Submission to the Joint Committee on Treaties: Kyoto Protocol

McMahon. S

Information to advance discussion on whether Australia's national interest is advanced by ratifying the Kyoto Protocol

August 24, 2000

Contained herein are samples of journal articles and academic research papers published well within the brief of the Treaties Committee inquiry into whether ratification of the Kyoto Protocol on climate change is in Australia's national interest.

ASSESSMENT:

1. The agreement, as it stands, is totally inadequate – whether it is ratified or not - it does not represent a significant or serious attempt by world leaders to address the issue of global warming.

   In terms of Australia's national interest, other submissions will undoubtedly mention the economic potential of green industries and the social and political advantages of a stronger local focus to the management of human impacts on the land.

   Australia's national interest will be well served by all these things and the present Australian government COULD take serious steps towards aligning national interest with global interest. Australia has the knowledge resources to initiate a global renaissance in sustainable energy and resource use.

   This first gesture (ratification) and the recognition of physical facts – such as; we live on a dry, isolated continent on a planet three quarters covered with water, one tenth with ice – could lead to government sponsorship of export-earning green industries, providing Schmacher-stle intermediate technology to "developing countries".

   In the medium to long term, Australia's national interest is likely be critically influenced by the changing climate. The politics of climate change may leave Australia – and the woreld – unprepared for an ice melt of the rapidity suggested in *Lupus Antarcticus*. Critically Killingbeck has warned that by the time we can prove we have initiated a rapid melt (200 – 600 years) there will be little we can do to stop it or slow it down. At this time scale (and even today, with well entrenched destabilisation of the global climate system) the "national interest" is largely indistinguisable from the global interest.

2. Current emphasis on "scientific uncertainty" - as a reasonable justification for the stalling or retardation of environmental remediation – presupposes that there can be such a thing as "scientific certainty". This is preposterous. Scientists are explorers; scientific research is the application of the known upon the unknown. Consequently, environmental risk assessment is subject to the capacity of current scientific knowledge to understand nature; to correlate observations with theory and establish reasonable projections into the future.

3. It is physically possible for Antarctica to melt, practically unnoticed, despite scientific monitoring of the global climate and Antarctica itself. If;

   (a) science has simply identified *a triggering mechanism for climate change*

   (b) in amongst an incomplete (but growing) understanding of how the climate system operates, *particularly the interdependencies and sensitivities of climate components* such as phyotoplankton, soils, sea ice etc.

   (c) the change initiated is *rapid* (in glacial time scales) to include interactive life system of the

   (d) an inadequate understanding of the "*healthy* operation" of the climate system

   (e) the scientific estimate of the *human influence* is underestimated by:

3	surface warming effect of water vapour
1.5	atmospheric warming effect of water vapour
2	using the short-hand of C02 Doubling – effectively counting the relative warming constant of C02 with non-C02 gases at the same time as acknowledging the C02 emission levels will double from their 1850 level
2	the lag time between the emission of atmospheric gases and their temperature effect and also the thermal inertia of the world's oceans; slows the effect but amplifies its intensity when the delayed impact is felt.

References/Appendices:

McMahon. S (1998) "Climate; changing science	1
Global row over value of human life" in NS	32
MacKenzie. D (1995a) Polar meltdown fulfils worst predictions" in NS	33
Highfield. R (1997) Alarm at melting ice caps / Anon. (1993) Global warming from underground	34
Peterson. C (1991) "Leafing through Antarctica'as balmy past" in NS 9/2/91 / Anon (1996) Lake life thrived at the South Pole" in NS 29/6/96	35
Kleiner, K. (1994) "Climate change threatens southern Asia" in NS 27/8/94	36
Pearce. F (1996) Big freeze digs a deeper hole in ozone layer in NS 16/3/96	37
Anon (1992) Harmful ultraviolet doubles in Antarctica" in NS 18/1/92 / Pearce. F (1995) "Lucky escape for ozone layer" in NS 8/4/1995	38
MacKenzie. D (1995b) "Rich and poor split over ozone" in NS 9/12/95	39
MacKenzie. D (1995c) "Ozone deal could backfire" in NS 16/12/1995	40
Pearce. F (1994) "Is broken ocean pump a global warning?" in NS 19/3/1994	41
Pearce. F ( ) "Global warming chills out over Pacific" in NS	42
Pearce. F ( ) "World lays odds on global catastrophe." / US left behind as Europe backs cuts" in NS 8/4/	43
Pearce. F (1993) Bedtime warming bafles climatologists" in NS 20/1/1993	44
Anon ( ) Rocks contradict weather records of warming trends" in NS 17/8/91 / Anon ( ) "Is coral bleaching caused by global warming? in NS / Hecht. J. (1996) "Cold water poured on climate models" in NS 6/4/96	45
Anderson. I (1991) Global warmings rings true" in NS 21/9/1991	46
Walker. G (1995) "Diluted ocean threatens Western Europe's weather" in NS 11/11/1995 / Gribbin. J ( ) Plants issue their own global warming" in SN	47

Pearce. F (1994) "Will global warming plunge Europe into an ice age?" in NS 19/11/94	48
Hecht. J (1995) Shallow methane could turn on the heat" in NS 8/7/1995	49
McMahon. S, Cramond. J (1999) *Global environmental protection and the human response ability [pages 10 – 12]*	50
Vaughan. D. G. , Doake. C.S.M (1996) "Recent atmospheric warming and retreat of ice shelves on the Antarctic Peninsula" in NATURE vol 379, 25 January 1996. [328 – 331]	54
Greenpeace (1998) Antarctica on WWW: http://www.greenpeace.org/-climate/antarc_report/ant1.html	58
Killingbeck. D (1996) [extract from] *Lupus Antarcticus; the Great White Wolf of Warming* Castlmeine, 1996.	68
"Actively surging West Antarctic ice strems and their response characteristics" in *Annals of Glaciology* 24: 1997. Internatioinal Glaciological Society pps 409 -	76
Jacobs. S. S. Hellmer. H.H (1996) "Antarctic ice sheet melting in the Southeast Pacific" in *Geophysical Research Letters* vol 23, No. 9 pps 957 – 960, May 1 1996	82
McMahon. S (2000) "Ecological incohernece" [from appendix in McMahon, Cramond (1999)	86
CNN (1997) "Global Warming will melt Antarctic ice shelves" in WWW http://www.energy-gb.com/news/dNO37.htm	93

Climate; changing Science

an Individual Research Report

by Stephen McMahon

Graduate School of Environmental Science,
Monash University, Clayton Victoria.
1998

"Consider how the world appears to any man, however wise and experienced in human life, who has never heard one word of what science has discovered about the cosmos.

To him the earth is flat; the sun and moon are shining objects of small size that pop up daily above an eastern rim, move through the upper air, and sink below a western edge; obviously they spend the night somewhere underground.

The sky is an inverted bowl made of some blue material. The stars, tiny and rather near objects, seem as if they might be alive, for they "come out" from the sky at evening like rabbits or rattlesnakes from their burrows, and slip back again at dawn. "Solar system" has no meaning to him, and the concept of a "law of gravitation" is quite unintelligible - nay, even nonsensical. For him bodies do not fall because of a law of gravitation, but rather "because there is nothing to hold them up" - i.e., because he cannot imagine their doing anything else. He cannot conceive space without an "up" and "down" or even without an "east" and "west" in it.

For him the blood does not circulate; nor does the heart pump blood; he thinks it is a place where love, kindness, and thoughts are kept.

Cooling is not a removal of heat but an addition of "cold"; leaves are green not from the chemical substance chlorophyll in them, but from the "greenness" in them.

It will be impossible to reason him out of these beliefs. He will assert them as plain, hard-headed common sense; which means that they satisfy him because they are completely adequate as a SYSTEM OF COMMUNICATION between him and his fellow men.

That is, they are adequate LINGUISTICALLY to his social needs, and will remain so until an additional group of needs is felt and is worked out in language."

B.E.Whorf (p.251)

Front Cover: Topographic map of the Antarctic ice sheet (heights in metres) deduced from the ERS-1 altimeter data. Drewry. D.J. (1995) p. 310.

Introduction

Consider the fate of experts in historical time; wizards and political advisers. At a time when the fund of scientific knowledge was small, they may have survived only as long as their "science" was good; while their explanations of the world proved fruitful, productive and reliable.

As the sum of scientific knowledge has grown, so the institution of science has spread, dividing into disciplines of dedicated inquiry. Together, the range of sciences form the body of knowledge; an encyclopaedic collection of scientific investigation and exploration. It serves both society and scientists. The former has the confidence and security of a vast reference resource, updated and reviewed by all working scientists, and the latter are able to pursue their intellectual interests; becoming specialists rather than generalists. The pressure on historical experts is absorbed by the contemporary scientific community.

While, there are occasions when people question science or the rate of scientific progress, this is usually on moral grounds, such as in the case of genetic engineering for example. It is generally not the case that people question scientific methods or theories - this is left to other scientists; it is a role for which only they are assumed qualified.

In fact, it is the process of debate and discussion between scientists that establishes a level of security and satisfaction with the knowledge that we do have. By leaving it to scientists to debate the higher points of science, we are collectively reassured that only the "best science" will endure the process of qualified criticism and analysis.

In 1995 the Intergovernmental Panel on Climate Change (IPCC) announced that world scientists had succeeded in identifying the "signal" of human-induced climate change from the "static" of climate variability. However, this announcement was made with the caveat that observed changes are still within the range of climate variability.

Why can't science be more explicit about the changes that the world's climate is likely to experience? How much can we expect from high-level scientific expertise? What does scientific uncertainty mean?

This report is concerned with these secondary questions: the operating processes of scientific investigation; the logic of science. This report is a study of *adequacy*.

The methodological approach of this report has been to conduct a literature survey and engage with scientists in order to conduct a meta-science review of climate change science. This report focuses on the social constructions that underpin scientific investigation, interpretation and expectations of certainty.

This report is not about proving or disproving global warming. It is a study of scientists studying nature. It is the story of climate; changing science.

1 Uncertainty

During the 1970s, scientists raised concerns about global cooling; saying that the world was heading into another ice age. Just a decade later, scientists raised concerns about global warming. For both scientists and politicians such dramatic opposites are a significant problem; for credibility and policy, respectively.

