Proof that mankind causes

Kyoto based flawed

Today's temperatures are supposedly higher than at any time in the past thousand years. This claim is the central pillar of the Kyoto Protocol, which takes effect this month. It is largely based on the celebrated 'hockey stick' graph of temperature history since the year 1000, published by Michael Mann and colleagues in 1998 and 1999. However, according to Canadian researchers Stephen McIntyre and Ross McKitrick, Mann's hockey stick is no more than a statistical artifact. Their quest to verify the accuracy of this pivotal study of global warming raises questions about the integrity of world climate research.

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climate change is refuted

protocol on statistics

Few people dispute that the earth is getting warmer, but there are people – so-called "climate skeptics" – who question whether the change is historically unique and whether it is the result of human activity. These skeptics are generally outsiders, reviled by "true" climate researchers.

On the one hand, Michael Mann, the first author of the two noted hockey stick papers (in *Nature* in 1998 and in *Geophysical Research Letters* in 1999), is the unofficial king of climate research. In 2002, *Scientific American* included him as one of the top 50 visionaries in science. On the other hand, the two Canadian skeptics are outsiders: Ross McKitrick is a Professor of Economics and Stephen McIntyre is a mineral exploration consultant – which Mann likes to call a conflict of interest.

Climate skeptics are most prolific on the internet, a platform for novices, the scatterbrained and the experienced alike. Not surprisingly, the climate researchers who we consulted (predominantly Dutch) presumed the work of the two Canadians to be unconvincing. *Natuurwetenschap & Techniek* was initially skeptical about these skeptics as well. However, McIntyre and McKitrick have recently had an article accepted by *Geophysical Research Letters* - the same journal that published Mann's 1999 article. This, together with the positive responses of the referees to this article, quickly brought us around.

Even *Geophysical Research Letters*, an eminent scientific journal, now acknowledges a serious problem with the prevailing climate reconstruction by Mann and his colleagues. This undercuts both Mann's supposed proof that human activity has been responsible for the warming of the earth's atmosphere in the 20th century and the ability to place confidence in the findings and recommendations of the influential Intergovernmental Panel on Climate Change (IPCC). The political implication is a serious undermining of the Kyoto Protocol with its world-wide agreements on reducing emissions of CO_2 and other greenhouse gases.

In their two seminal papers, Mann and his colleagues purported to reconstruct Northern Hemisphere temperatures for the last thousand years. Since 1000, temperatures gradually decreased (the shaft of the hockey stick), only to increase sharply from 1900 onwards (the blade). The implication is obvious: human interference caused this trend to change.

McIntyre and McKitrick merely attempted to replicate this oft quoted study. In doing so, they identified mistake after mistake. They also discovered that this fundamental reconstruction had never actually been replicated by the IPCC or any other scientist.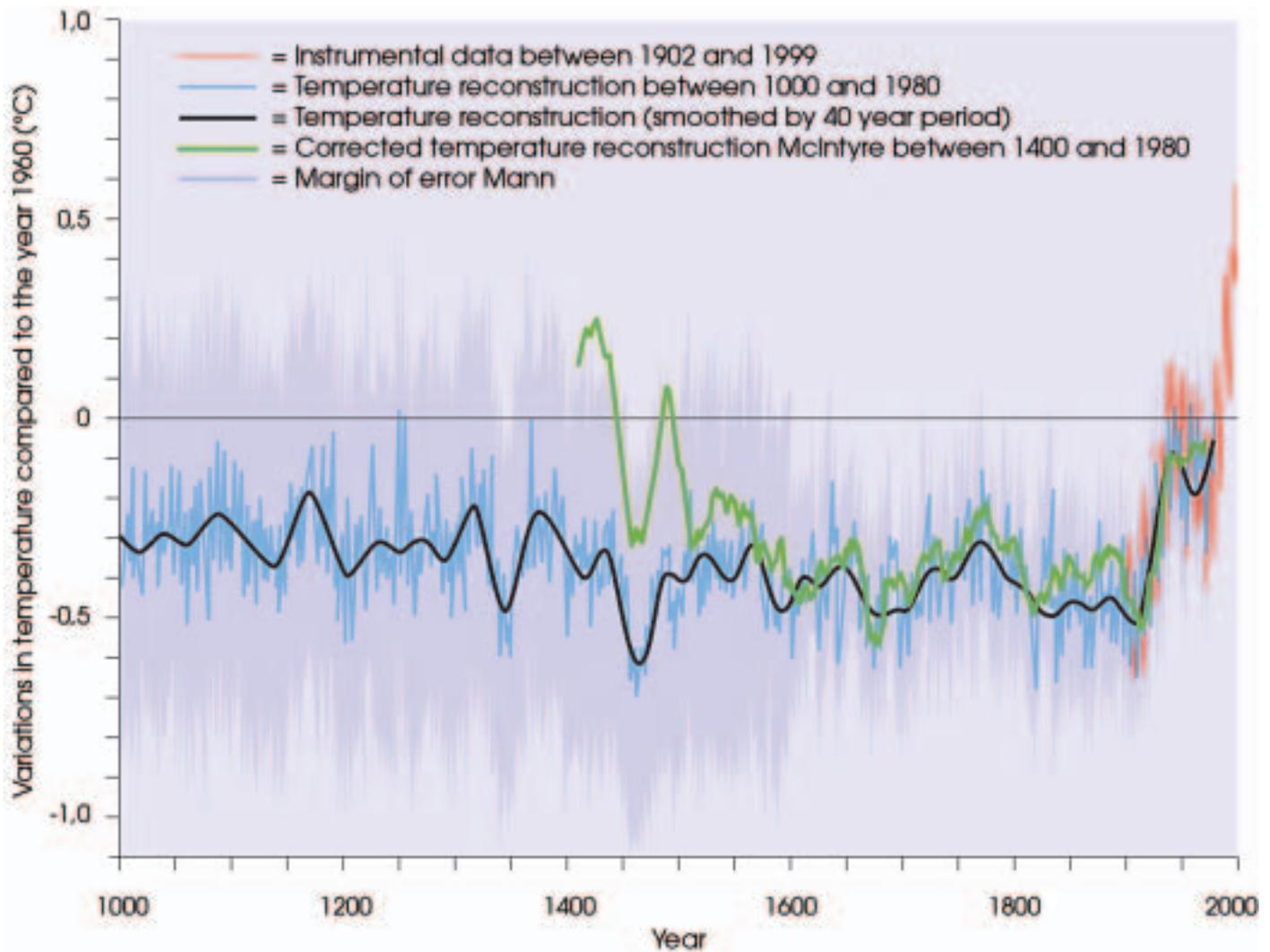 In their replication, basically derived from the same data, temperatures in the 15th Century were just as high as they are today – an outcome that takes the edge off the alarmist scenario of anthropogenic global warming.

