Climatic outlooks: from revolutionary science to orthodoxy

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Abstract

Earlier this year considerable media attention was devoted to predictions that an El Niño event may be developing. In the Australian media these predictions were accompanied by warnings that the El Niño would likely lead to drought. In *The Age* on 18 July, the financial company Merrill Lynch used these forecasts to warn of the effects on some major companies dependent on agriculture. According to Barry White, national coordinator of the Climate Variability in Agriculture Program, 40% of farmers[1] take into account the predicted likelihood of an El Niño event. Three decades ago Australian interest in the El Niño, even amongst atmospheric scientists, was almost non-existent, and the media and the general public had never heard of the term. Most meteorologists believed, with good reason, that climate prediction was impossible. This was despite the fact that Australian scientists had been studying what we now call the El Niño - Southern Oscillation for nearly a century. Charles Todd, as long ago as 1888, identified an example of the global climate linkages that make up the phenomenon. In the early decades of the 20th century E. T. Quayle, from the Bureau of Meteorology, initiated the research that underpins our current climate prediction system. It took over 60 years for this research to lead to operational climate outlooks. Now El Niño "experts", and climate forecasts, abound. The transmutation of the El Niño and climate prediction from revolutionary science to orthodoxy illustrates how interactions between individuals, chance events, technology, and culture, can lead to paradigm shifts.

Introduction

On Sunday morning, 7 July 1991, I was woken by two sounds. The first was the fanfare for the 6am ABC news on the motel radio-alarm clock in Dubbo – my family and I had stopped there on our drive to the Gold Coast for a vacation. The announcer led the bulletin with the news that the Bureau of Meteorology was forecasting an El Niño event, and that this would likely be accompanied by drier than normal conditions over central NSW. This was hardly news to me, or to my family. Two days earlier I had been involved in the regular monthly climate outlook meeting of Bureau staff at which we had decided to issue a press release about the developing El Niño and likely drought. The other sound I heard, though, was unexpected – the sound of heavy, continuous rain. That sound, and the rain, accompanied us for the remainder of the drive to the Gold Coast. We arrived at the Coast with the rain still falling. The (very wet) Courier-Mail billboards outside every newsagency and milk bar trumpeted:

DROUGHT FEAR
EL NIÑO
RETURNS

My family thought this was hilarious – it took their minds off the question of what we could do at a beach resort in heavy, continuous rain. Luckily for the vacation, and me, if not for farmers, the rain stopped later that day and the remainder of the vacation (and in fact the rest of the year) was dry through northern New South Wales and Queensland.

The fact that we could issue a climate forecast, even if at times such forecasts led to embarrassment, was not something atmospheric scientists thought feasible when I started my career in 1971. This paper describes my personal view on how scientific understanding about El Niño, or at least its relationship to Australia, has evolved. I will focus on the last three decades, which have seen a revolution in our beliefs about the predictability of climate.

Historical setting

Before I provide my perspective of this recent change in the fortunes of the El Niño - Southern Oscillation, we need to set the scene by discussing the earliest work on the phenomenon, and the Australian climate. Some of the earliest descriptions of the Australian climate noted the unusually high variability of the rainfall. William Stanley Jevons after studying only 18 years of data[2] noted that:

> "I shall have to show in the course of this part of the work that the Australasian climate is one of irregular rains, and is thus distinguished from most climates where the rains are pretty equable and constant although less in total amount."

This concept of high rainfall variability was quickly established in the Australian consciousness:

> "…the climate is not only niggardly on the whole, it is a most capricious tyrant, destroying at uncertain intervals what it has reared in a few milder seasons."[3]

This high variability is the result of the influence of the El Niño - Southern Oscillation. Countries and areas affected by this phenomenon really are lands "of droughts and flooding rains" and I quoted Dorothea Mackellar's "My Country", to stress this point, in a paper[4] documenting this enhanced variability.