Theory

Figure 1: Global average pathways for energy in the atmosphere. A notional 100 units comes from the Sun. After (Bigg, 1996, 12) The Greenhouse Effect: responsible for the Earth's average surface temperature of 15 ^{0}C, 31 - 33 ^{0}C more than it would be without the atmospheric gases.

As Ramanathan and others have written, "...the formal foundation for the greenhouse theory of climate change was laid in 1896 by Arrhenius who dealt with the climatic effects of changes in atmospheric CO_2. On the basis of his finding that a doubling of atmospheric CO_2 would warm the globe by 5 K, Arrhenius concluded that past glacial epochs may have occurred largely because of a reduction in atmospheric CO_2." (Ramanathan, 1988, 294).

According to the theory, atmospheric gases absorb and re-radiate heat energy, from the sun and the Earth. If it were not for the "greenhouse gases" the Earth would lose more heat than it gains from the Sun, resulting is a global mean temperature of approximately -18 ^{0}C, the temperature of the outer atmosphere.

"On a global-annual basis, the surface emits 390 W m^{-2}, whereas the radiation emitted to space, as measured by satellites, is only about 237 W m^{-2}. The balance of 153 W m^{-2} is the infrared radiation effectively trapped by the atmosphere (including clouds). (Ramanathan, 1988, 294)

Expectations

According to theory, the thermal inertia of oceans would slow the warming in the Southern hemisphere, compared to the predominantly land surfaces of the Northern hemisphere. Also, warming was expected to be more pronounced in polar regions and least in the tropics. (Pearce, 1993 (a))

Validation/Measurement

Scientists use the double negative "not inconsistent" to demonstrate the connection between carbon emissions and temperature increase. From 1957/58 instruments at Mauna Loa, Hawaii recorded emissions of CO_2. (Paterson, 1996) Ice cores from Antarctica have supported the correlation between $C0_2$ concentrations in the atmosphere and rising air temperatures. (Houghton., 1995)

Gases: In 1995, the IPCC announced that 1992 figures for carbon dioxide (CO_2) methane (CH_4) and nitrous oxide (N_20) emissions had grown by 30%, 145% and 15% respectively. And at current levels (1994), CO_2 would lead to an atmospheric concentration of 500 ppmv, doubling the pre-industrial concentration of 280 ppmv by the end of the 21st century. (Houghton., 1995, 3)

Temperature: Global mean surface air temperature has increased by between about 0.3 and 0.6 ^{0}C since the late 19th century.... Night-time temperatures over land have generally increased more than daytime temperatures....Regional changes are also evident.[e.g.] recent warming has been greatest over the mid-latitude continents in winter and spring, with a few areas of cooling, such as the North Atlantic ocean. Precipitation has increased over land in high latitudes of the Northern Hemisphere, especially during the cold season." (Houghton et al , 1995,4)

"Even if the amounts of $C0_2$ in the atmosphere stabilise at double today's levels the IPCC estimates that by the end of the 21st century the global temperature will have increased by between 1.5 ^{0}C and 4.5 ^{0}C. "(Rind, 1995, 36)

Corroborating existing data

Jones and Wigley, together with colleagues at the Climatic Research Unit of the University of East Anglia initiated a project to collect and analyse every available historical temperature record. Through a process of regional cross-checking, comparison and allowance for changes in technique and the heat island effect of modern cities, they came up with a data base from 1,584 stations in the Northern Hemisphere and 293 in the Southern Hemisphere. They expressed the temperatures of all stations in terms of deviations from average temperatures during a reference period (1950 - 1970) for which reliable global data was available.

Their calculations showed two things; 1) global climate varied considerably from year to year, and 2), the earth had experienced an overall warming trend of 0.5 ^{0}C since the late 19th century. (Jones, Wigley, 1990, 68)

Figure 2: Combined land-surface air and sea surface temperatures (^{0}C) 1861 to 1994, relative to 1990. The solid curve represents smoothing of the annual values shown by the bars to suppress sub-decadal time-scale variations. The dashed smoothed curve is the corresponding result from IPCC (1992) after (Houghton et al , 1995, 26)

Complicated inter-connections in climate system

There are many feedbacks in the climate system. Some will accentuate the warming and others will mitigate or dampen it.

Ice Albedo: Ice and snow reflect the solar radiation, whereas melting ice as water, will absorb it. Sea ice with overlying snow reflects about 40 to 60% of the solar radiation, whereas the open ocean at high latitudes reflects only 20 to 30%. Melting the sea ice during spring and summer can increase the polar ocean absorption of solar radiation by as much as 50 - 100 W m^{-2}, which should be compared with the direct $C0_2$ radiative heating of about 4 W m^{-2}. (Ramanathan, 1988, 295)

Water vapour: In one-dimensional climate models, where this feedback can be selectively turned off, the H_20 greenhouse feedback amplifies the air temperature warming by a factor of ~1.5 and the surface warming by a factor of ~3. (Ramanathan, 1988, 295)

Clouds: Clouds increase the albedo (reflectivity) of the planet from about 10% (the clear sky albedo) to the observed value of 30%. An increase in the planetary albedo of just 0.5% is sufficient to halve the greenhouse effect of $C0_2$ doubling. (Ramanathan, 1988, 295).

Solar variation: Computer models predict that the change in the global radiation balance caused by increases in greenhouse gases is roughly equivalent to a 1% increase in the luminosity of the sun. (Jones, Wigley, 1990, 73) Average solar radiation can vary by as much as 0.4% on a daily basis, and about 0.1% over a sunspot cycle [translating] into a temperature fluctuation of 0.15 - 0.30 ^{0}C at the Earth's surface - equivalent to decadal temperature changes attributed to the enhanced greenhouse effect. (Bryant, 1997)

Sulphate particles: Injected into the atmosphere by volcanoes and fossil fuel burning, they could cancel out around 25 % of the global warming that results from the heat trapping effect of greenhouse gases. (Mathews, 1994)

Observations

Sea Level: Global sea level has risen by between 10 and 25 cm over the past 100 years and much of the rise may be related to the increase in global mean temperature." (Houghton et al., 1995, 4) The present average rate of global sea level rise over the last century is about 1 mm a^{-1}. (Budd, 1991, 280) This is significantly higher than the average over the last several thousand years... thermal expansion of the oceans accounts for 2 - 7 cm and the general, global retreat of glaciers is responsible for between 2 - 5 cm. (Warrick et al. 1995)

Ocean Warming: Sea surface temperatures in the Indian and much of the Southern ocean have warmed by up to one degree between 1962 and 1987. (Melbourne Age. 1997) Deep ocean temperatures measurements in the south-western Pacific Ocean in 1992 and the North Atlantic in early 1994 all show an increase of about 0.5 ^{0}C. (Thwaites, 1994, Bindoff, Church, 1992)

Mountain freezing point gaining altitude: The freezing point for ice caps on tropical and sub-tropical mountains - where the air temperature reaches 0 ^{0}C - has been gaining altitude since 1970 at a rate approaching 4.5 metres a year. (Highfield, 1997)

Antarctic mass balance: " ...a warmer climate should increase the accumulation rates, causing sea level to fall. .. the observational evidence is insufficient to say with any certainty whether the ice sheet is currently in balance or has increased or decreased in volume over the last 100 years." (Warrick et al.,1995, 363)

Sea Ice: Comparisons of satellite data between 1978 and 1994 revealed a statistically significant decline in Antarctic sea ice of 1.4 per cent per decade. The decline of Artic sea ice is 4.3 per cent per decade." (MacKenzie, 1995 (d))

Disintegration of Antarctic Peninsula Ice shelves: In January 1995, 4200 square kilometres of the northern Larsen Ice Shelf broke away... the two northern-most sections of the ice shelf fractured and disintegrated almost completely within a few days. This break-up followed a period of steady retreat that coincided with a regional trend of atmospheric warming... Between 1966 and 1989, the Wordie Ice Shelf decreased from ~2000 to 700 km^2, probably as a result of regional atmospheric warming. (Rott, 1996, 788) Temperatures in the Antarctic Peninsula have increased 2.5 ^{0}C since the 1940s. (Paren, WWW, 1998)

Ice streams: The West Antarctic ice sheet drains roughly one-third of its mass into the Ross Ice Shelf. Ice Streams B, D and E are the primary routes. (Bindschadler, 1997, 410) In 1991 they were moving with velocities typically of a few hundred metres per year. (Budd, 1991) In 1997, ice streams B, D and E all showed evidence consistent with ongoing surge behaviour modelled for glaciers. (Bindschadler, 1997)

Glaciers: Pine Island Glacier, West Antarctica has retreated 1.2 $\pm$ 0.3 kilometres per year between 1992 and 1996, which in turn implies that the ice thinned by 3.5 $\pm$ 0.9 metres per year. The fast recession is attributed to enhanced basal melting of the glacier floating tongue by warm ocean waters conditions .... An increase in seawater temperature from +1.5 ^{0}C to +2.0 ^{0}C increases basal melting by 30%...Sediment cores collected in Pine Island Bay show that a substantially more extensive ice-shelf cover was present perhaps as recently as 100 years ago in Pine Island Bay... (Rignot, 1988, 549)

Figure 3: Retreat of Antarctic Peninsula ice shelves after Vaughan, Doake, 1996, 328

Possible signs of global warming

Coral Bleaching: Coral bleaching has been associated with sea surface temperature increases of 2 to 3 ^{0}C near Tahiti, the Caribbean and Thailand. (Anon., 1991(a))

Ocean flip: Scientists have discovered a salinity and temperature inversion in the deepest water of the Mediterranean... (Mackenzie, 1995 (a))

Breakdown of the Odden Feature: The Odden Feature, Greenland, one of four areas in the world that drive the world's ocean circulation system, has broken down. There has been no substantial convection to the deep ocean of the Greenland Sea for 40 years, and especially in the past 10 years... convection that a decade ago took surface water down to a depth of four kilometres now reaches only one kilometre. (Pearce, 1994(b), 4)

Plankton "hole": Surface warming of parts of the Pacific Ocean off California by around 1.5 ^{0}C has been linked to an 80 per cent decline in zooplankton since 1951. (Pearce, 1995, (g))