The criticism by the Canadians is mostly technical in nature: they claim that Mann and his colleagues have misused an established statistical method – principal component analysis (PCA) – so that their calculations simply mined data for hockey stick shaped series and that Mann's results are statistically meaningless. They have traced the problem to a simple error in a few lines of computer code.

The scientists that we consulted did not immediately recognize the implications of Mann's eccentric method, suggesting the possibility he himself may not have been aware of the apparent mistake. However, in response to our inquiries, Mann denies any errors and rejects any criticism in strident terms.

The conclusion of McKitrick and McIntyre, after being engaged in nearly two years of heated discussions with Mann and other scientists, is alarming: there is something amiss in climate research. Have Mann and his fellow researchers committed fraud? McIntyre: "That is too strong a legal term. What we can say is that the IPCC and many paleoclimatologists have not provided their readers with 'full, true and plain disclosure' (to use another legal term), especially if it involves reporting results adverse to their claims. There is no excuse for anything less than complete disclosure of all data and methods and it is shocking that the authors of the major studies refuse to do so. We have found that peer review of paleoclimate journals is a very limited form of due diligence. If scientific studies are going to be used to justify policy decisions costing billions of dollars, a much more rigorous form of review is needed."

The "Consensus" Up to January 2005, none of McIntyre and McKitrick's findings had been published by major scientific journals. Thus, in the opinion of established climate researchers, there was no reason to take them seriously. Climate researchers were quite comfortable in their consensus and repeatedly referred to this "consensus" as a basis for policy. The official expression of the "consensus" comes from the IPCC. This group, under the flag of the United Nations, comes out with a bulky report every five years on the state of affairs in climate research. Hundreds of climate researchers from every corner of the world contribute to it. In the third report in 2001, Mann himself was a Lead Author of the chapter on climate reconstructions.

Figure legend:
- = Instrumental data between 1902 and 1999
- = Temperature reconstruction between 1000 and 1980
- = Temperature reconstruction (smoothed by 40 year period)
- = Corrected temperature reconstruction McIntyre between 1400 and 1980
- = Margin of error Mann

Y-axis: Variations in temperature compared to the year 1960 (°C)
X-axis: Year

Mann's hockey stick graph was the only climate reconstruction to make it to the IPCC *Summary for Policy Makers*. Its conclusion read: "It is likely that, in the Northern Hemisphere, the 1990s was the warmest decade and 1998 the warmest year during the past thousand years." This statement has been used by governments the world over to promote the Kyoto Protocol.

"To climate skeptics, the statement was like a red flag to a bull", explains Rob van Dorland of the Dutch KNMI (Royal Netherlands Meteorological Institute). Van Dorland is a lead author of the next IPCC report that will appear in 2007. "It's really too definitive a statement. Truthfully, we are far from knowing with certainty how natural climate factors, such as volcanic eruptions and solar activity, affect the earth's climate. The IPCC made a mistake by only including Mann's reconstruction and not those of other researchers."

A brief analysis of Prof. Dr. Ton van Raan of the Dutch CWTS (Center for Science and Technology Studies) shows that the 1998 article of Mann and his colleagues in *Nature* has been cited two times more often than is usually the case for such publications. More striking, according to Raan, is the increase in references over the past two years, whereas most articles are usually 'worked out' after four years. A plausible explanation is the prominent position of the hockey stick in the third IPCC report.

Dot.Com Stephen McIntyre first came across the hockey stick in late 2002. The Canadian government used the graph to promote the Kyoto treaty. McIntyre explains by telephone: "When I first saw the graph, it reminded me of Dot.Com profit forecasts, which were also hockey sticks. It was a compelling graphic, but, in the mineral exploration industry, my own field, compelling graphics are one of the techniques used to interest investors in financing mineral exploration."

McIntyre, who studied math at the University of Toronto, has scrutinized promotional graphics and large data sets for years. "From my own experience, I thought that the graphic looked excessively promotional. A trick of mining promoters is to over-emphasize some isolated results. I wondered if this had been the case with the hockey stick as well. I thought that it would be interesting to look at the data underlying this graphic – as though I was looking at drill core from an exploration project. The interest was simply personal; I had no intention of writing academic articles and never expected what happened afterwards."