One of the areas affected by the El Niño - Southern Oscillation phenomenon, with consequently amplified rainfall variability, is India. Much of the early work on climate prediction was initiated as a result of the disastrous drought-related Indian famines of the late 19th century. Henry Blanford, the first Imperial Meteorological Reporter to the Government of India, observed that the atmospheric pressure over the countries surrounding the Indian Ocean had been abnormally high during the Indian monsoon failure of 1877 and 1878. We now regard this period as one of the strongest El Niño events on record (I will discuss why later in this paper). Blanford requested further information on atmospheric pressure conditions at this time, from other meteorological observers around the world, including Charles Todd in South Australia. Todd was obviously intrigued by Blanford's report, and noted that Australia was also in drought in 1877. In the next major Australian drought, in 1888, Todd concluded[5] that "there can be little or no doubt that severe droughts occur as a rule simultaneously over the two countries". This tendency for Indian and Australian droughts to occur at the same time we now know is just one of the many "teleconnections" that are an essential feature of the El Niño - Southern Oscillation phenomenon. "Teleconnections" are associations or linkages between climate anomalies in different parts of the world. Ångström[6] appears to be the first to have used the term. Todd's conclusion appears to have been ignored or overlooked until I found it while researching for a paper[7] on the 1888 Australian drought, in a newspaper article published by Todd and two other 19th century Australian meteorologists in late 1888.

Despite Todd's finding remaining undiscovered, over the next few decades several meteorologists, most notably Gilbert Walker, one of Blanford's successors in India, documented many teleconnections, named them the Southern Oscillation, and demonstrated its potential use in seasonal prediction. In Australia, E. T. Quayle[8] showed early in the 20th century that atmospheric pressure in Darwin could be used for seasonal prediction in southeast Australia. Quayle simply related the observed atmospheric pressures at Darwin with later rainfall over southeast Australia. Darwin pressure is half of the Southern Oscillation Index or SOI, an index now commonly used in Australian seasonal climate prediction. Quayle was, in part, inspired by Walker's work on the Southern Oscillation to look at Darwin pressures as a predictor, although he had much earlier[9] suggested that the number of "monsoonal" depressions over summer could be used to forecast winter Victorian and New South Wales rainfall. Treloar[10], another Bureau scientist, also built on Walker's work and presented empirical evidence that total September-May rainfall in far north Australia could be predicted using Darwin pressures. There seems to have been little, if any, effort to use Quayle's (or Treloar's) work in operational climate prediction in Australia. I suspect this was because:

1. The work underlying the forecast relationships was statistical, with doubts about whether these relationships would continue to hold in the future. Quayle only had a few decades of data to examine, so there was a good chance that the relationship was a fluke.
2. No one had a theory to explain the teleconnections or the lag relationships. Grant was speaking for most atmospheric scientists in the middle of the 20th century when she warned[11] of the "dangers of purely empirical studies of relationships between meteorological variables. Such relationships can only be established by an increased knowledge of the underlying physical processes".
3. The empirical relationships did not work very well through the 1920s and 1930s, which was when Quayle, perhaps, was testing them.
4. By the late 1930s the focus of meteorologists had shifted from climate to daily weather forecasting, especially for aviation.
5. From the late 1940s, as computers were developed, attention shifted even more to weather prediction, including the development of computer models.

Throughout the atmospheric sciences in the middle decades of the 20th century climatology was "neither respected nor valued"[12]. According to Kenneth Hare[13] "…only the old, the halt, and the infirm could be appointed to the climatological branch; the able-bodied men were expected to be forecasters". Climatology was regarded as "mere book-keeping … to be posted to the climatological branch of a national weather service was like being made an intelligence officer, or a lighthouse keeper; it was a terminal appointment"[14]. As a result of the shift in focus away from climate science, in the nine-month training course for meteorologists that I completed in 1971 the Southern Oscillation was dealt with in less than 10 minutes. And my lecturer said that all it meant was that when pressure was high here it was low somewhere else and that "it wasn't very important".