Tropical warming: "...average tropospheric temperature in the tropics has increased since 1965 by nearly 1 ^{0}C. More importantly, the water vapour content of the middle troposphere has increased, above the equatorial Pacific, by 20-30%...... The results indicate an intensification of the hydrological cycle, especially over the warmest oceans and they also suggest tropical circulation changes ... These parameters indicate a destabilisation of the marine boundary layer, which cannot be systematic error .... the trends are not affected by the frequency of cold or warm El Nino-Southern Oscillation (ENSO) events." (Flohn, Kapla, 1989, 244)

Non-greenhouse climate observations

El Nino: Researchers have said that El Nino events, apparently triggered by a build up of very warm water in the western Pacific, are likely to become more frequent with the warming of the oceans. (Pearce, 1993 (b)) El Nino events occurred for five years running from 1990 to 1995. (Rind, 1995)

UV doubles in Antarctica: The ozone hole over Antarctica stayed open longer in 1990; allowing twice the average level of UV radiation to reach the Earth's surface. (Anon., 1992)

Proxy Data

Meteorological temperatures are not the only measures available to monitor temperature. There are many proxy climate indicators. Mann et al in Jones reconstructed global scale temperature patterns since 1400 AD using such proxies and if ranked in descending order, he said that; "...the best proxies would be long instrumental records, followed by historical records, tree density, tree-ring widths, ice cores, and corals. .... (Jones, 1998, 544)

Bore Holes: Underground temperature measurements show a mean increase of 0.041 ^{0}C per year between 1963 and 1990. (Anon, 1993(a)) Sixty-one boreholes from 29 different sites in the Northern Hemisphere have established that ground temperatures increased 1 - 2 ^{0}C over the past 100 to 150 years. (Anon.,1991(b))

Tree rings: There has been no episode in the past 1000 years to match the growth in the tree ring width of the past 25 years and the temperature rise it indicates. (Anderson, 1991, 13)

"The limited available evidence from proxy climate indicators suggests that the 20th century global mean temperature is at least as warm as any century since at least 1400 AD." (Houghton et al., 1995, 5)

2. Scientific dispute

Cultural values

A general characterisation of scientists might be that they are measured in their speech and not prone to exaggeration or over-statement when presenting their research. Science is presented as value-neutral, objective and rational. Sassower has said that this style of presentation is culturally and socially conditioned; "...adopted by scientists because they know that their culture values and respects this attitude towards one's pronouncements ..."(Sassower p. 44)

Impartiality and objectivity also provides a measure of credibility; allowing the research to speak for itself. "Whether oracles are called "witch doctors" ... or scientists ... makes no difference to their cultural position in society because they perform a dual function commonly associated with oracles, that is saying something with a great deal of authority about a particular event as if that event is certain to occur and at the same time connecting the event to the people; delivering a message to an audience that has a set of expectations." (Sassower p. 44)

The normal process of knowledge accumulation and ratification occurs within disciplines according to a process known as peer review. Contemporary research is submitted to a variety of disciplinary journals. These journal articles are then sent to reviewers with sufficient knowledge in the particular field. The author's name is removed so as not to prejudice the research with her/his reputation, personal history etc and the reviewers then consider the scientific merit of the paper. It is then sent back to the author, via the journal, corrections and revisions are made and the paper re-submitted and then ultimately published.

In the process of writing a paper, scientists acknowledge each other and their work; developing links, weighing empirical data and following theoretical lines of argument. This process legitimates both, the body of knowledge itself, through consolidation, extension and annotation, and the author, by acknowledging her/his peers and the community of science. In the recent past (20 - 30 years ago) scientists included the collective pronoun "we" rather than the first person "I' in their papers; furthering the perception of a united, consensual scientific community.

Scientific research is generally expensive and increasingly dependent on private funding. (Etzioni-Harvey) The connection between science and society; technology and industry thus results in a mutually dependent relationship. Science serves society, not simply for utilitarian reasons but more exactly to maintain itself; to garner the financial resources to secure its operation.

By remaining impartial and objective, science can maintain a posture of advice and service. This view is borne out by former Chair of the IPCC, Bert Bolin in O'Riordan., Jager, "... [he] noted that the role of science should be to delineate a range of future opportunities, and analyse what the implications of development along one course or another might be... not to recommend one or the other." (O'Riordan., Jager, 1996, 3)

Dependent on the non-scientific mainstream, science adopts value-neutrality as a cultural value or ethic. This avoids conflict and removes science from the restrictions of moral and political judgement. Science provides the product and eco-political structures deal with the policy.

Science is therefore the ideal "servant" for government; they hold much influence, but relatively little direct power over others. (Etzioni-Halevy, 1985, 11) By engaging with eco-political institutions while maintaining distance from policy making responsibilities directly, science culture establishes the necessary influence and power to safeguard its autonomy and authority.

In 1988, NASA scientist, James Hansen, told the US Congress that he was 99 per cent sure that "...current temperatures represent a real warming trend". (Pearce, 1989, 1)

This statement has since been challenged by other scientists, as being too strong and based on poor science.

Hansen's claim of 99% certainty was contrary to the professionalism and cultural ethic within science. While he may have felt justified to make a claim of near certainty, his colleagues realised that the weight of evidence to the contrary challenged the credibility of the entire scientific community.

The facts of dissent

In the late 1980s, there were a number of facts that strongly contradicted predictions of global warming:

The meteorological temperature record was not long (commenced 1850) and readings were concentrated in the Northern Hemisphere. Temperature readings can vary due to changes in location and types of instruments. (Jones, Wigley, 1990, 67)

The entire reference period (1950 - 1970) for the Jones and Wigley study sat within a period of sustained cooling from 1940 - 1970. The IPCC has established that mean global surface temperatures increased by 0.3 - 0.6 ^{0}C since the late 19th century, and by about 0.2 - 0.3 ^{0}C over the last 40 years. (Houghton et al. 1995, 15)

The cooling between 1940 and 1970 coincided with a period when greenhouse gas emissions were increasing rapidly. (Jones, Wigley, 1990, 73)

The hemispheric records was in conflict with expectations. As the Southern Hemisphere has more ocean than the Northern, it was expected to warm more slowly, but in the 1980s this was the area where the effects were strongest.

Also, while models predicted warming would be pronounced in the Artic and minimal in the tropics, the reverse had been true over the past 50 years. (Pearce, 1993 (a))

And **some parts of the world were getting colder**; Greenland, northeastern Canada and some of the Soviet Artic islands. (Pearce, 1991)

Fifty percent of the observed warming trend in this century could be attributable to a natural internal fluctuation. Over the course of a century low-frequency temperature variations can be as large as 0.2 - 0.3 ^{0}C. (Jones, Wigley, 1990, 72)

“The observed increase is consistent with the lower end of the temperature increases predicted by the computer models. Consequently, the temperature records, as well as the predictions of mathematical models, provide substance both to those who believe the evidence warrants action now and to those who believe the evidence is still too weak.“ (White, 1990, 22)

Utility of Science

The IPCC, established in 1988 to investigate the scientific evidence of climate change, developed parameters for climate research:

Radiative forcing: the perturbation of the energy balance of the surface-troposphere system, after allowing for the stratosphere to re-adjust to a state of global mean radiative equilibrium.

Climate sensitivity: long term (equilibrium) change in global mean surface temperature following a doubling of atmospheric $C0_2$ (or equivalent $C0_2$) concentration.

These terms have defined the focus of climate change science. The development of radiative forcing values, has enabled scientists and politicians to assess greenhouse gases and feedbacks; to compare and contrast calculated effects with satellite monitoring of heat escape from the upper atmosphere.

Climate change science is a relatively new field of inquiry. The complex connections within the climate system are reflected in the disciplinary make-up of climate change scientists. Scientists come from a range of disciplines and apply their specialised knowledge to particular climate change questions.

It is not humanly possible or reasonably expected that individual scientists have a comprehensive understanding of all climate processes. Scientists can only talk with authority about their area of expertise. Through forums such as the IPCC, pieces of specialised knowledge form the body of climate change science.

The multi-disciplinary nature of climate change necessarily leads to a significant level of “inter-disciplinary dependence”. For example, the mass balance of Antarctica, affects research in other fields ie. estimates of sea level rise due to thermal expansion. The reverse is also true; estimates of radiative forcing and climate sensitivity impact on glaciology’s ability to determine the ice sheet’s vulnerability to external forcing.

With mathematical models; Global Circulation Models (GCMs) scientists are able to address specific climate questions by parametising known factors eg. greenhouse gases, heat fluxes etc. and explore past and future climates, based on data collected from paleoclimates. Commonly, a doubled $C0_2$ value is used to represent anthropogenic greenhouse gases.

Due to the spatially and temporally limited temperature records, computer modelling has been the principal tool of climate change science. It has been extremely useful in addressing areas of uncertainty. Specifically:

Sulphate particles: The Global Circulation Model team at the Hadley Centre succeeded in reproducing the global trend in temperature back to 1860, taking into account the effect of pollution by sulphate particles. Their model showed sulphate cooling to be slightly greater than expected; offsetting about 30% of greenhouse warming. Even so, with “business as usual” emissions at their present rate, the model still predicted a net global warming of around 0.2 ^{0}C per decade. The Hadley model showed a period of relatively constant temperatures from 1860 to 1920, a steep rise of around 0.3 ^{0}C during the 1930s and 1940s, then another period of relative stability until 1970. Since then, temperatures have climbed more or less continuously, and are currently around 0.3 ^{0}C higher than the 1951 to 1980 average. (Mathews, 1994)

Solar cycle: Researchers accurately mapped the climatic influence of the sunspot cycle. In identifying the 80 - 90 year long oscillating cycle they matched it with temperature records going back to 1870. Researchers were also been able to isolate solar variation over the last 100 years and found that the solar output varied by no more than $\pm$ 0.5%. “A cooling of the Earth of this magnitude may indeed be beginning about now, but the warming due to increased emissions of greenhouse gases is already twice as large, and is getting larger.” (Gribbin, 1991,14)

GCMs are limited; it is not possible to represent the entire climate in full detail and complexity. Modellers must make assumptions; eg. many coupled atmosphere-ocean models have a “slab ocean”; internal processes are not well represented. Similarly, with sea ice:

“During the July-September 1986 experiment in the eastern Weddell Sea we found a mean snow thickness of 14-16 cm on the surface of first year ice. Since the ice itself is so thin, this was sufficient to bring the ice surface below sea level in 15 - 20% of cases, leading to the infiltration of sea water into the overlying snow and the formation of either a wet slushy layer of top of the ice, or in the case of freezing, the formation of a “snow ice” layer between the unwetted snow and the original ice upper surface. ... in multi-year ice in the western Weddell Sea the snow thickness was much greater. The average was 0.63 m over undeformed ice and 0.7 m over deformed ice. This was sufficient to push the ice surface below sea level in almost every case ... The resulting flooded layer will have an enormous effect on passive microwave signatures, making it difficult to unequivocally identify multi-year ice using current algorithms and will also have an impact on mass and

Figure 4 First year and multi year ice in Weddell Sea after energy balances of sea ice which must be taken into account in modelling efforts." (Wadhams, 1994, 52)

To the scientific mindset of the IPCC, investigating scientific evidence of climate change required identifying the "signal" of change from the "static" of climate variability. In 1995, having incorporated sulphate cooling (- 0.5 Wm^{-2}) in their estimates of global warming (2.5 Wm^{-2}), this task was completed to the IPCC's satisfaction;

"Our ability to quantify the human influence on global climate is currently limited because the expected signal is still emerging from the noise of natural variability, and because there are uncertainties in key factors. These include the magnitude and patterns of long term natural variability and the time-evolving pattern of forcing by, and response to, changes in concentrations of greenhouse gases and aerosols, and land surface changes. Nevertheless, the balance of evidence suggests that there is a discernible human influence on global climate." (Houghton. et al., 1995, 5)

However, there was considerable uncertainty about the climate system itself. John Houghton, Chair of the IPCC's science working group, said that scientists were applying the triage method to scientific uncertainties; (Houghton. et al., 1995) The IPCC identified five key areas:

- sources and sinks of greenhouse gases, which affect predictions of future concentrations;
- clouds, which strongly influence the magnitude of climate change;
- oceans, which influence the timing and patterns of climate change;
- polar ice-sheets, which affect predictions of sea-level rise;
- land surface processes and feedback, which affect hydrological and ecological processes. (Steering Comm.CC. 1995 p. 71)

Political Science

Science and politics share the operational process of dividing fields and issues respectively, into a set of smaller problems. For example, the "environment" composes a number of issues; biodiversity, resource use, deforestation, desertification, acid rain, climate change, ozone hole etc.

This process serves both science and government. For the latter, each issue is negotiated separately, balancing priorities of various economic, political, social and environmental interest groups within the broader context of a government's attitude towards "the environment". For science, the process provides opportunities for furthering legitimacy via government research and contributes to the advancement of expertise and increased specialisation within science.

The political influence on climate science is directive and substantial. As the funding bodies for science, national governments and private industry determine the parameters of climate research and guides the scientific perspective on climate itself.

This perspective has increasingly become localised.

- The Framework Convention on Climate Change required governments to produce inventories of greenhouse gas emissions. While an inventory of gas emissions is a necessary step towards building models on their global impact, it effectively concentrates domestic and international attention on the emissions of individual countries. International conventions aimed at limiting emissions can then be stalled by arguments over targets and the performance of individual countries.
- Now that climate change is established as an actuality, national governments require accurate modelling of regional impacts. There is a widespread appreciation that climate change will bring both winners and losers, and advances in climate modelling offer the best chance for planning and adaptation measures.

The direct radiative forcing values of greenhouse gases have a political and scientific utility because they are; 1) measurable (or at least able to be calculated based on instrumental observations), 2) more controllable than indirect effects and feedbacks such as water vapour, the abundance of which is directly related to air temperature and therefore difficult to quantify. Instruments are not currently able to measure stratospheric water vapour. (Nicholls, 1995, 161)

However, the delineation of environmental issues, and the focus on direct radiative forcing, has enabled:

- Modifying the combined radiative forcing of CFCs and HCFCs; 0.25 Wm^{-2} to 0.15 Wm^{-2} due to the negative forcing resulting from stratospheric ozone depletion. (Houghton. et al., 1995) This may be legitimate in terms of "cause" but not in effect. For example, global warming and the ozone hole both impact on Antarctica, the severity of the former is the subject of much scientific study. However, seen as separate issues and then related according to one parameter; their influence on the radiation budget, the full environmental impact is obscured and possibly even the need for its study removed.
- Ozone depleting CFCs were replaced with fully fluorinated compounds (FFCs) responsible for less than 1% of greenhouse warming but with atmospheric lifetime of up to 50,000 years. The atmospheric concentration of sulphur hexafluoride, the most potent greenhouse gas evaluated by the IPCC, is increasing at around 8% per year. (Anon. 1995(a))
- The direct radiative forcing of methane is 0.47 Wm^{-2}. (Houghton. et al., 1995) The indirect effect of methane emissions is to increase water vapour in the stratosphere. (Ramanathan, 1988, 299) This is as significant a problem as $C0_2$ in the troposphere (Killingbeck, 1996, 10) and responsible for polar stratospheric clouds that contribute to the seasonal weathering of the ozone layer over Antarctica. (Pearce, 1989, 21)

The development of Global Warming Potential indices presages another development; the merging of science with politics. GWPs value greenhouse gases according to their "policy lifetime", determined by international conventions, not their atmospheric lifetimes. Also, these "lifetimes" are calculated comparatively, usually with $C0_2$. ((Houghton. et al., 1995)) As $C0_2$ has various lifetimes, depending on whether it is taken up by plants, ocean or atmosphere, this comparison is problematic.

The normal process of peer review has been altered in the preparation of IPCC reports; individual scientists contributed to sections of the IPCC report according to their field of expertise, but the Policy-maker's Summary was subject to consensual agreement. (Pearce, 1995 (a)

Thus, the resolution of scientific enquiry; the posting of results, was subject to a political process that involved industry and environmental groups, as well as scientists and government.

3. Change

Science Education

The main focus of early science education is to train students in scientific methods. This involves demonstrating the validity of present scientific knowledge with a series of “textbook” exercises. Fleck says that this learning process is analogous to the physiology of movement; for each “active” muscle, its partner must be immobilised. So it is with learning. “The corresponding features in the operation of cognition are purposive, directed determination and cooperative abstraction, which complement one another.” (Fleck, 1979, 30)

So, in order to learn, a student becomes an active participant in an institutional or cultural process where mental wandering or independent disagreement is suppressed. As Whorf says; “... if intelligent means quick to learn, perhaps it also means receptive and hence too credulous.” (Whorf. p. 35) This concept is supported by Fleck: “In the field of cognition, the signal of resistance opposing free, arbitrary thinking is called a fact.” (Fleck, 1979, 101)

As a student progresses to higher levels of proficiency, the teaching method and approach changes. “But as the student (the addressee of the didactic process) improves his [her] skills, the expert can confide to him [her] what he does not know but is trying to learn (at least if the expert is also involved in research). In this way, the student is introduced to the dialectics of research, or the game of producing scientific knowledge.” (Sassower. p. 71).

Persistence of Scientific Knowledge

Fleck has introduced the concept of thought collectives and stresses that it “...is not to be understood as a fixed group or social class. It is functional, as it were, rather than substantial, and may be compared to the concept of field of force in physics. A thought collective exists whenever two or more persons are actually exchanging thoughts.” (Fleck, 1979, 102) And the third participant in the dialogue is the body of knowledge itself, producing a mood or commonality between the speakers. (Fleck, 1979)

Through the process of peer review new insights are incorporated into the total system of knowledge. In hindsight, they “explain better” what was once adequate but incomplete. “Facts are never completely independent of each other. ..every fact reacts upon many others... It is characteristic of advanced knowledge, matured into a coherent system, that each new fact harmoniously - though every so slightly - changes all earlier facts. Here every discovery is actually a recreation of the whole world as construed by a thought collective.” (Fleck, 1979, 102)

A thought collective is therefore the carrier of the theoretical basis and the accepted assumptions of any sphere of research. It determines how the object of study is perceived, and what is understood to be error. (Fleck, 1979) Elementary science education establishes the context and extent of what is known, and how it can be proved or understood to be true and this process continues and deepens throughout a scientist’s involvement in her/his field of research.

This does not mean that science stagnates; perpetuating “old ideas” despite new insights. It simply means that there is a persistence in the views of a thought collective. “Whatever is known has always seemed systematic, proven, applicable and evident to the knower. Every alien system of knowledge has likewise seemed contradictory, unproven, inapplicable, fanciful or mystical.” (Fleck, 1979, 22)

Dispute over the greenhouse theory is an example of the operation of a thought collective: a community of scientists, with access to the same data, arriving at divergent conclusions. The disagreement is not unusual. It is the consequence of commonality within the thought collective of atmospheric science.

As Fleck says: “Every pronouncement leaves behind either the solution or the problem, if only the problem of the problem’s own rationality. The formulation of a problem already contains half its solution. Any future examination must return along existing thought tracks. The future will never be completely isolated from the past, whether normal or abnormal, except when a break with it occurs as the result of the rules characteristic of the thought structure in question.” (Fleck, 1979, 37)

The fundamental proposition of greenhouse warming theory was that doubling preindustrial emissions of $C0_2$ would cause a 5K increase in mean global air temperature. The link between $C0_2$ and temperature has been tested and contested:

- paleoclimatic evidence from 3 million years ago, when the Earth was a few degrees warmer than today, show that the $C0_2$ concentration in the atmosphere was not much higher than it is now. (Rind, 1995)
- Ice cores from glacial and interglacial periods show $C0_2$ concentrations as 180 ppmv and ; 270 - 300 ppmv respectively. (Ramanathan, 1988, 294)

As scientists on both sides of the debate have considered the influence of sulphates, solar variation, clouds etc. the parameters for the debate have remained: $C0_2$, temperature and the atmosphere.

Factors that affected the input and output of the climate system *as it is understood from an atmospheric perspective* were isolated; leaving the signal of climate change *in atmospheric terms:* temperature, rainfall and sea level rise (from thermal expansion of the oceans).

The very success of climate modelling; its facility for explaining variations in the global mean temperature record, and identifying the climate change "signal", has reinforced both the method of enquiry and the theory.

