the next five or so years," says Funk, "before we can seriously estimate what fraction of the total galactic cosmic-ray flux is accelerated in their shock fronts."

Another central question is whether SNRs can really accelerate protons all the way up to 10^6 GeV, where a prominent kink (the so-called knee) in the overall CR spectrum is thought to mark the transition to higher-energy protons coming from beyond our galaxy. "For the answer to that one," says Funk, "we'll have to rely on ground-based arrays of Cherenkov telescopes and water tanks" now under construction[3] or on drawing boards.

Bertram Schwarzschild

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Earth's land surface temperature trends: A new approach confirms previous results

The newcomers to the task looked at many more weather stations and used a geostatistics technique to adjust for data discontinuities.

People have been measuring and recording temperatures since the 17th century, and scientists have been using those data to estimate a mean global temperature since the late 19th century. As weather stations increased in precision and in global coverage, especially in the last half of the 20th century, they facilitated better estimates of the mean global temperature—a key indicator of possible climate change.

For the past 30 years, those estimates have primarily been done by three independent teams: the Climatic Research Unit[1] (CRU) of the University of East Anglia in the UK, in collaboration with the Hadley Center of the UK Met Office; NASA's Goddard Institute for Space Studies[2] (GISS); and the National Oceanic and Atmospheric Administration's National Climatic Data Center[3] (NCDC).

Their task is not a simple one. For decades, researchers have compiled databases of historic temperature records from disparate sources in more than 100 countries. Analysts must correct those raw data for discontinuities in a given station's time series caused by factors unrelated to climate, such as installation of an instrument, a move to a new location, or changes in recording practices. Next they must sort the global trend from the expected local weather fluctuations. In addition, they must account for the uneven global coverage, with more plentiful data from North America, for example, than from Africa. Despite different approaches to those tasks, the three main groups have produced consistent results: All report an increase in the global temperature over the past century.

Given the importance of the temperature trends to the climate discussion, critics have focused on possible biases from such factors as data selection or the urban heat island effect—the warming experienced by some weather stations as the surrounding area becomes more densely developed. Scientists with the CRU, GISS, and the NCDC have checked and corrected for such biases in various ways, but some critics remained unconvinced.

To address some of the concerns, a fourth group recently took a different approach to the problem. Richard Muller of the University of California (UC), Berkeley, and his daughter Elizabeth started the Berkeley Earth Surface Temperature project under the auspices of the nonprofit Novim Group in Santa Barbara, California; the project's collaborators include scientists from UC Berkeley, Lawrence Berkeley National Laboratory, and Oregon State University. The results were recently published,[4] although the work has been posted on the group's website (http://www.berkeleyearth.org) and publicly discussed for the past year.

The group's temperature estimates, done so far just for land surface temperatures, agree well with those from previous profiles. (See the figure on page 19.) The Berkeley group extended its analysis back to 1750, a century earlier than in other studies, although the sampling in the early period was poor. It might be useful to compare such data with estimates from various temperature proxies, says Zeke Hausfather of C3 Energy in Redwood City, California. In future work, the Berkeley team plans to incorporate marine temperatures, as the other three groups have done, since oceans represent 70% of Earth's surface.

Thomas Karl, NCDC director, welcomes the entry of a fourth independent research group that makes different assumptions to analyze the same variable. Gavin Schmidt of NASA's GISS comments that the particular approach taken by the Berkeley team addresses several specific criticisms: that the prior analyses did not use enough data and that they used flawed procedures for correcting data discontinuities.

Differing approaches

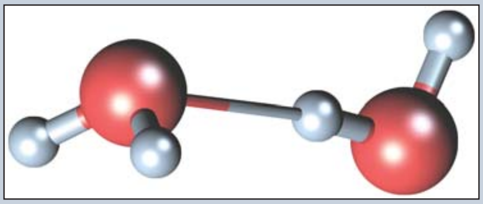
A key distinction of the Berkeley group's treatment is that it allows analysts to handle short and discontinuous temperature records; the other three groups, by contrast, have relied on stations with fairly long temporal records, usually on the order of decades. No more than about 8000 sites have been included in past analyses. The Berkeley group works with temperature records from about 40 000 sites.

