapor to torrential rainmaker. According to Weckwerth, though, the mission’s overall success is already crystal clear: “We’re really pleased with IHOP.”

On the Web
IHOP2002
SuomiNet
http://www.suominet.ucar.edu
IHOP2002 data assimilation (University of Oklahoma)
http://twister.ou.edu/IHOPAbstract.html