However, modelling requires; 1) simplification, due to the complexity of the climate system, and 2) assumptions, according to the specific problem. "What remains is no longer a part of real life with all its unpredictabilities, but an isolated system posing convergent, and therefore in principle soluble, problems. The solution of a convergent problem, at the same time, proves something about the isolated system, but nothing at all about matters outside and beyond it." (Schmacher, 1977, 40)

The available scientific knowledge is predominantly from the disciplines of atmospheric science and meteorology. It is these sciences that provide the instrumental record. The placement of these instruments is based on the long-term utility of these sciences. They are established and commercially-useful instructional sciences; weather prediction is crucial for a number of industries, particularly agriculture and shipping.

Therefore, assumptions and thought constraints from the domain of atmospheric science underscore climate change science. The triage method, adopted by the IPCC to improve scientific understanding of climate processes, does not challenge these underlying assumptions. Rather, they are the fundamental basis for research.

The term "$C0_2$ equivalent" was developed when it was realised that other gases, most importantly, CFCs, were also responsible for absorbing infrared radiation. It begs the question of how equivalence is judged. The answer; in terms of heat trapping or temperature effect, is derived from the atmospheric science thought collective. They are not equivalent in terms of naturally available processes for their removal; non-$C0_2$ gases absorb heat energy at infrared band-widths not currently blocked by naturally occurring gases and; the secondary effects of methane and CFCs (as discussed) conceivably put them in a different category to $C0_2$.

Similarly, "$C0_2$ Doubling", used in climate modelling to represent all anthropogenic greenhouse gases; represents two things at once; 1) that all other gases have a heat retention value close to that of $C0_2$, hence "doubling" the $C0_2$ effect and 2) the original proposition: the doubling of $C0_2$ alone.

The progressive development and adoption of "$C0_2$ Doubling" may lead to serious underestimates by climate scientists if it is applied literally rather than figuratively in climate models. $C0_2$ concentrations in the atmosphere are so large that the gas is optically thick. The $C0_2$ greenhouse effect scales logarithmically with the concentration, while it is linear for those gases that absorb in the atmospheric window of heat escape between 7 and 13 μ (Ramanathan, 1988, 294)

Temperature increase is a measurable result of the greenhouse effect. However, more accurately the effect causes extra retention of the Earth's heat; $C0_2$ (at approximately 350 ppm) is responsible for the strong absorption in Figure 5; water vapour (10,000 - 40,000 ppm) absorbs right across the infrared spectrum. (Emsley, 1992) Increased temperature will increase water vapour. (Ramanathan, 1988) Killingbeck says that the temperature focus of climate science and politics is a significant error. "We are not discussing reflectable short-wavelength radiant energy with which the status quo has come into balance, but the transfer of additional low temperature heat energy by air and water." (Killingbeck, 1996)

Figure 5: Heat escape from the upper atmosphere. Sample spectra from the infrared interferonmeter spectrum onboard Nimbus 3 satellite. The dashed lines indicate the outgoing longwave blackbody emission at the temperatures indicated. The scene is tropical Pacific Ocean under clear sky conditions. After Ramanathan, 1988, 294

The advancement of climate science is consequently limited by the wholesale adoption of principles from one particular discipline that seem to provide a measure of certainty; a connection between cause and effect. The importance of atmospheric processes is not doubted, but their ability to accurately define the workings of the climate-as-system is questionable.

The objects of study themselves "...do not carry a label indicating the appropriate level at which they ought to be considered. Nor does the choice of an inadequate level lead the intelligence into factual error or logical contradiction. All levels of significance up to the adequate level, ie, up to the meaning ... are equally factual, equally logical, equally objective, but not equally real." (Schmacher, 1977, 53)

Climate as System

Schmacher has identified two types of sciences; "...those that are primarily descriptive of what can actually be seen or otherwise experienced, and those that are primarily instructional of how certain systems work and can be made to produce predictable results. We might give botany as an example of the former, and chemistry of the latter." (Schmacher, 1977, 118)

Computer modelling is clearly an example of an instructional science. The biosphere, a significant component of the carbon and water cycle, is not featured in most GCMs due to difficulties in its representation.

Figure 6: Schematic view of the components of the global climate system (bold), their processes and interactions (thin arrows) and some aspects that may change (bold arrows) After Houghton et al., 1995

While some argue that $C0_2$ fertilisation, via increased emissions, could be a good thing for agriculture, it has been discovered that plants close their stomata when temperatures rise above 25 ^{0}C and $C0_2$ is abundant. (Gribben, 1995 (b)) A similar effect has been found with rainforests. (Greenpeace, WWW, 1998) Both of these discoveries demonstrate that biological life is not passive to climate change but also contributes a climate changing effect. By retaining moisture, plants and rainforests will reduce cloud cover and cause extensive drying in the grass-covered interiors of major continents (Gribben, 1995 (b)) and the forests themselves. (Greenpeace, WWW, 1998)

Although weather and climate processes can be explained in instructional science terms; as fluxes of heat and temperature, the climate system as a whole may be more appropriately a descriptive science. Lovelock, proponent of the Gaia theory, has had considerable success predicting and proving self-regulatory interactions of biota and the environment. One of his discoveries is the link between ocean plankton and cloud formation. (Charlson et al., 1987) Scientists are investigating the effect of UV radiation on plankton (Weiler, Penhale, 1994) and ocean stratification, caused by warming of the surface waters, has already led to the starvation and 80 per cent loss of plankton species off the coast of California. Plankton remove 20 - 40 per cent of atmospheric $C0_2$. (Pearce, 1995 (g))

David Rind in his article; *Drying out the tropics*, explains how climate scientists have long believed that the tropics would be unaffected by warming. Evidence from the peak of the last ice age, showed that while the world cooled by 4 - 5 ^{0}C, the temperature of the tropical ocean hardly changed. And more limited evidence from 3 million years ago, when atmospheric $C0_2$ concentration, and global average temperature, were not much higher than today, led to the same conclusion. The reason for the temperature stability of the tropics lay in a vigorous ocean circulation system. (Rind, 1995, 39)

He found that vigorous poleward ocean currents would transport more heat to high latitudes and sea ice would melt slightly, reducing the amount of sunlight reflected back to space and warming the Earth. He also established that there is; "...more water vapour in the atmosphere over the tropical western Pacific Ocean than over the cooler tropical eastern Pacific, and that there is generally more in summer than in winter. In other words, in warmer conditions, water vapour increases in the atmosphere at all levels... everywhere except the polar regions, low-level clouds actually become thinner as the temperature increases. One possible reason is that the extra water vapour might increase the size of the water droplets in the clouds, and thus make them more likely to precipitate as rain.... In tropical regions, an increase of 4 ^{0}C in air temperature means that around 30 % more moisture can be evaporated from the ground. The oceans warm more slowly, because their heat capacity is much greater, so the increase in evaporation from the warming ocean is much less. Computer models show that a 4 ^{0}C rise in global air temperature would lead to a 12 % increase in evaporation. The oceans provide the water for most of the planet's rain, so this leads to a similar increase in global precipitation. However, a 12 % increase in rainfall would not be enough to make good the attempt by the land to lose 30 % more of its water by evaporation... A 4 ^{0}C warming would bring frequent droughts to middle latitudes as well, and arid climates would extend about 35 ^{0} north and south of the equator." (Rind, 1995, 39)

Figure 7: Schematic of the thermohaline circulation of the global ocea. The broken arrows represent the major surface components of the circulation. The continuous line denotes the deep water circulation After Bigg, 1996, 17

The ocean circulation system is driven by four small areas of the world's oceans. One occurs where the waters of the Mediterranean enter the Atlantic. The other three are all in polar regions; in the Greenland and Labrador Seas of the far North Atlantic and the Weddell Sea off Antarctica. The normal operation of the "pumps" causes salt to be separated out from seawater at -1.9 ^{0}C. Dense, saline water then sinks to the bottom of the ocean and moves through the world system. (Pearce, 1994 (b)) The system distributes and mixes the extremes of the Earth's heat, from Antarctic Bottom Water to the equatorial sea surface waters, via a 1,000 year water cycle. It has been linked to changes between ice ages and interglacials. (Broecker et al., 1985).

While the slowing and eventual breakdown of the ocean circulation system has been modelled for doubled $C0_2$ and quadrupled $C0_2$ respectively, (Manabe in Dickinson et al., 1995, 213) the break-down of the Odden Feature, Greenland, responsible for removing perhaps a quarter of the carbon dioxide taken to the deep ocean (Pearce, 1994 (b)) will presumably place extra stress on the remaining "pumps" driving the world system. Modelled changes to the system indicate a 5 ^{0}C cooling in Europe. (Pearce, 1994(c))

"Radiative forcing" and "climate sensitivity" are terms derived from atmospheric processes and validated by scientific understanding as it is today. Fundamentally, they are based on a "healthy" eco-system able to recycle naturally occurring greenhouse gases and modulate the Earth's climate through ice ages and interglacials, according to triggering effects as understood by climatologists. The atmospheric focus of climate science, while adequately demonstrating the human influence, may actually inhibit the advancement of scientific understanding; specifically in terms of the "equivalence" of greenhouse gases. In light of this, it would seem that IPCC estimates of climate sensitivity, are under-stated.

Observations

The identification of the climate change signal in 1995 has not resolved scientific uncertainty about the causes of natural variability. "Most of the uncertainties surrounding the causes of recent climate change will never be resolved because the necessary historical data are lacking...Together with advances in modeling, data to be gathered in the coming decades will reduce the uncertainties ... and lead to better predictions of climate change." (Jones, Wigley, 1990, 73)

However, this view does not indicate an awareness of the subjective dimensions to research, and the limitations of atmospheric bias within climate change science. It also assumes that "change" will be recognisable from variability.