One of the first steps in calculating a global temperature is to homogenize the data—that is, detect and correct for discontinuities in the temporal data set from each station. For example, analysts may compare the time records from adjacent stations, which should be experiencing roughly the same weather conditions. Any jump in one time series not seen in others is flagged, and the dataset is adjusted accordingly.

When the Berkeley collaborators encounter a discontinuity, they break the data set into two records and treat the resulting fragments as independent records from the same location. Such an approach effectively multiplies the number of record fragments they handle by about a factor of four, to something like 170 000. The compensation for the discontinuities—or offsets—is determined by the team's global statistical treatment.

For any global temperature esti-

Water dimer yields to spectroscopic study



Water is Earth's principal greenhouse molecule: It's responsible for well over half of the atmosphere's absorption of solar and terrestrial radiation. So it's a crucial ingredient in any model of Earth's radiation balance and climate. But the study of atmospheric water's absorption spectrum has for decades been fraught with mystery and controversy. In addition to the expected spectral lines—corresponding to transitions between discrete rotational, vibrational, and electronic quantum states—the spectrum includes a broad continuum absorption that has yet to be fully explained.[1]

Beginning in the late 1960s, and especially since the late 1990s, some researchers have suspected that at least part of the continuum could be due to water dimers. As gas-phase molecules collide with one another, every so often two of them form a hydrogen bond (as shown in the figure), remain together for a time, and then go their separate ways. The dimer would have a different set of quantum states than the monomer and thus a different spectrum.

But dimers had never been spectrally characterized at ambient temperatures, so no one knew whether the dimer absorption actually matched the water absorption features they sought to explain. The dimer spectrum was also needed for measuring the dimer's prevalence under atmospheric conditions—or for confirming that it was present in appreciable quantities at all.

Through the years many groups have tried to measure the dimer's vibrational spectrum in the IR. Two high-profile papers claimed detection, but both failed to stand up to scrutiny.[2] The problem was that dimers could be formed only in the presence of many more water monomers, and the vibrational modes of the weakly bound dimer were just too difficult to convincingly disentangle from those of the monomer.

The rotational spectrum was in many ways more promising. The dimer and monomer have completely different moments of inertia, so their rotational spectra should not overlap as much. And rotational spectra comprise many equally spaced spectral lines, which can be more conclusively identified than isolated vibrational lines. But rotational transitions occur at microwave frequencies, and traditional microwave spectrometers lack the sensitivity to detect the weak dimer spectrum.

Mikhail Tretyakov and colleagues at the Institute of Applied Physics of the Russian Academy of Sciences in Nizhniy Novgorod have remedied that problem by building a microwave resonator spectrometer based on a Fabry–Perot cavity. An absorbing sample placed in the cavity reduces the cavity's *Q* factor. By measuring changes in the *Q* factor, the researchers can record microwave spectra with unprecedented sensitivity.

In collaboration with theorist Claude Leforestier (University of Montpellier, France), who had computationally predicted the dimer's rotational spectrum, Tretyakov and colleagues realized that their spectrometer might be able to detect dimers in room-temperature water vapor at low pressure.[3] It took them three years to upgrade their instrument to make the low-pressure measurements. But as soon as they did, they saw four equally spaced absorption peaks exactly where Leforestier said they would be.[4]

The observed peaks are four times broader than predicted, and they barely rise above the noise. Tretyakov and colleagues attribute the difference to a simplifying approximation made in the calculations: that the dimer is a symmetric rotor with two equal moments of inertia. Accounting for the dimer's slight asymmetry, and for its many low-frequency vibrational modes that influence the rotational spectrum, would have made the calculations prohibitively difficult. Still, it came as a surprise that the approximation would affect the width of the peaks but not their placement.