McIntyre sent an email to Michael Mann in spring 2003 asking him for the location of the data used in his study. "Mann replied that he had forgotten (!) the location. However, he said that he would ask his colleague Scott Rutherford to locate the data. Rutherford then said that the information did not exist in any one location, but that he would assemble it for me. I thought
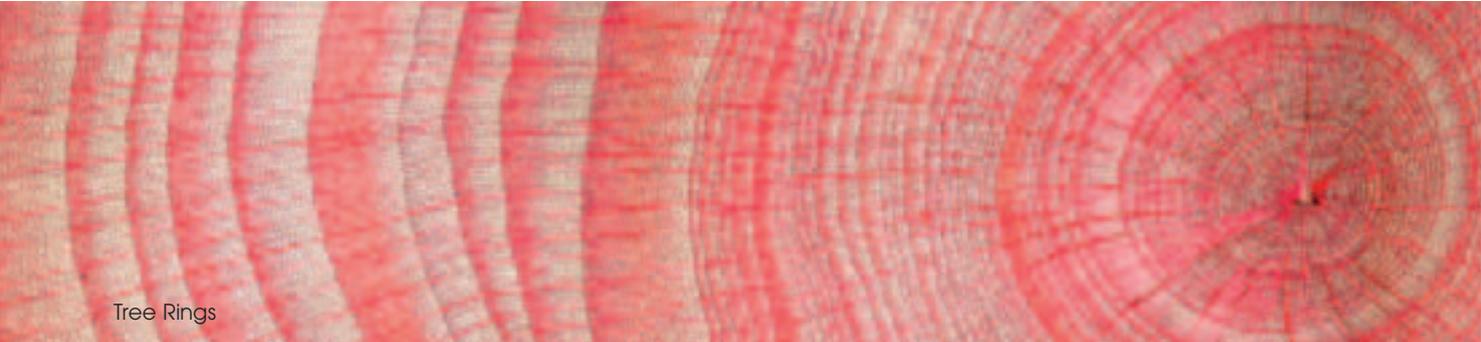
Tree rings Every tree ring gives a temperature indication for the year in which it was formed. Other factors influencing the annual growth are the type of tree and its age, the level of CO2 in the atmosphere and the humidity.

this was bizarre. This study had been featured in the main IPCC policy document. I assumed that they would have some type of due diligence package for the IPCC on hand, as you would have in a major business transaction. If there was no such package, perhaps there had never been any due diligence on the data, as I understood the term. In the end, this turned out to be the case. The IPCC had never bothered to verify Mann, Bradley and Hughes' study."

Despite billions of dollars spent on climate research, academic and institutional researchers had never bothered to replicate Mann's work either. In 2003, McIntyre tackled the job and, from an unusual hobby, the task has since grown to become almost a fulltime occupation. On an internet forum for climate skeptics, he met Ross McKitrick, Professor of Economics at the University of Guelph, just outside of Toronto. Since meeting in person in September of 2003, the two have been working on the project together. McIntyre does most of the research and McKitrick asks questions and assists in the writing of papers.

Tree Rings How do you determine the average temperature for the whole of the Northern Hemisphere? Today the answer seems straightforward: average the temperature measurements of all ground stations (approximately 5000). Even though the majority of stations are on land, the coverage at sea, where buoys are used, is adequate, making for a representative overview.

Reliable temperature measurements have only been available since around 1850. Before this period, researchers have to rely on indirect indicators, or "proxies", such as tree rings, ice cores, sedimentary layers and corals, of which tree rings are the most commonly used. Tree ring widths and density can be measured on an annual basis. But while tree rings are easy to date, they are more difficult to use to measure temperature. Ring width is not just determined by the temperature, but also precipitation, fires, insects, competition within the stand, type of soil and so forth. Scientists studying tree rings will summarize the growth at one site into a single index (a 'chronology'), which might start, for instance, at 1470 and end at 1980. In North America, there are hundreds of such "chronologies", many of which are publicly available from the World Data Center for Paleoclimatology, a public archive. Ice cores may have an accurate temperature signal (although even here precipitation plays a big role), but the obvious disadvantage is their extreme locations. The apparent solution is a multi proxy approach, now customary in climate research.

Calibration Mann's study is the best known of the multi proxy studies. He used mostly tree rings, but also used ice cores, corals and older documentary temperature and precipitation data (primarily for Western Europe). Mann and his colleagues calibrated their proxies to temperature records in the period 1902 to 1980, making the assumption that the relationship between proxies and temperature is constant over time, allowing them to use past proxy values to estimate past temperatures.

For a realistic reproduction of the temperature in the entire Northern Hemisphere, Mann and others attempt to have a relatively even geographic distribution of proxies. This posed a difficulty. The majority of proxies were tree ring "chronologies", especially from the U.S. Southwest.

To achieve more even geographic distribution (and avoid being swamped by North American tree ring data), Mann used PCA to summarize "networks" of tree ring sites, the largest of which was in North America. The 1998 article reported the use of 112 proxy series, of which 31 were principal component (PC) series (from six networks with over 330 sites).

However, for some reason, Mann and his colleagues did not accurately document the data they had actually used. McIntyre: "Of the series and sites listed in the original documentation, 35 were not actually used. To further confuse matters, in November 2003, over five years after publication, Mann stated that they had actually used 159 series, instead of the 112 mentioned in his *Nature* article or in Rutherford's email. Zorita et al., cited by Mann, also used 112."

We decided to inquire with Dr. Eduardo Zorita of the GKSS Research Center in Geesthacht, Germany, who has also recently examined the calculations behind the hockey stick. His response: "This is the first time that I've heard of the number 159. In our analysis of the hockey stick, we do not use the actual data, but a series of pseudo proxies, proxies we take from our simulations. We have always assumed 112 pseudo proxies"

In December 2003, McIntyre and McKitrick sent a detailed notification to *Nature* of the discrepancies between Mann's actual data set and his published listing, which prompted *Nature* to order a Corrigendum in July 2004. This did not resolve the problem.