One way to highlight the shift in emphasis in meteorology is to contrast two public comments, made about 60 years apart, on the feasibility of climate prediction. The first was published by Ellsworth Huntington, the geographer and environmental determinist, who visited Australia in the early 1920s and asked[15]:

> "Why should not Australia find out how to predict the general types of weather six months or a year in advance?…That this can be done and that the general character of the weather for six months or a year in advance can some day be predicted with considerable accuracy seems certain. It is merely a question of securing able men, giving them every possible facility for investigation at home and abroad, and permitting them to study their problems for years without being forced to show immediate practical results".

Sixty years later we no longer had Huntington's confidence (perhaps because we had not been provided with "every possible facility for investigation"?). At a 1983 meeting on El Niño's impact on Australia, a senior Bureau scientist was asked why the Bureau did not issue forecasts based on the statistical relationships found by Quayle and others. In reply he pointed out that we needed data from all over the world to make forecasts for just five days ahead, so the idea that a single number (the SOI) could be used to forecast a season ahead was just not credible. This was the orthodox view about climate prediction amongst meteorologists in the 1970s and early 1980s.

Attempts had been made to prepare forecasts out to a month or more, both in Australia and overseas. Kenneth Arrow, the 1972 Economics Nobel Laureate was a weather officer in the US Air Force during the Second World War. Some officers had been assigned the task of forecasting the weather a month ahead, but Arrow found that these forecasts had no skill. The forecasters agreed with this assessment and asked their superiors to be relieved of this task. The reply was "The Commanding General is well aware that the forecasts are no good. However, he needs them for planning purposes"[16].

In Australia, the Bureau of Meteorology experimented with thirty-day forecasts in the 1960s. These forecasts extrapolated the observed broad-scale circulation fields around the hemisphere (ie, they did not use any information about the El Niño - Southern Oscillation), and used these extrapolations to estimate temperature and precipitation for the ensuing month. The forecasts showed little if any skill[17] and were discontinued at the start of the 1970s.

Despite the widespread belief that climate was fundamentally unpredictable, some researchers continued to study the (now unfashionable) Southern Oscillation (see Allan et al.[18] for a history of research into the phenomenon; also see Glantz and Nicholls[19] for a chronology of interest in El Niño). By the 1960's, Hendrik Berlage, working in what was then the Dutch East Indies and in the Netherlands, had recognised that the Southern Oscillation was related to the temperature of the east equatorial Pacific Ocean. Jacob Bjerknes demonstrated how El Niño events could produce climate teleconnections. Since then, the Southern Oscillation and the El Niño have been lumped together as the El Niño - Southern Oscillation. Within Australia, Sandy Troup at the CSIRO Division of Meteorological Physics wrote one of the classic papers[20] on the Southern Oscillation.

The modern era

So, by the time I started working in the Synoptic Research Branch of the Bureau of Meteorology, a substantial amount of documentation of the El Niño - Southern Oscillation was available, but tended to be hidden in obscure reports or occasional journal articles. My first task in the Bureau was as the most junior member of a team studying a severe drought in the (soon to be independent) Papua New Guinea. This drought was most severe in the highlands between June and September of 1972. Our report[21] was prepared speedily but did not suggest a cause to the drought. Not until the following year (much too late to be of any value in prediction) did I realise that the El Niño of 1972 had been a major influence on the Papua New Guinea drought[22]. The main reason for this delay in attributing the 1972 drought to El Niño was the slowness of data collection, especially from the oceans – we simply did not know that an El Niño was under way, while we were studying the drought that it was causing. But neither had we been looking for an El Niño – a meeting on the development of long-range forecasting in the Bureau of Meteorology, chaired by the then Director of the Bureau, W. J. Gibbs, in February 1972, did not even mention the El Niño - Southern Oscillation[23]. The El Niño was not on anybody's radar. The historical impact of the El Niño - Southern Oscillation on Papua New Guinea has now been comprehensively documented[24]. Soon after the 1972 El Nino and drought, the idea that the Southern Oscillation was an important control on Australia's climate was documented by Barrie Pittock[25] and Peter Wright[26]. There was still widespread scepticism amongst atmospheric scientists about the feasibility of seasonal climate prediction. Bruce Morton, at the end of a conference on climate change and variability held at Monash University in 1975 noted that "…to predict when seasonal and annual forecasts will form a useful part of our meteorological services is itself a long-range forecast, and at present beyond our skills"[27]. However, Wright, at the same conference, did note that calculation of the lag relationships associated with the Southern Oscillation would "…greatly improve prospects for seasonal forecasting"[28].