The need for reflexive processes in science is demonstrated in Fred Pearce's book; *Turning up the Heat*. The hole in the ozone layer was discovered in the late 1970s but not announced until 1988. Two instruments aboard an American satellite, had been collecting data since 1978 suggesting that the ozone was disappearing at a rate of 1% a year, and 3% at certain latitudes. "The figures were unbelievable and scientists decided that a mechanical diffuser plate which serviced both instruments had deteriorated producing spurious readings... The scientists operating the ground monitors had devoted too much time to plugging the data into their models of what they thought was happening to the ozone layer, and too little time sifting the data itself for trends. Indeed, their desire to produce statistically tidy graphs meant they weeded out the very data which showed the decline in ozone... since nobody was looking for a seasonal fall in ozone levels, nobody looked at the data season by season. Investigators simply averaged all the data taken during a year. Then, since fluctuations appeared greatest in winter and least in summer, they weighted the annual averages to take more account of summer readings... Finally, since fluctuations were smallest nearer the equator, researchers weighted the global averages in favour of stations in the tropics - just where, we now know, the dip in ozone levels was least marked...They could not have done a better job of obscuring the trend if they had tried." (Pearce, 1989, 29)

Schmacher says there are four fields of experience and science is primarily concerned with just one; the field of appearance. (Schmacher, 1977, 115) The instruments of science are sophisticated extensions of the scientist's own sense organs; they monitor only what it is they have been designed to perceive. And it is the scientist's subjective judgement that determines the design and operation of her/his instruments. As Schmacher says; "... the understanding of the knower must be adequate to the thing to be known." (Schmacher, 1977, 49).

"Natural" variability is extremely difficult to distinguish from "unnatural" change, particularly when it occurs in long-term processes, for which there is an inadequate record of change or a record of irregular or anomalous change.

El Nino frequency: Where once the ENSO phenomenon occurred every four or five years and had a warm (El Nino) and cool (La Nina) phase, El Nino phases occurred every year between 1990 and 1995. (Rind, 1995) Wang in Nicholls "...found that the characteristics of the onset of the Pacific-wide warming associated with an El Nino changed after the mid-1970s. Indeed, there appears to have been a rather distinct change in ENSO in 1976/77. Since then, there have been relatively more frequent El Nino episodes with only rare excursions into the other extreme...the recent ENSO behaviour...appears to be unusual in the context of the past 120 years." (Nicholls et al., 1995, 165)

Sea ice Anomaly: Although reasonably stable from year to year, evidence suggests that sea ice extent diminished significantly (by about 2 million km^2) between 1973 and 1980, then increased by 1 million km^2 up to 1982 and has remained fairly constant since then. (Wadhams, (1994, 45) Zwally makes the point that 1973 was the year of largest sea ice extent and that sea ice decline was associated with the Weddell polynya (a body of ice-free water) in the mid 1970s. He says that from 1966 to 1973, ice cover was increasing during a period when temperatures were also increasing. (Zwally, 1994)

Retreat of Antarctic Peninsula ice shelves: Dr Julian Paren from the British Antarctic Survey said that BAS scientists preferred to call the 2.5 ^{0}C surface temperature increase since the 1940s in the Antarctic Peninsula a strong regional warming. "This is because no GCM predicts that the region should be oversensitive to changes in greenhouse forcing..." (Paren, WWW, 1998)

Figure 8: Southern hemisphere Sea ice extent anomalies relative to the average for 1973 - 1991. The trend line is generated from a 39 point binomial filter applied to the monthly anomalies. Heavy bars represent winter months (June, July, Auguest) After Houghton, 1995

Each of the above can be incorporated into the body of knowledge as variations of natural phenomena. The atmospheric basis of climate science can provide explanations and postulate theories, but it fails to advance understanding on why they are happening.

The increased sea-ice cover during a period of increasing temperatures superficially indicates that warming promotes the growth of sea ice, except it is sitting low in the water, weighed down by snowfall (see figure 4) and therefore subject to ocean warming.

All of these events are linked by ocean circulation and ultimately perhaps, to the Antarctic "pump". Antarctic Bottom Water forms in the Weddell Sea when sea ice forms and mixes with colder, less saline Ice Shelf Water (ISW) from beneath the major ice shelf; the Ronne-Filchner Ice Shelf." (Paren, WWW, 1998)

It is possible that cause and effect are being confused; an Antarctic ice melt, rather than being a casuality of climate change, may actually be the cause (if not at least a major feedback).

Antarctica is perceived most often in terms of its potential in terms of sea level rise. This is qualified by the fact that sea ice and ice shelves will not contribute significantly to sea level as they are floating and will merely displace their own weight. (Budd, 1988) While half of the estimated sea level rise is unaccounted for (Warrick et al., 1995) and the range of uncertainty of Antarctic mass balance is equivalent to observed sea level rise (Budd, 1988), the main focus for climate science should perhaps be Antarctica's role in the ocean circulation system.

Since research by Jacobs et al (1996) "...suggests that the Antarctic Ice Sheet is currently losing mass to the ocean " it is recommended that world scientists explore the effect that this influx of fresh water would have on the world system.

The coincident changes to the ENSO and Weddell Sea ice in the 1970s is also recommended as a subject of further study; possibly in conjuction with the World Ocean Circulation Experiment.

Table 1: Melting rates of Antarctic ice shelves after Jacobs et al (1996)

Change and language

Having determined that climate change is a reality, scientists are experiencing something similar to a group of people that have moved to a foreign country; where the language is similar but with unexpected and incongruous differences. Generally they can "make do" while they immerse themselves in the culture but increasingly, they discover that words they know well have embarrassing meanings in this new country. If we consider the current state of climate knowledge as a language system; concepts, relationships and grammatical laws, then the following illustrates their dilemma;

Observations - (may) reinforce and consolidate meaning of established "words"

Uncertainty - no words

Variability - broadening of definition or changing to new meaning

Change - new meaning

The fundamental problem for climate science is incorporating observations into the vagaries of climate variability. It is a double-edged sword as evident from one researcher's comments about the breakdown of the Odden Feature; "Theories about deep-water formation were developed at a time when the ocean seems to have been very stable. But maybe the ocean is normally this variable. Whether we should be worried by the shutdown of convection or just curious is hard to say." (Pearce, 1994 (b), 4)

The reality of climate change is also generally difficult for non-scientists to appreciate because; 1) it is often simply associated with temperature increases and; 2) the word has many scales of meaning; "change of mind", "change of heart". It becomes more definitive when associated with mechanical operation (change gears) and physical movement (change address). However, there is almost always the possibility of a change back. There are no appropriate words in popular English to describe the climatic definition, although the phrase "change of life" denoting menopause and the end of a woman's menstruation comes closest. Even in this case, the change referred to is possibly more philosophic, encouraging women to consider themselves as participants in the world beyond the strict limitation of their role as potential or actual mothers. Change in this case is perhaps more attitudinal than physical, although it applies to an irreversible physical process.

Conclusion: Consensus?

The significance of the 1995 IPCC announcement is open to interpretation.

For scientists, the identification of the climate change “signal” from the “static” of climate variability, was a significant call to action. In fact, in the context of apolitical scientific neutrality, and the constrictions of justifiable uncertainty, this statement was the strongest and most definitive statement that could have been made.

However, politicians, journalists and the general public, not bound by the cultural and professional conventions of unemotional reasonability, may pay more attention to the qualifiers of the announcement; it may appear uncertain and inconclusive.

For critics of global warming; those unaware of the latest research, or who doubt the validity of current models, the announcement was a non-binding, consensual statement - inconsistent with the facts as they know them to be. The IPCC is, after all, a scientific forum that includes members from industry and environmental groups. While it is significant that such a wide range of vested interests can reach agreement, it can be argued that the conclusion has been derived via political means, not scientific.

Any scientist (journalist or politician) can focus on the uncertainties in the science, and slow or stall what is ultimately a political issue. A challenge to any detail of the science; ie feedbacks, model parameters, sulphates, solar variation, paleoclimates, even if already addressed by the scientific community, can call into question the whole issue of climate change. One “reputable” voice is all that is needed to challenge the growing body of evidence of global warming.

And scientific criticism is not unfounded. There are significant limitations with climate models; the reliance on instructional sciences to explain the climate in a series of convergent problems is problematic in itself.

While science remains primarily in the field of appearance, with little conscious awareness of the subjective dimensions of investigation, “truth” in science can never be established. The best that science can do, is establish that observations fit with what is understood to be true. Significantly, this means that certainty in science can *never* be achieved. If certainty was possible, science would stagnate. To paraphrase Linguist, Benjamin Lee Whorf, scientific progress has occurred when people have learned to think differently about things that had been reasonably well understood up until that time.

There has never been a need for the body of science, or eco/political institutions to assess the normal operation of the climate system in toto. Now that the world’s climate is potentially undergoing radical change, data streams and computer modelling will yield little useful information, without the fundamental reference point of a healthy system.

While many scientists correct the inappropriate analogy of the “greenhouse”, the image and the popular understanding of the word carry the theory; it is an effect that produces optimal conditions for life, and not simply human life. More exactly, it is an effect that allows for the presence of water in all three of its forms; liquid, gas (vapour) and solid (ice).

Science is a product of, and a support to, the cultural and social theories of its time. The context for climate science is the world-wide physical and economic dependence on fossil fuel. The choice of “enhanced” (greenhouse effect) over the more technically accurate “additional” has a particular economic and political rationale. It diverts the popular mind from associations of human activity stressing a natural phenomena, and instead, suggests improvement. Effectively this term rejects and reverses the image of fossil fuel pollution as an environmental assault, and replaces it with the perception that it is Man (sic) improving on Nature.

Popular knowledge and media attention are key factors in the science of climate change. Governments will not move to change entrenched dependence on fossil fuel power and industries without the “permission” that comes from scientifically and environmental literate electorates. Such awareness depends heavily on media reinforcement. However, it is the nature of the media to look for the “good story” and there are few better than two scientists debating the end of the world (or at least the end of a stable and predictable climate system).

References:

Alley. R.B. (1998) “Icing the North Atlantic” in Nature vol. 392 p. 335 - 337.

Allison. I (1979) “Antarctic sea ice growth and oceanic heat flux” in Sea level, Ice and Climate Change I.A.H.A. Publication no. 131 p. 161 - 170

Anderson. I. (1991) “Global warming rings true” in New Scientist 21 September 1991 p.13

Anon. (1995(a)) “Cinderella gas lasts longest of all” in New Scientist 8 April 1995 p.5

Anon. (1993(a)) “Global warming from underground” in New Scientist 15 May 1993

Anon. (1991(a)) “Is coral bleaching caused by global warming?” in New Scientist 17 August 1991

Anon. (1992) “Harmful ultraviolet doubles in Antarctica” in New Scientist 18 January 1992

Anon. (1996(c)) “Lake life thrived at the South Pole” in New Scientist 29 June 1996

Anon. (1996(c)) “Lamont scientist cites Water Vapour in Climate Shifts” in Columbia University Record vol. 21 no. 28 24/5/96.