McIntyre: "The Corrigendum implies that 139 series were used, but the difference between this and other information has never been reconciled."

Independently of these problems, McIntyre had earlier decided to check the PC calculations for tree ring networks, by doing fresh calculations with original data from

the World Data Center for Paleoclimatology (WDCP) His PC results were very different from Mann's. He and McKitrick then sent the full data set (originally downloaded from Mann's FTP site from the address provided by Rutherford) back to Mann for confirmation that this was actually the dataset used in MBH98. In response, Mann stated that he did not have the time to answer this or any other request.

While comparing Mann's data to official WDCP versions, they found that Mann had sometimes used outdated versions. Replacing them with the archived versions and carrying out fresh PC calculations, McIntyre and McKitrick then tried to replicate Mann's Northern Hemisphere temperature calculations from scratch. The results largely coincided with the hockey stick, except for the 15th Century, when their calculated temperatures were considerably higher than Mann's and were even higher than corresponding estimates in the 20th Century. McIntyre emphasized: "We did not claim to have discovered a warm medieval period; we only stated that, given the many defects in the study, it could not be used to assert that the 1990s were the warmest years of the past millennium.

Their paper was published in the interdisciplinary journal *Energy and Environment* in October 2003. They published all the algorithms online at www.climate2003.com, together with further explanations of their methods. They knew something was amiss with Mann's PC analysis, but couldn't quite put their finger on it yet. The article aroused considerable interest and debate but was mostly ignored by climate researchers.

Ice cores also have year rings.

Faulty Data Mann's early responses were quite unexpected. McIntyre: "On the website of David Appell, an American science journalist, Mann stated that we had used the wrong data and somehow we failed to notice errors in the data. This was outrageous, as we had downloaded the data from his own FTP site from the location provided by his own colleague, Scott Rutherford; we had described countless errors in great detail and had re-collated over 300 series to avoid these problems. Now, according to Mann, we should have taken the data off a different address at his ftp site, but this new address had never been mentioned in any publication or even on his own website."

A little later, Mann and his colleagues said that they had used a stepwise procedure for PC calculations to deal with missing data, while McIntyre and McKitrick had not. McIntyre: "This was when the figure of 159 series first appeared. There is no mention of this stepwise method in his *Nature* article. A PCA calculation fails if there is any missing data. For the tree ring networks, in the earlier periods, many sites become unavailable. So now it turned out that Mann and his team had redone PCA calculations in steps. The figure of 159 series came from using different PC versions from different steps. Mann refused my request to identify the 159 series, but there was enough information on the controversial early 15th century, we estimated the most likely sequence and proceeded on."

But McIntyre and McKitrick were most intrigued by the attribution by Mann and his colleagues of the difference in results to three "key indicators" – most notably the North American PC1 , showing that, with different handling of these three series, they also obtained high early 15th century results. McIntyre and McKitrick decided, for the time being, to concentrate on the years 1400 to 1450, the period with the biggest discrepancies: "Mann's own response showed that his temperature reconstruction for the first half of the 15th Century depended on PCs from the North American network. We decided to find out everything that we could about these three indicators."

Because of the discrepancy between the published methodology and the methods actually used, the ambiguity over the data sets and the sudden claim that 159 series had to be used, McIntyre and McKitrick requested original source code from Mann in order to fully reconcile their results. Mann refused. McIntyre and McKitrick then requested both *Nature* and the *National Science Foundation*, who had financed Mann's research project, to compel disclosure. Both organizations refu-

Creating a Hockey Stick

Multiproxy-studie

For his climate reconstruction, Mann uses proxies, series of data that serve as temperature indicators. Proxies could be trees, ice cores, corals or older existing temperature and precipitation data.

Unusual Standardization

Before you can perform a principal component analysis, you need to standardize your data. Normally, you would determine the mean and the standard deviation of the data. The mean would then be subtracted from each column after which they would be divided by the standard deviation. With a normal distribution, 95% of the data would fall between -2 and +2 units of the standard deviation. Mann bases both the mean and the standard deviation on just the period between 1902 and 1980. Through this calculation all data is standardized. This included the data from before 1902. For tree II this has very little consequences as the mean obtained through both calculations is virtually identical. For tree I the effect is substantial: the data for the period 1902 to 1980 fall between -2 and +2, while a large part of the other data fall outside of this area.