After my experience with the New Guinea drought and El Niño I was convinced that we could use the Southern Oscillation for seasonal prediction. When I stumbled across the early work of Quayle, I realised we now had 60 years of independent data, not available to Quayle, to confirm that Darwin pressures (or the SOI) could be used to forecast east Australian rainfall from about the middle of the year[29]. The new, independent data also allowed confirmation that Indonesian early wet season rainfall could be predicted[30], as had been suggested by Braak[31] over 60 years earlier. I also showed that the date of onset of the Australian wet season[32] and seasonal tropical cyclone activity around Australia[33] could be predicted using the SOI. The tropical cyclone paper was reviewed by Bill Gray from Colorado State University who went on to demonstrate that Atlantic hurricane activity could also be predicted[34] using the El Niño - Southern Oscillation. Subsequent work by many researchers has demonstrated that the phenomenon affects tropical cyclone activity in all the ocean basins, and forecasts are now available on the internet[35].

Tentative attempts to forecast an early onset to the North Australian wet season were made in late 1981, based on the relationship between onset date and the El Niño - Southern Oscillation. A forecast was released to the media in Darwin, but the Bureau of Meteorology decided not to implement an SOI-based forecast system, at that time, for reasons quite similar to those I suspect stopped the use of Quayle's work earlier. The two main reasons were because the system was "patchy" (ie, it only worked for some seasons and regions) and because the relationship and why it could lead to climate predictions was not understood. The work was purely empirical, with no theoretical understanding of the causes of these relationships. Amongst meteorologists, whose work now relied on the dynamical prediction of weather with a strong theoretical underpinning, the complete reliance on empirical results was regarded with suspicion.

By the time the major El Niño of 1982 appeared, there had been some improvements in data collection, and it had been realised that the El Niño was the product of tropical Pacific air-sea interaction. Some scientists had even found what appeared to be useful clues to the onset of an El Niño. Satellites now provided global sea surface temperatures. However, the eruption of El Chichon contaminated these measurements. As late as October 1982, some Northern Hemisphere climatologists were convinced that there would not be an El Niño in 1982/83. In Australia we were concerned about the very high Darwin atmospheric pressures apparent from May 1982. Such high pressures had been a clear sign of an El Niño event in the past, so it seemed to us by mid-year that a major El Niño was under way[36] with predictable consequences. At a September 1982 seminar with the politically-incorrect title of "Farmers and the Weatherman" I observed that we were unlikely to get drought-breaking rains until well into the next year (since El Niño related droughts usually lasted into the New Year). I used the onset of the El Niño that year as an excuse not to plant a garden around my new house. There were more important impacts of the El Niño however. Close relationships were established at this time between Queensland agricultural scientists Greg McKeon and Graeme Hammer and climate researchers, partly because of the public statements that the drought was likely to persist into 1983. These relationships have led to Australia being the world-leader in climate forecast applications[37], because we have been able to combine meteorological knowledge with an understanding of agriculture.