The next step for the researchers is to measure the spectrum under different temperatures and pressures and at different wavelengths—information that they need before they can begin to investigate the dimer's involvement in the atmosphere. They also hope to use their spectrometer to detect even more elusive atmospheric species, such as a water–nitrogen complex.

Johanna Miller

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mates, analysts must combine individual records into a global average. Typically, they divide the globe into a grid and, for each grid square, estimate the temperature—or more commonly, the temperature anomaly compared with some long-time local average. The different groups adopt different methods for combining and weighting the data from stations in or near each grid square into a representative value for that area. They also use different methods to estimate the value in a grid square that doesn't enclose a reporting station.

Rather than first adjusting the offset variables for measurements at each site and then computing the global average temperature, as the other groups do, the Berkeley method essentially does those tasks at one time. Robert Rohde of the Berkeley Earth project explains that his group used a standard geostatistics technique known as kriging.

Basically, the Berkeley method is cast as a very large minimization problem. The variable to be minimized is the best estimate of the temperature caused by the local weather, or the deviation of the local temperature from the global average. Its mean should average to zero over long time periods or large spatial scales. One can write the temperature measurement for a given place and time as the sum of four terms: an average global temperature T_{avg}; the positional variation caused by latitude or elevation; the measurement bias, or offset variable; and the temperature associated with local weather. Turning that equation around gives the local weather term for a given month expressed as the measured temperature for that month minus the global mean T_{avg}, the positional variation, and the offset variable.

Values for T_{avg} and for the station offset variables emerge from a global minimization procedure. As Rohde explains, he and his collaborators weighted the monthly weather term from each grid square by a factor related to its correlation with other stations and to the station density. They then summed those monthly terms over all grids and all times and adjusted the offset variables and the monthly means T_{avg} to minimize the mean square of the local weather term. After each minimization, the values of the offset variables are used to calculate new estimates of T_{avg}, and the process is iteratively repeated.

Data sets

The Berkeley group drew on 14 previously compiled databases. (Most of those[5] were in the process of being included in a new version[3,6] of the Global Historical Climatology Network that the NCDC maintains and uses.) Although many of those databases are available to the public in various forms, Schmidt credits the Berkeley team with pulling them all together and releasing them in a consistent way.

Muller says that his aim throughout has been transparency. His team has put not only the raw temperature data but the computer code used in its analysis on its website. He encourages others to make their own assumptions and do their own calculations.

Barbara Goss Levi

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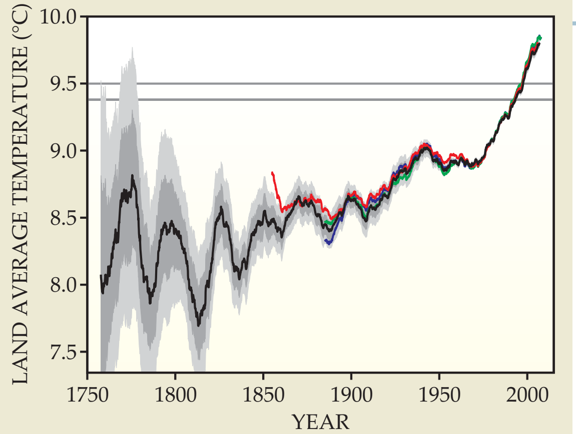

Global land surface temperatures, shown as 10-year running averages. The new estimate made by the Berkeley Earth Surface Temperature project is shown in black, with shaded areas representing uncertainties of one and two standard deviations. The curve compares well with land-only averages calculated for times after 1850 by three other groups: the Climatic Research Unit of the University of East Anglia and the UK Met Office Hadley Center (red); NASA's Goddard Institute for Space Studies (purple); and the National Climatic Data Center of the National Oceanic and Atmospheric Administration (green). Those groups reported temperature anomalies relative to various base periods, so the Berkeley analysts added a constant factor to each to match the absolute calibration shown. (Adapted from ref. 4.)