Proxies

- ▲ = Tree rings
- ✳ = Year rings ice cores
- ▣ = Coral
- ▢ = Older temperature measurements (before 1850)
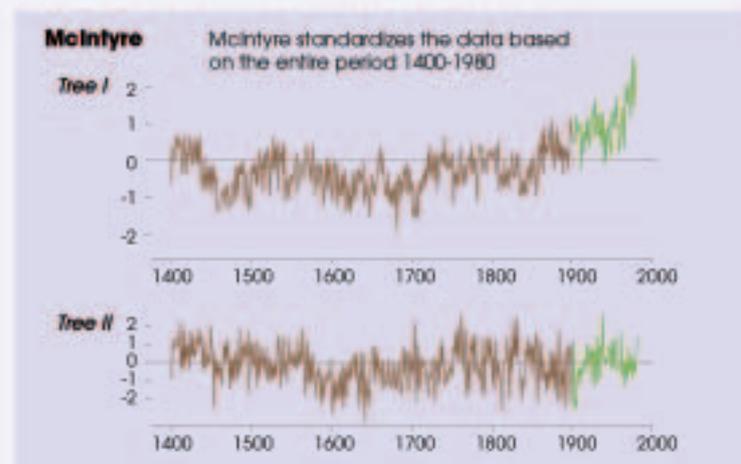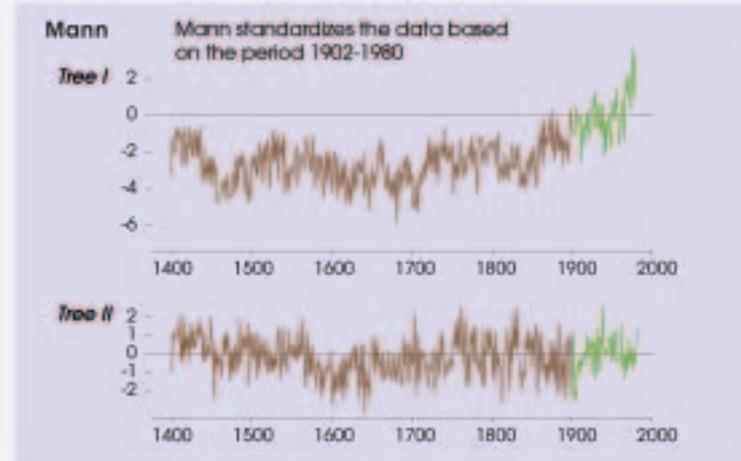- ◇ = Older precipitation data (before 1850)
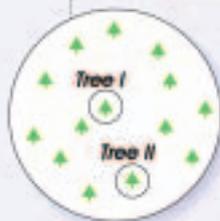
Geographical Distribution

In some areas hundreds of tree rings are available. For an even distribution of proxies in the Northern Hemisphere, Mann uses the principal component analysis to reduce the series to a manageable number of principal components.

Mann — Mann standardizes the data based on the period 1902-1980

McIntyre — McIntyre standardizes the data based on the entire period 1400-1980

The Canadian researchers Stephen McIntyre and Ross McKitrick have demonstrated that the method Mann and his colleagues use to reconstruct the temperature of the Northern Hemisphere in the past thousand years leads to a significant overvaluation of tree ring series with a hockey stick shape.
Using two time series of trees, we demonstrate the effect of the unusual standardization that Mann works with. The time series of tree I has a clear hockey stick shape, that of tree II does not show any trends. Tree I is a bristle cone pine from the Sheep Mountains in California. This tree was given most importance in the calculation of the PCs in the North American network. Tree II was given hardly any weight at all.

sed, although *Nature* did require Mann to publish a new description of his methodology.

Meanwhile, the stepwise PC issue did not end the story, as the difference in results persisted after McIntyre implemented it. McIntyre tried to replicate the North American PC series at the newly disclosed location at the FTP site Once again, he could not do so.

Mining for hockey sticks But McIntyre did make an interesting find at Mann's FTP site, – a Fortran program of about

500 lines for the calculation of tree ring PCs, virtually the only source code on the entire site. They carefully studied the script and found something very unusual. McIntyre: "In a conventional PC calculation in a high-level language, the mean of each series is subtracted from each column prior to the rest of the algorithm. Instead of doing this, Mann's Fortran program had only subtracted the 1902-1980 mean from each column. This is a highly unusual procedure and had not been mentioned in the *Nature* article."

Principal Component Analysis
The standardized data are used to run a PCA. Tree I is plotted along the x-axis and tree II is plotted along the y-axis. The result is a cloud of dots. With the PCA, the two dimensional cloud is reduced to one dimension, the principal component (PC). A PCA can be used to track series with the biggest distribution. As a result of his unusual standardization, Mann detects a better distribution along the x-axis (tree I) than the y-axis (tree II). The PC is almost parallel to the x-axis which means tree I is given most importance. In McIntyre's graph, both trees have roughly the same weight. This is why the PC runs at an angle of around 45 degrees.

Colder and Warmer Years
All data is projected on top of the PC. The result is a line on which there are green and brown dots. Colder years are on the left and warmer years on the right. With Mann's method, virtually all warm years are green, meaning they fall in the 20th Century. With a normal standardization green and brown dots are intermingled.

Plotted in time, Mann's dots create a hockey stick shape, whereas the normal procedure also shows a warm period in the 15th Century.

Data post 1900
Data pre 1900

Special thanks to Mia Hubert
Chaos wetenschap & Techniek / Schwandt Infographics

The seemingly small change has major consequences for the end result and explains most of the difference between the graph of McIntyre and McKitrick and the hockey stick for the 15th century. McIntyre: "The effect is that tree ring series with a hockey stick shape no longer have a mean of zero and end up dominating the first principal component (PC1); in effect, Mann's program mines for series with a hockey stick shape. In the crucial period of 1400-1450, in the critical PC1 of the North American network, the top-weighted Sheep Mountain series, with a hockey stick shape gets over 390 times the weight of the least weighted series, which does not have a hockey stick shape."

At our request, Dr Mia Hubert of the Katholieke Universiteit Leuven in Belgium, who specializes in robust statistics, checked to see if the Mann's unusual standardization influenced the climate reconstruction. She confirms: "Tree rings with a hockeystick shape dominate the PCA with this method."

McIntyre and McKitrick decided to perform another check. Using computer simulations of so-called 'red noise', they generated networks of artificial tree ring data over the period of 1400-1980. Red noise is commonly used in climatology and oceanography, because, like many natural processes, it has a constant mean as well as (randomly distributed) pseudo-trends that reverse and cancel out over time.

McIntyre: "In each simulation, there are some red noise series that happen to go up in the 20th century, some that go down and basically everything in between. If we used Mann's method on red noise, we consistently obtained hockey sticks with an inflection at the start of the 20th century. We have repeated the simulation thousands of times and in 99% of the cases, the result of the PCA was a hockey stick."