Around this time a colleague, John McBride, suggested that we should write a paper describing the seasonal relationships between the El Niño - Southern Oscillation and Australian rainfall. I was not enthusiastic – I thought this had been adequately described and documented, and was generally understood. But John insisted and so I insisted that he should be the lead author, partly because he suggested the idea, partly because I did not think the paper would be cited very frequently. I was wrong – the paper[38] has probably been the most-cited paper for both of us.

I was also wrong about how widely accepted was the relationship between the El Niño - Southern Oscillation and Australian rainfall. Many, perhaps most, meteorologists were still suspicious. In March 1983 the Australian drought broke, while the El Niño was still strong. A senior meteorologist told me that this demonstrated that there was no real relationship between El Niño and Australian rainfall. In fact Australian droughts often break while the warm sea surface temperatures of the El Niño are still in existence in the east equatorial Pacific – in many cases in the past the breaking of the Australian drought has been the first sign that the El Niño was about to collapse.

The scepticism of many atmospheric scientists about the use of El Niño in climate prediction was still strong, partly because there was still no fully-developed theory of the phenomenon, and no computer model had simulated the phenomenon. The potential use of the El Niño - Southern Oscillation in climate prediction still rested on empirical relationships found by Quayle, Walker and others, although these had now been repeatedly confirmed by decades of new data. Another reason for the reluctance to issue climate forecasts was the fact that the relationship between the El Niño - Southern Oscillation and Australian rainfall had varied somewhat over time[39]. In the absence of a detailed physical understanding of the phenomenon, the only way to see if this was a likely to be a major problem was to find more data. Useful rainfall records for Australia did not go back much further than the late 19th century, although we had good dates of El Niño events back for 500 years (from documentary evidence of flooding on the Pacific coast of South America). One day when I grumbled about this lack of early data to my wife Jill (who had been a librarian for ten years in the Australiana section of the State Library of Victoria) she told me to check the reports from the 18th and 19th century governors of New South Wales to the colonial secretary in London. I searched these reports for mentions of drought (not too hard – the reports are all published and indexed!) and found that most of the droughts from 1788 to 1841 (ie, up to the instrumental era) were associated with El Niño events[40]. So, even if there was some variation in the relationship, it had been generally consistent for over 200 years.

I needed more data than this, however, to argue that the phenomenon had been affecting this country for a very long time (and would therefore, presumably, continue to affect us). I started to argue[41] that the well-known adaptations of the Australian biota to highly variable rainfall suggested that the El Niño - Southern Oscillation had been operating and amplifying climate variability in Australia for thousands of years. This argument has now received some support. Tim Flannery, for instance, suggests[42] that: "Judging by the way the Australian flora and fauna have adapted to it [the El Niño - Southern Oscillation], I suspect that it has been in operation for very much longer [than the historical climate record]".

When I presented this argument at a symposium the University of Melbourne in 1987 I added the claim that highly-variable climates would make permanent agriculture less attractive and thus hunter-gatherer societies might have survived longer in areas affected by the El Niño - Southern Oscillation. I pointed out that those hunter-gatherer societies that did survive into the 19th century were indeed located in areas affected by the El Niño - Southern Oscillation. Anthropologists at the symposium attacked me as a "climate determinist" for raising this suggestion. In the face of this determined attack I squibbed it, and never submitted the hunter-gatherers argument for journal publication, although it remains in the symposium proceedings[43]. Nevertheless, I was convinced that the adaptations of the Australian fauna and flora to the highly variable rainfall meant that the El Niño - Southern Oscillation had been operating for a very long time, and that it should continue to be useful in climate prediction. The argument that the irregular rainfall associated with the El Niño - Southern Oscillation would make agriculture a less attractive way of life seems a more acceptable argument nowadays[44], at least for Australia. Tim Flannery notes[45], for instance, that "It makes an enormous amount of sense to me to see the lack of agriculture by Australian Aborigines as a fine-tuned adaptation to a unique set of environmental problems".