Anon. (1993(b)) “Lightning clues to the world’s temperature” in New Scientist 25 September 1993.

Anon. (1997) “Oceans are warming up” in The Melbourne Age 1 April 1997

Anon. (1995(b)) “Pacific plankton go missing” in New Scientist 8 April 1995 p.5

Anon. (1991(b)) “Rocks contradict weather records of warming trends” in New Scientist 17 August 1991.

Anon. (1996(c)) “US West Coast Waters Warming - even without an El Nino” in San Francisco Chronicle May 1996.

Balogh. S. (1997) “Carefree Aussies court blindness” in The Australian 25 January 1997

Bentley. C.R (1997) “Rapid sea-level rise soon from West Antarctic Ice Sheet collapse?” in Science vol. 275 p. 1077 - 1078.

Bigg. G.R. (1996) The oceans and climate Cambridge University Press. Cambridge. Great Britain pp. 266

Bindoff. N.L, Church. J.A (1992) “Warming of the water column in the southwest Pacific Ocean” in Nature vol. 357 p59 - 62

Bindschadler. R (1997) “Actively surging West Antarctic ice streams and their response characteristics” in Annals of Glaciology vol. 24 p. 409 - 414.

Bindschadler. R, Vornberger. P (1998) “Changes in the West Antarctic Ice Sheet since 1963 from declassified satellite photography” in Science vol. 279 p. 689 - 692.

Bishop. J.F, Walton. J.L.W. (1981) “Bottom melting under George VI Ice Shelf, Antarctica” in Journal of Glaciology vol. 27. no. 97 429 - 447

Broecker. W.S (1994) “Massive iceberg discharges as triggers for global climate change” in Nature vol. 372 p. 421 - 424.

Broecker. W.S, Peteet. D.M, Rind. D (1985) “Does the ocean-atmosphere system have more than one stable mode of operation?” Nature 315: 21 - 25

Bryant.E. (1997) Climate Process & Change Cambridge University Press. Cambridge. pp 209

Budd. W.F. (1991) “Antarctica and Global Change” in Climatic Change 18: 271 - 299.

Budd. W.F. (1988) “Expected sea-level rise from climatic warming in the Antarctic” in Pearman. G.I. (ed) Greenhouse: planning for climate change p 74 - 82

Burke. J (1985) The Day the Universe changed British Broadcasting Corporation. London. pp. 352

C.S.I.R.O. Marine Research (1998) “Window to the deep sea found in Antarctica” in http://www.marine.csiro.au/PressReleasesfolder/24jun98.html

Charlson. R.J, Lovelock. J.E, Andreae. M.O, Warren. S.G (1987) “Oceanic phytoplankton, atmospheric sulphur, cloud albedo and climate” in Nature vol. 326 p 655 - 661

Chen. R.S, Boulding. E, Schneider. S.H (eds) (1983) Social science research and climate change D. Reidel Publishing Company. Holland. pp. 255.

Climate Change Study, Steering Committee (1995) Climate Change Science: current understanding and uncertainties Australian Academy of Technological Sciences and Engineering. Parkville, Victoria. pp. 100

Cook. E, Bird. T, Petersen. M, Barbett. M, Buckley.B, D'Arrigo.R, Francey. R, Tans. P (1991) "Climate change in Tasmania inferred from a 1089 year tree ring chronology of Huon Pine" in Science vol. 253 p. 1266 - 1268.

Dansgaard. W, Johnsen. S.J, Clausen. H.B, Dahl-Jensen. D, Gundestrup. N.S, Hammer. C.V. Hvidberg. C.S, Steffensen. J.P, Sveinbjornsdottir. A.E, Jouzel. J, Bond. G (1993) "Evidence for general instability of past climate from a 250-kyr ice-core record" in Nature 364: 218 - 220.

Davidson. G. (1992) "Icy prospects for a warmer world" in New Scientist 8 August 1992 pp 23 - 26

Delmas.R.J, Ascencio. J.M, Legrand. M (1980) "Polar ice evidence that atmospheric CO_2 20,000 yr B.P. was 50% of present" in Nature vol. 284 p. 155 - 157.

Denton. G.H. et al (1979) "Reconstruction and disintegration of ice sheets for the CLIMAP 18,000 and 125,000 Years B.P. Experiments: Results" Abstract in Journal of Glaciology vol.24 no. 90 pps 495 - 496.

Dickinson. R.E, Meehl. G.A, Washington. W.M. (1987) "Ice albedo feedback in a C02 doubling simulation" in Climatic Change 10: 241 - 248.

Dickenson. R.E, Meleshko. V, Randall. D, Sarachik. E, Silva-Dias. P, Slingo. A (1995) "Climate Processes" in Houghton.J.T. et al (eds) Climate Change 1995 p 199 - 227.

Doake. C.S.M, Vaughan. D.G. (1991) "Rapid disintegration of the Wordie ice shelf in response to atmospheric warming" in Nature 350: 328 - 330.

Doake. C.S.M (1987) "Some aspects of the flow of the Ronne ice shelf" in van der Veen. C.J, Oerlemans. J (eds) Dynamics of the West Antarctic Ice Sheet D. Reidel Publishing Co. p. 75 - 98.

Dolgin. I.M. (1986) Climate of Antarctica: papers presented at the All-Union Symposium on the study of the climate of Antarctica Oxonian Press. New Delhi. pp. 213.

Drewry. J.J. (1979) "Late Wisconsin Reconstruction for the Ross Sea Region, Antarctica" in Journal of Glaciology vol.24 no. 90 pps 231 - 244.

Drewry. D.J. (1995) "Polar Ice Sheets: ice sheet - climate interactions" in Hempel. G. (ed) The Ocean and the Poles: Grand challenges for European cooperation p 245 - 314

Edwards. R. (1995) "Not yodelling but drowning" in New Scientist 11 November 1995.

Emsley. J. (1992) "On being a bit less green" in New Scientist 17 October 1992 p. 53 - 54

Etzioni-Halevy. E (1985) The Knowledge Elite and the Failure of Prophecy George Allen & Unwin. London. pp. 136

Fahrback. E, Augstein. E, Olbers. D (1994) "Impact of shelf and sea ice on water mass modifications and large scale oceanic circulation in the Weddell Sea" in Hempel.G (ed) Antarctic Science p. 167 - 187

Falk. J, Brownlow. A (1989) The Greenhouse challenge: what's to be done? Penguin Books. Ringwood. Australia. pp. 341

Fastook. J.L. et al (1979) "A closer look at the proposed late-Wisconsin-Weicheslican Artic Ice Sheet" Abstract in Journal of Glaciology vol.24 no. 90 pps 497 - 500.

Fisher. D.E. (1990) Fire & Ice: the Greenhouse Effect, ozone depletion and nuclear winter Harper and Row. New York. pp. 232.

Fleck. L. (1979) Genesis and development of a scientific fact English translation by Kuhn. T. from 1935 original German print. University of Chicago Press. pp. 203

Flohn. H, Kapala. A. (1989) "Changes of tropical sea-air interaction processes over a 30 year period" in Nature vol. 338 p. 244 - 246.

Foster. R (1998) "Necessary expertise for I.P.C.C's forthcoming Third Assessment Report" Personal communication. 28 March 1998

Frederick. J.E, Snell. H.E. (1988) "Ultraviolet radiation levels during the Antarctic spring" in Science vol 241 July 1988 438 - 440.

Frolich.R. (1989) "The shelf life of Antarctic ice" in New Scientist 4/11/1989 pp 42 - 45.

Glasgow. L. (1993) "Antarctic theory skates on thin ice" in New Scientist 27 March 1993

Gordon. J.E (1980) "Recent climatic trends and local glacier margin fluctuations in West Greenland" in Nature vol. 284 p. 157 - 159.

Gould.J, Church.J. (1996) "Oceans and Climate" in Physics World Dec. 1996 pp. 33 - 37

Graedel. T.E., Crutzen. P.J. (1995) Atmosphere, Climate and Change Scientific American Library, a division of HPHLP. New York. pp.196

Greenpeace. (1998) Antarctic Warming: Early signs of Global Climate Change http://www.greenpeace.org/~climate/antarc_report/index.html

Greenpeace. (1998) Climate Change Database http://www.greenpeace.org/~climate/database/search.html

Gribben. J. (1995) "Absorbent clouds cast shadow on climate models" in New Scientist 25 March 1995

Gribben. J. (ed) (1986) The Breathing Planet Basil Blackwell and New Scientist. Oxford, U.K. pp 360

Gribben. J. (1991) "Climate change - the solar connection" in New Scientist 23 November 1991 p. 14

Gribben. J. (1995)(a) "Global warming cuts no ice in Greenland" in New Scientist 11 November 1995

Gribben. J. (1990) Hothouse Earth: the Greenhouse Effect and Gaia Bantam Press. London. pp. 273

Gribben. J. (1995)(b) "Plants issue their own global warning" in New Scientist 30 September 1995

Gribben. J. (1995)(c) "Smokestacks cool northern oceans" in New Scientist 14 October 1995. p. 18,

Hecht. J. (1994) "California's climate poised on a knife edge" in New Scientist 25 June 1994.

Hecht. J. (1996) "Cold water poured on climate models" in New Scientist 6 April 1996

Hecht. J. (1992) "Polluted atmosphere offsets ozone hole" in New Scientist 18 January 1992.

Hecht. J. (1995) "Shallow methane could turn on the heat" in New Scientist 8 July 1995

Hempel.G (ed) (1994) Antarctic Science Springer-Verlag Berlin. Heidelberg.

Hempel. G. (ed) (1995) The Ocean and the Poles: Grand challenges for European cooperation Gustav Fischer Verlag. Jena, Germany. pp.381

Highfield. R. (1997) "Alarm at melting ice caps" in The Melbourne Age 5 April 1997

Holmes. B. (1995) "Artic ice shows speed of climate 'flips'" in New Scientist 4 March 1995

Horgen. J. (1993) "Antarctic Meltdown" in Scientific American March 1993 pp 7 - 12.