Apparently, Mann did not like the results in directory Backto_1400_Censored

The conclusion is that Mann's climate reconstruction methodology would have yielded a hockey stick graph, from any tree ring data set entered into the model as long as there is sufficient red noise.

The two Canadians are no longer just one voice crying in the wilderness. On October 22, 2004 in *Science*, Dr. Zorita and his colleague Dr. Hans von Storch, a specialist in climate statistics at the same institute, published a critique of a completely different aspect of the 1998 hockey stick article . After studying McIntyre's finding at our request, Von Storch agrees that "simulations with red noise do lead to hockey sticks. McIntyre and McKitrick's criticism on the hockey stick from 1998 is entirely valid on this particular point."

Discrepancies and Duplications There was yet another important discovery to follow McIntyre: "When we compared data as used by Mann with original archived data, we found one and only one example where the early values of a series had been extrapolated – a cedar tree ring series from the Gaspé peninsula in Canada. The extrapolation, from 1404 back to 1400, had the effect of allowing this series to be included in the critical early 15th century calculations. When we did calculations both including and excluding the series, we found that the difference was considerable. In some cases, the temperature was as much as 0.2 degrees Celsius lower using the modified Gaspé series as compared with the archived version.

"More strangely, the series appears twice in Mann's data set, as an individual proxy, and in the North American network. But it is only extrapolated in the first case, where its influence is very strong." McIntyre and McKitrick went back to the source of the Gaspé series and then to the archived data at the World Data Center for Paleoclimatology. "We found that although the Gaspé series begins in 1404, up until 1421, it is based on only one tree. Dendrochronologists (tree ring researchers) generally do not use data based on one or two trees. The original authors only used this series from 1600 onwards in their own temperature reconstructions. This series should never have been used in the 15th century, let alone counted twice and extrapolated."

McIntyre and McKitrick submitted a paper to *Nature* in January 2004. Mann and his colleagues were invited to respond. McIntyre: "They raised an interesting point. They stated that the North American PC1 was not just based on the Sheep Mountain series, but that fourteen other series were also highly weighted in it. In late March, we sent in a second version of the article in which we demonstrated that these fourteen tree rings were all from highly controversial bristlecone pine series, stu-

died by Graybill and Idso in 1993, which showed an unusual growth spurt in the 20th Century. Graybill and Idso themselves attributed the growth spurt to higher concentrations of CO_2 in the air, because they were able to show that it was not caused by increased temperatures. Oddly enough, in their 1999 article, Mann and his colleagues had actually admitted the same thing: "A number of tree ring series at high altitudes in the western part of the United States seem to show a prolonged growth spurt that is more pronounced than can be explained with the measured increase in temperature in these regions."

Now, a number of years later, Mann's defense includes the remark that these same series form the "dominant" part of the Northern American PC1, and accordingly, justifies their inordinate influence on the temperature reconstruction of the entire Northern Hemisphere.

The "Censored" Folder As the story unraveled, more intrigue came to the surface. McIntyre: "On Mann's FTP site, the directory for the North American network contains a subdirectory with the striking name BACKTO_1400-CENSORED. The folder contains PCs that looked like the ones we produced, but it was not clear how they had been calculated. We wondered if the folder had anything to do with the bristlecone pine series: this was a bulls eye. We were able to show that the fourteen bristlecone pine series that effectively made up Mann's PC1 (and six others) had been excluded from the PC calculations in thecensored folder. Without the bristlecones sites, there were no hockey sticks for Mann's method to mine for, and the results came out like ours. The calculations used in Mann's paper included the controversial bristlecone pine series, which dominate the PC1 and impart the characteristic hockey stick shape to the PC1 and thereafter to the final temperature reconstruction. Mann and his colleagues never reported the results obtained from excluding the bristlecone pines, which were adverse to their claims."

"Imagine the irony of this discovery. After we published our findings in *Energy and Environment*, Mann accused us of selectively deleting North American proxy series. Now it appeared that he had results that were exactly the same as ours, stuffed away in a folder labeled CENSORED."

When McIntyre and McKitrick submitted the second version of their article to *Nature*, they discussed the dubious role of the bristlecone pine series and reported the CENS-ORED subdirectory. "*Nature* then asked us to shorten our article to a mere 800 words and we did. Months went by and then we were told that they were now only willing to permit us 500 words and the content was too 'technical' to be dealt with in 500 words."

McIntyre and McKitrick were understandably frustrated. Compunding matters, Mann and his colleagues had by then published a corrigendum (*Nature*, 1 July 2004). McIntyre: "This corrigendum, however, is very misleading. Our main criticism, concerning the principal components calculations, was not addressed, even though the procedure was inaccurately described in the original article. We were given an advance proof of the text of the corrigendum and had provided feedback on it. But after the page proof stage, they inserted the statement that 'none of these mistakes influence our earlier results'. Naturally, we do not agree with this claim at all." *Natuurwetenschap & Techniek* directly asked *Nature* whether this claim had been externally peer reviewed and was told that *Nature*'s policies do not require peer review of corrigenda, implying that it was not refereed.

Turning Tide In January 2005, an adapted version of McIntyre and McKitrick's paper was accepted for publication by *Geophysical Research Letters* (GRL). The issue will come out in early 2005, as will a new issue of *Energy and Environment* containing a second publication by the two Canadians on implications of their GRL findings. Judging by the reactions of the referees of GRL, which McIntyre made available to us, the tide may be turning in the climatology field. One referee stated: "S. McIntyre and R. McKitrick have written a remarkable paper on a subject of great importance. What makes the paper significant is that they show that one of the most important and widely known results of climate analysis, the "hockey stick" diagram of Mann et al., was based on a mistake in the application of a mathematical technique known as principal component analysis (PCA)."