My interest in the various adaptations to the highly-variable climate associated with the El Niño - Southern Oscillation arose because I had been trying to develop methods for the direct prediction of impacts of the phenomenon on crops, human health (Australian Encephalitis), and native fauna and flora. In the mid-1980s Col Limpus from the Queensland National Parks and Wildlife Service contacted me regarding observations of large year-to-year fluctuations in the numbers of breeding green turtles. Some of his colleagues thought this might reflect variations in indigenous hunting of the turtles, but Col thought they might be related to the El Niño - Southern Oscillation and it proved to be so. This meant that we could predict[46], well in advance, the numbers of breeding turtles (useful for management purposes) and also dismiss the theory that the variations were the result of direct human action. This was one of several examples I used to demonstrate that the El Niño - Southern Oscillation could be used to make direct predictions of impact variables (such as crop yields) without worrying too much about predicting the intermediate, climate variables[47]. I saw this as a means to side-step the reluctance of meteorologists to initiate seasonal climate prediction using the El Niño - Southern Oscillation.

Operational climate prediction begins

In 1986 the success of the first computer model forecast of an El Niño changed the situation, and meant that my efforts on impact prediction and the historical (and pre-historical) relationship between drought and El Niño suddenly became little more than interesting sidelights. The forecast, by Mark Cane and Steve Zebiak, was received suspiciously by many scientists (I was very dismissive of it) but it proved to be correct. This successful forecast made El Niño - Southern Oscillation forecasting respectable in the eyes of most meteorologists, and provided a further boost to research on the phenomenon. By this time, some of the details of how the ocean and atmosphere interacted to link the (atmospheric) Southern Oscillation and the (oceanic) El Niño had been worked out. This also helped legitimise the phenomenon, in the eyes of physical scientists, leading to enhanced interest in its use in prediction.

Media and political interest in the phenomenon also increased. After an article about El Niño and its impact on Australian crops appeared in the Adelaide Advertiser in early 1988, Senator Robert Ray, representing the Minister for Administrative Services, answered a question without notice about seasonal forecasting. The question alluded to an article in the Adelaide *Advertiser* claiming that Bureau of Meteorology funding was insufficient to allow El Niño monitoring and prediction. Ray stated[48] that "The Bureau's ability to monitor these climatic fluctuations and its scientific understanding of phenomena such as El Niño and the so-called southern oscillation have reached the stage where it expects soon to be able to begin issuing regular public advice through the media on the general state of the climate system over Australia and the likely seasonal outlooks". Mike Coughlan, from the Bureau's National Climate Centre, and I had been preparing and revising a proposal for the forecasts for over a year at that stage. Through 1988 we prepared trial seasonal outlooks, but these were not released to the media (they were stamped "Confidential"). Then a *New Scientist* article on 25 March 1989 criticised the Bureau for not releasing warnings of the likelihood of widespread wet conditions. Severe flooding had followed these heavy rains. The article observed that the Bureau had noticed the similarity of the current climate situation to previous widespread flooding events "but feared that they might be wrong and so made no public warnings". Soon afterwards the seasonal outlooks started to be distributed to the media. These forecasts were still based on the statistical relationships dating back to Quayle's early work[49].

Now I want to return to the 1877/78 El Niño event – the event I noted earlier as one of the strongest on record. We only know this because of a series of fortuitous connections. The Southern Oscillation Index (SOI) is one of the main indicators for comparing strengths of historical El Niño events. The SOI uses atmospheric pressure data from Tahiti and Darwin. The Tahiti data were available from 1877, but the Bureau of Meteorology seemed to have destroyed the Darwin observations before 1882 early in the 20th century, because of doubts about their reliability. I stumbled across the Darwin pressure data for 1876-78 in a volume of meteorological observations made in South Australia published by Charles Todd[50], and mentioned this to Jill, now a Bureau librarian but still with a professional interest in Australian historical documents. That same day another Bureau librarian had shown Jill a list of old documents dealing with meteorology that he had found in a rarely-opened draw in the Library. Jill realised that one of the documents listed what appeared to be the original observations journal for Darwin, and that the list was annotated with what looked like archivist's codes. Jill suggested we look for the journal in the Australian Archives, and indeed that was where we found it, in Darwin. Ian Butterworth from the Bureau's Northern Territory Regional Office painstakingly copied the daily observations (the journal was too delicate for photocopying) and Rob Allan from CSIRO checked and corrected them. We now had the original observations and could calculate the SOI for the 1877/78 El Niño event. So we could compare[51] the 1877/78 and the 1982/83 events (the 1982/83 event seems to have been the stronger, but not by much).

The very strong 1982 El Niño led to a major improvement in observations. The equatorial Pacific Ocean was now instrumented with buoys that reported sea surface and sub-surface temperatures, via satellite, almost instantaneously. By the 1991 El Niño we were monitoring the east Pacific in "real time", allowing the forecast I mentioned at the start of this paper. In 1994, when the next El Niño developed, we issued a press release in predicting an increased likelihood of drier than normal conditions. This time the forecast was issued just as a major rain-bearing system drifted over southeast Australia. Even as we made the forecast we knew we would be lambasted by colleagues, friends and the media for talking about a drought while the rain pelted down. But the rain lasted less than a month, and the remainder of the year was dry, as expected.

Through the 1990s, public, media, and meteorologists became more familiar with the El Niño - Southern Oscillation and its potential for prediction. Much of this increased familiarity was the result of efforts in Queensland initiated by Graeme Hammer and Greg McKeon. With Roger Stone, an ex-Bureau of Meteorology employee, Jeff Clewett, and many others, they worked to raise the level of understanding and application of the phenomenon throughout Queensland agriculture. Nationally, Mary Voice (from the Bureau's National Climate Centre), David White (Bureau of Resource Sciences), and Barry White (coordinator of the Climate Variability in Agriculture Programme), all worked[52] to ensure that the public could access forecasts, and could understand them. These forecasts are quite complicated, so presentation is important, if we are to achieve the best possible use.

The importance of the presentation of the forecasts became very clear during 1997. Our confidence in our predictions had increased by the 1997/98 El Niño. The forecasts made in 1991 and 1994 had contributed to this. By the 1997 event also, we were more confident in our understanding of how the forecasts should be presented. Because the climate has a strong "chaotic" element to it, even in areas where the El Niño - Southern Oscillation is a major controlling factor, forecasts should not be expressed in deterministic terms (such as "We predict a drought"). Instead, the existence of an El Niño shifts the probability distribution, making drier than normal conditions more likely than in other years. Our forecasts, by the 1997 event, were expressed as probabilities, and we thought we understood how people would interpret these forecasts. When parts of eastern Australia received good rains in spring 1997, then, we were surprised at the vehemence of the attacks on us and our forecasts in the media. Our forecast for spring 1997 indicated that there was up to a 66% chance of rainfall being in the lowest historical tercile (compared with a climatological probability of 33%). So, although the prospects for "dry" conditions were doubled by the existence of the El Niño, this did not seem to justify the attack as a "wrong" forecast when spring rains turned out to be average to good. However, the flood of news of El Niño related disasters from around the world appeared to push forecast users to expect the worst. So we read articles criticising the forecasts, with headlines such as "El Niño fails as a reliable indicator"[53]. We learnt from this experience that even with great care it is difficult to express probabilistic forecasts in a way that will be interpreted and applied in the way we expect. So I searched the cognitive science literature[54] for ways to improve the presentation and dissemination of the forecasts. We are still some way from getting the message across correctly. A journalist on the Channel 10 news on 18 July, 2002, discussing the drought situation around Bourke, stated that "With no rain predicted here until March next year…".