The same referee also writes: "McIntyre and McKitrick found a non-standard normalization procedure in the Mann et al. analysis. Their paper describes this procedure; it was an apparently innocent one of normalization, but it had a major effect on their results. The Mann et al. normalization tends to significantly increase the variance of data sets that have the hockey-stick shape. In the Mann et al. data set, this turned out to be bristlecone pines in the western United States. Thus the hockey stick plot, rather than representing a true global average of climate for the past thousand years, at best represented the behavior of climate in the western US during that period. This is an astonishing result. I have looked carefully at the McIntyre and McKitrick analysis, and I am convinced that their work is correct."

The referee ends with: "I urge you not to shy away from this paper because of its potential controversy. The whole field of global warming is currently suffering from

the fact that it has become politicized. Science really depends for its success on an open dialogue, with critics on both sides being heard. McIntyre and McKitrick present a cogent analysis of the global warming data. They do not conclude that global warming is not a problem; they don't even conclude that the medieval warm period really was there. All they do is correct the analysis of prior workers, in a way that must ultimately help us in our understanding of past climate, and predictions of future climate. That makes this a very important paper. I strongly urge you to publish it."

Climate researchers can now no longer dismiss McIntyre and McKitrick's efforts with the remark that they didn't publish in an authoritative journal. Mann, Bradley and Hughes, meanwhile, continue to defend themselves quite aggressively. One of the *Nature* referees noticed this as well: "I am particularly unimpressed by the MBH style of 'shouting louder and longer so they must be right'."

Mann has obviously decided to defend his graph to the bitter end. Not too long ago, he and his team launched a weblog, www.realclimate.org, in which they strike back very aggressively. Mann's main criticism of McIntyre and McKitrick's previous calculations is that they should have expanded the list of North American PCs from two to five, so that the bristlecone pines in the fourth PC (PC4) could be included.

The problem with the principal components analysis is that there is no objective criterion for the number of principal components that are relevant. Strictly speaking, a data set with a hundred proxies will yield as many principal components since the PCA does nothing other than present the data in a different manner. The difference is that principal components can be ran-

Harvesting tree rings.

not be allowed to override the rest of the data set.

Not surprisingly, McIntyre is unfazed by the criticism: "Mann claims that his PC1 (essentially the bristlecone pine series) represents a dominant trend in the North American network. Using his incorrect standardization, the PC1 does account for 38% of the NOAMER network variance. However, in a correct calculation, the bristlecones are demoted to the PC4 and only account for 8% of the variation. Hardly a dominant trend, like Mann claims. His argument to increase the number of PCs is simply a desperate move to salvage the hockey stick. Look at this from a robustness point of view: Mann has claimed in print that his result is so robust that even removing all his tree ring data will not overturn it. Now all of a sudden, he insists that a single PC4 based on the controversial bristlecone pine data plays the deciding role in the temperature history of the entire Northern Hemisphere."

Robustness When we put forward some of the criticism to Mann, Bradley and Hughes in an email, we received an elaborate response within the hour (for the full response, see www.natutech.nl). Apart from the stock arguments that McIntyre and McKitrick are not real scientists, Mann rationalized the presence of the directory BACKTO_1400-CENSORED on his FTP site: "After publication of the first hockey stick in 1998, we ran a number of sensitivity tests to determine if we could come to a reliable reconstruction without having to correct certain tree ring series at high altitudes for non-climatological effects, like the influence of CO_2. We reported on this in the publication of 1999."

McIntyre is not satisfied: "In his second publication, Mann mentioned problems with the bristlecone pines, but only with regards to the period of 1000-1399 and not the 15th Century that is in this file. More importantly, if you know there are problems with the bristlecone pines, the obvious test would be to eliminate them from the calculation and see what the effect is. This is exactly what Mann did in the directory BACKTO_1400-CENSORED. When he did not like the results, he did not report them and proceeded to include the bristlecone pines in his final analysis."

We asked Mann about the apparent inconsistency between the claimed robustness and the evidence that the shape of his hockey stick relies heavily on the bristlecone pines in the NOAMER network. Mann responds that he can reach the same results even without doing a PCA, arguing that you could simply use all 95 proxies individually in the calculations: "There is no clearer proof that McIntyre and McKitrick claims are false."