During the 1997/98 El Niño there were El Niño cartoons, El Niño jokes, El Niño posters. Articles about it appeared in Time magazine, and many other general publications. Taxi drivers, journalists, my children's teachers (to my children's embarrassment) – everyone wanted to talk about the El Niño. It is interesting that even though there had been many attacks on the El Niño – based forecasts during 1997, by the time forecasts of a 2002 El Niño started appearing, even more organisations and media outlets were publicising (and sometimes exaggerating) the potential consequences for Australia. During winter 2002 it was difficult to read a newspaper, even the business pages, or watch a TV news bulletin without seeing a reference to El Niño. This partly reflects how in Australia we seem now to have equated El Niño with drought[55], even though not all droughts are related to El Niño events (and vice versa). So the eastern Australian drought of 2002 was destined to be linked, in the media and public psyche, to El Niño. This has been a remarkable change in three decades – from a time when meteorologists could ignore the phenomenon and its potential use in prediction. Other countries, including the USA, now also use the El Niño – Southern Oscillation in seasonal climate prediction. The successful use of the phenomenon in climate prediction in Australia encouraged its use elsewhere.[56]

Another change is that other climate signals, such as the Antarctic Circumpolar Wave (ACW), are now trumpeted as ways to improve our predictions. Two decades ago it seemed impossible to convince our colleagues of the reality of the El Niño - Southern Oscillation and its use in prediction. Now it is all too easy to suggest a new "predictor" that will, so it is claimed, provide more accurate predictions than the El Niño - Southern Oscillation. One reason why this has become easier is the great improvement in the availability of global historical climate data sets, such as precipitation, and the availability of computers to analyse these data. Three decades ago, the collection of appropriate data and a search for ways to predict climate variations would require several people, large computers (for that time), and some months. Nowadays, these calculations can be done on the internet, using other people's software, computers and data sets, in a few minutes, from anywhere in the world. What once might have taken three months and could only be done with extensive computing and technical support, can now be done in three minutes at any internet café[57], anywhere in the world, by anyone.

The availability of such resources, and their "democratisation", is one reason why "new" climate phenomena are being postulated with increasing frequency. The speed with which new climate phenomena are now proposed to enhance our climate predictive skill contrasts with the slow acceptance of the El Niño - Southern Oscillation as a predictive tool. As I have noted earlier, one of the reasons for the slowness in the acceptance of the El Niño - Southern Oscillation was that for many decades there was no theory explaining its characteristics. Nor was there, until recently, a computer model capable of simulating, let alone predicting, its development. The empirical evidence supporting its use in prediction was very strong and well documented, but a meteorological community committed to theory and modelling as a basis for belief did not consider this sufficient. Once theoretical concepts and modelling studies were available to underpin the empirical evidence of the El Niño - Southern Oscillation, its acceptance was quite rapid. In turn, the success of the phenomenon in prediction has, I believe, opened the door to the acceptance of other climate "predictors" based purely on empirical evidence. This may not, however, be without its dangers – purely empirical results can be flukes. This is almost certainly the case for some of the recently proposed climate predictors.

Concluding remarks

The story of the development of the science of El Niño to the point where it is used routinely in operational forecasting provides a classic example of how scientific "facts" develop. Trenn and Merton[58] point out, paraphrasing Ludwig Fleck[59], that "Discovery in science, whether modification or transformation, and whether of a theory or its thought style, is a complex, socially conditioned product of collective effort". A complex of interactions and collective effort, including theoretical underpinning and computer simulations, as well as much empirical work, was needed to allow the atmospheric science "thought collective" to accept the feasibility of climate prediction. The lack of these elements, and the belief that the atmosphere was fundamentally chaotic and unpredictable at long lead times, formed what Fleck called a "structurally complete and closed system of opinions" which, earlier, offered resistance to the notion of climate outlooks. No single individual, or even a group of individuals, was responsible for reversing the belief that climate was unpredictable. Rather it was the work of many scientists over a considerable period that led to the change in the "thought collective" to the point where, now, many in the public and media believe the climate is more predictable than is actually the case.

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