ked in order of importance whereas the proxies can not: the PC1 is always the dominant pattern, followed by the PC2, etc. Depending on the amount of noise in the data and the aim of the study, one, two or even more PCs are used to represent the trends in the data. Normally a subtle trend in the PC4 should
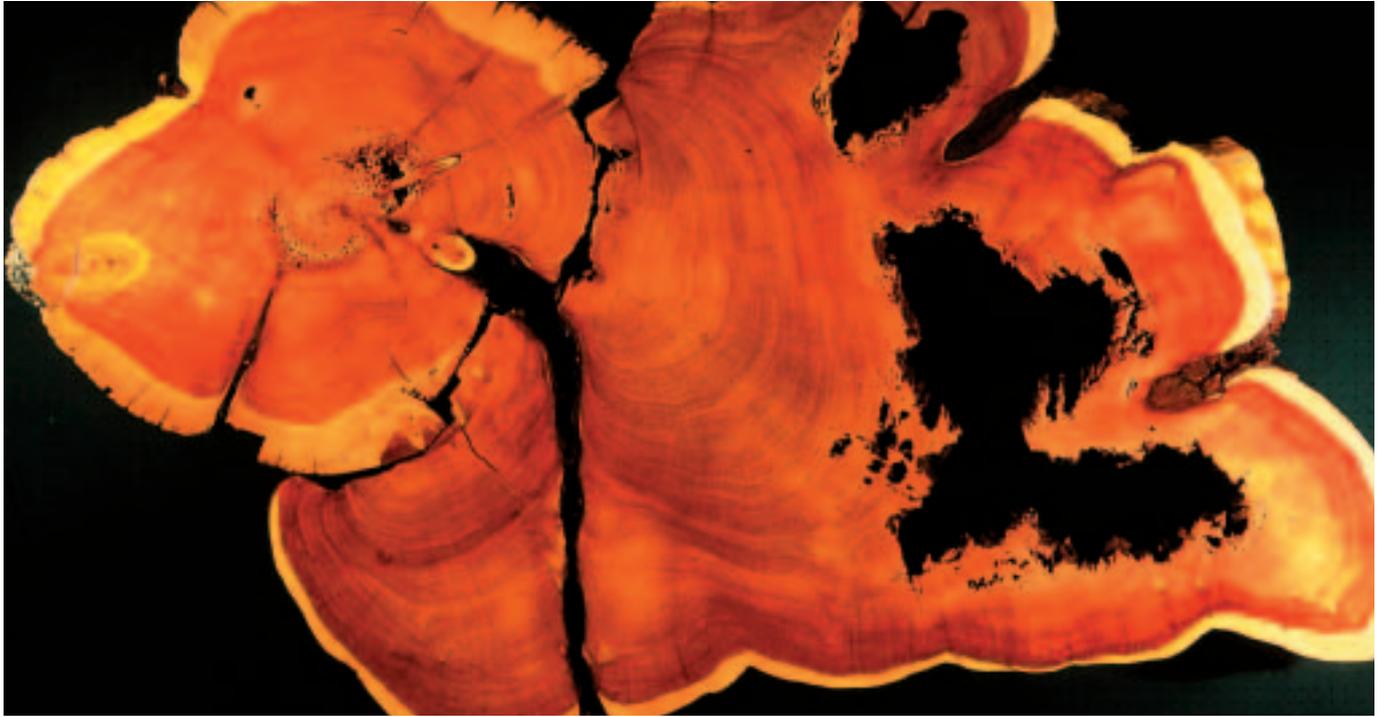
"Mann is a clever debater", McIntyre points out. "He ducks the question and tries to argue that he can reach the same results by using a different method. However, his argument is illogical. We stated that his method mines for hockey stick shaped series – he avoids this topic. We showed that the bristlecone pine series were emphasized by his mining method. That he can produce a hockey stick with another method that also allows the bristlecone pines to dominate is completely irrelevant. The bristlecone pine series are still essential for this new result. When you do the calculation without the bristlecone pines, the result does not resemble a hockey stick in any way."

Mann further argued that he is not the only scientist to have found the hockey stick graph: "Over a dozen other estimates based on proxy data yield basically the same result." The argument is not new to McIntyre: "The fact that other studies have produced similar results is not proof that Mann's method is valid."

At this point, McIntyre has growing doubts about the other studies as well. His initial impression is that they are also dubious. It is almost certain, or so he states, that the other studies have not been checked either. McIntyre: "Mann's archiving may be unsatisfactory, but other researchers, including Crowley, Lowery, Briffa, Esper, etc, are even worse. After twenty-five emails requesting data, Crowley advised me that he had misplaced his original data and only had a filtered version of his data. Briffa reported the use of 387 tree ring sites, but has not disclosed the sites. Other researchers haven't archived their data or methods or replied to requests."

"Mann speaks of independent studies, but they are not independent in any usual sense. Most of the studies involve Mann, Jones, Briffa and/or Bradley. Some datasets are used in nearly every study. Bristlecone pine series look like they affect a number of other studies as well and I plan to determine their exact impact. I'm also concerned about how the proxies are selected. There is a distinct possibility that researchers have either purposefully or subconsciously selected series with the hockey stick shape. I'm planning to use simulations to test if the com-

mon practice of selecting the so-called "most temperature sensitive" series also yield hockey sticks from red noise."

McIntyre and McKitrick draw far reaching conclusions from their research: "When the IPCC decides to base their policy on such studies, triggering the spending of billions of dollars, there should be more thorough checks. At some point, some one should have done an elementary check on the principal component calculations. This never happened and there is no excuse for this."

Rob van Dorland of the KNMI has read the article that will appear in *Geophysical Research Letters* and is convinced it will seriously damage the image of the IPCC. "For now, I will consider it an isolated incident, but it is strange that the climate reconstruction of Mann has passed both peer review rounds of the IPCC without anyone ever really having checked it. I think this issue will be on the agenda of the next IPCC meeting in Peking this May."

This brings climate research back to square one. McIntyre: "Our research does not say that the earth's atmosphere is not getting warmer. But the evidence from this famous study does not allow us to draw any conclusions about its extent, relative to the past thousand years, which remains as much a mystery now as it was before Mann's article in 1998 ∎

Information

The two articles by Mann et al. in which the hockey stick is calculated:
Mann, M.E. Bradly, R.S. and Hughes, M.K., 1998. Global-Scale Temperature Patterns and Climate Forcing Over the Past Six Centuries, Nature, 392, 779-787.
Mann, M.E. Bradly, R.S. and Hughes, M.K., Northern Hemisphere Temperatures During the Past Millennium: Inferences, Uncertainties, and Limitations, Geophysical Research Letters, 26, 759-762, 1999.

The polemics between McIntyre & McKitrick and Michael Mann:
www.uoguelph.ca/~rmckitri/research/trc.html
www.climate2003.com
www.realclimate.org