Houghton.J.T. et al (eds) (1990) Climate Change The I.P.C.C. Scientific Assessment Published for the Intergovernmental Panel of Climate Change by Cambridge University Press. Cambridge. pp.365

Houghton.J.T. et al (eds) (1995) Climate Change 1995: The Science of Climate Change: Contribution of Working Group 1 to the Second Assessment Report of the I.P.C.C. Published for the Intergovernmental Panel of Climate Change by Cambridge University Press. Cambridge. pp. 572

Hughes. T. (1973) "Is the West Antarctic ice sheet disintegrating?" in Journal of Geophysical Research 78: no. 33 pps 7884 - 7910.

Hughes. T.J. (1979) "Reconstruction and disintegration of ice sheets for the CLIMAP 18,000 and 125,000 Years B.P. Experiments: Theory" Abstract in Journal of Glaciology vol.24 no. 90 pps 493 - 495.

I.P.C.C. (1992) IPCC Supplement: scientific assessment of climate change: submission from working group 1 World Meteorological Organisation, United Nations Environment Program. pp.24

Jacobs. S.S, Hellmer. H.H, Doake. C.S.M, Jenkins. A, Frolich (1992) "Melting of ice shelves and the mass balance of Antarctica" in Journal of Glaciology vol. 38 no. 130 p 375 - 387

Jacobs. S.S, Hellmer. H.H, Jenkins. A (1996) "Antarctic ice sheet melting in the Southeast Pacific" in Geophysical Research Letters vol. 23. no. 9 p 957 - 960

Jackson.E, Goldsworthy. L. (1993) "Out of the Frying Pan, into the Fire; climate change in the oceans" in International Oceans Newsletter Greenpeace International 1993.

Jezek. K.C. et al (1979) " Electrical resistivity soundings on the Ross Ice Shelf, Antarctica" in Journal of Glaciology vol.24 no. 90 pps 321 - 343.

Jones. P (1998) "It was the best of times, it was the worst of times" in Science vol. 280 p. 544 - 545

Jones. P.D, Wigley. T.M.L. (1990) "Global Warming Trends" in Scientific American August 1990 p 66 - 73.

Kerr. R.A (1998) "Signs of past collapse beneath Antarctic ice" in Science vol. 281 p. 17 - 19.

Kiernan. V. (1995) "CFC smugglers risk the Earth for a few dollars" in New Scientist 28 January 1995

Killingbeck. D.L. (1996) Lupus Antarcticus: the white wolf of warming Self-published oral presentation on Antarctic ice melt. Castlemaine. 1996. pp. 30

Kleiner.K. (1994) "Climate change threatens southern Asia" in New Scientist 27 August 1994

Kukla. G.J, Angell. J.K, Korshover. J, Dronia. H, Hoshai. M, Namias. J, Rodewald. M, Yamamoto. R, Iwashima. T (1977) "New data on climatic trends" in Nature 270: 573 - 580.

Lawler. A (1998) "Global change fights off a chill" in Science vol. 280 p. 1682 - 1684.

Leggett. J. (ed) (1990) Global warming: the Greenpeace report Oxford University Press. Oxford pp. 554

Lingle. C.S, Clark. J.A. (1979) "Antarctic ice-sheet volume at 18,000 years B.P. and Holocene sea level changes at the West Antarctica margin" in Journal of Glaciology vol. 24 no. 90 p. 213 - 230.

Lock. G.S.H. (1990) The Growth and Decay of Ice Cambridge University Press. Cambridge. pp.434

Lovelock. J. (1991) Gaia: the practical science of planetary medicine Allen & Unwin. UK. pp. 192

Mae. S. (1979) "The basal sliding of a thinning ice sheet, Mizuho Plateau, East Antarctica" in Journal of Glaciology vol.24 no. 90 pps 53 - 61.

Manabe. S, Stouffer. R.J. (1993) "Century-scale effects of increased atmospheric C02 on the ocean-atmosphere system" in Nature 364: 215 - 218.

Mathews. R. (1994) "The rise and rise of global warming" in New Scientist 26 November 1994

MacAyeal. D.R. (1979) "A catastrophe model of the Paleoclimate" in Journal of Glaciology vol.24 no. 90 pps 493 - 495.

MacAyeal. D.R. (1992) "Irregular oscillations of the West Antarctic ice sheet" in Nature 359: 29 - 32.

MacAyeal. D.R. (1984) "Thermohaline circulation below the Ross Ice Shelf: a consequence of tidally induced vertical mixing and basal melting" in Journal of Geophysical Research 89:597 - 606.

MacKenzie. D. (1995)(a) "Ocean flip puts modellers on Med Alert" in New Scientist 8 September 1995

MacKenzie. D. (1995)(b) "Ozone deal could backfire" in New Scientist 16 December 1995

MacKenzie. D. (1995)(c) "Ozone's future is up in the air" in New Scientist 16 December 1995 pp. 14 - 15

MacKenzie. D. (1995)(d) "Polar meltdown fulfils worst predictions" in New Scientist 12 August 1995

MacKenzie. D. (1995)(e) "Rich and poor split over ozone" in New Scientist 9 December 1995

Marchant. H.J (1994) "Biological impacts of seasonal ozone depletion" in Hempel.G (ed) Antarctic Science p. 95 - 109.

Maslin. M. (1993) "Waiting for the polar meltdown" in New Scientist 4 September 1993 pp. 36 - 41

May. J. (1988) The Greenpeace Book of Antarctica: a new look at the Seventh continent Dorling Kindersley. London. pp. 192

Mercer. D.C, Peterson. J.A. (1988) "Australia and the greenhouse effect: the science/policy debate" in Pearman. G.I. (ed) Greenhouse: planning for climate change p. 708 - 724.

Mercer. J.H. (1978) "West Antarctic ice sheet and C02 greenhouse effect: a threat of disaster" in Nature 271: 321 - 325.

Mikolajewics.U, Santer. B.D, Maier-Reimer. E (1990) "Ocean response to greenhouse warming" in Nature vol. 345 p. 589 - 592.

National Research Council (1994) Solar influences on climate change National Academy Press. Washington. U.S.A. pp. 163

Nicholls. K.W, Makinson. K, Robinson. A.V. (1991) "Ocean circulation beneath the Ronne ice shelf" in Nature vol. 354 p. 221 - 223

Nicholls. N, Gruza. G.V, Jouzel. J, Karl. T.R, Ogallo. L.A, Parker. D.E (1995) "Observed Climate Variability and Change" in Houghton.J.T. et al (eds) Climate Change 1995 p 136 - 192

Nielsen. R. H. (1992) "Blowing hot and cold with climate models" in New Scientist 26 September 1992. p. 15.

Oeschger.H. (1994) "The polar ice sheets: a chronicle of climate and environment" in Hempel.G (ed) Antarctic Science p. 69 - 94.

O'Neill. E (1993) Environmental Chemistry Second Edition. Chapman and Hall. London. pp. 268

Orheim. O. (chair) (1979) "General discussion" in Journal of Glaciology vol. 24 no. 90 p. 469 - 478.

O'Riordan. T, Jager. J (eds) (1996) Politics of Climate Change: a European perspective Routledge. London. pp. 396.

Pain. S. (1992) "Runaway Greenhouse warming cannot be ruled out" in New Scientist 15 February 1992.

Palmer. D. (1996) "Floating golf balls swim off in search of food" in New Scientist 13 January 1996 p.7

Paren. J (1998) http://www.nerc-bas.ac.uk/public/info/iceshelf.html

Paterson. M. (1996) Global Warming and Global Politics Routledge. London. pp. 238

Pearce. F. (1996)(a) "Big freeze digs a deeper hole in ozone layer" in New Scientist 16 March 1996

Pearce. F. (1993)(a) "Bedtime warming baffles climatologists" in New Scientist 20 November 1993

Pearce. F. (1996)(b) "Deserts on our doorstep" in New Scientist 6 July 1996 pps 12 - 13

Pearce. F. (1994)(a) "Does polluted air keep the Artic cool?" in New Scientist 29 October 1994 p.19

Pearce. F. (1993)(b) "El Nino roars back against the odds" in New Scientist 8 May 1993.

Pearce. F. (1995)(a) "Experts blow cold on climate claims" in New Scientist 11 November 1995

Pearce. F. (1995)(b) "Fiddling while Earth warms" in New Scientist 25 March 1995 pp 14 - 15

Pearce. F. (1997) "Global warming chills out over Pacific" in New Scientist 22/2/1997. p. 16.

Pearce. F. (1995)(c) "Global warming "jury" delivers guilty verdict" in New Scientist 9 December 1995

Pearce. F. (1995)(d) "Hottest year heralds global warming" in New Scientist 23 December 1995. p. 5

Pearce. F. (1994)(b) "Is Broken Ocean Pump a Global Warning?" in New Scientist 19 March 1994. p.4

Pearce. F. (1995)(e) "It ain't 'arf dangerous, mum" in New Scientist 16 December 1995

Pearce. F. (1995)(f) "Lucky escape for ozone layer" in New Scientist 8 April 1995.

Pearce. F. (1995)(g) "Pacific plankton go missing" in New Scientist 8 April 1995 p.5

Pearce. F. (1995)(h) "The Costa del Carbon Dioxide" in New Scientist 6 May 1995 pp 14 - 15

Pearce. F. (1989) Turning up the heat: our perilous future in the Global Greenhouse The Bodley Head. London pp. 230

Pearce. F. (1992) "UN fears pollution curbs could raise temperatures" in New Scientist 4 January 1992 p. 5.

Pearce. F. (1991) "Warmer winters fit greenhouse model" in New Scientist 19 January 1991.

Pearce. F. (1994)(c) "Will global warming plunge Europe into an ice age?" in New Scientist 19 November 1994 pp 20 - 21

Pearce. F. (1995)(i) "World lays odds on global catastrophe" in New Scientist 8 April 1995 p. 4

Pearman. G.I. (ed) Greenhouse: planning for climate change CSIRO Division of Atmospheric Research. E.J. Brill. Leiden, The Netherlands pp. 752

Penvenne. L.J. (1996) "Volcanoes take their cue from changing climate" in New Scientist 29 June 1996

Peterson. C. (1991) "Leafing through Antarctica's balmy past" in New Scientist 9 February 1991

Pollack. H.N, Chapman. D.S (1993) "Underground records of changing climate" in Scientific American June 1993 p. 16 - 22.

Radok.U. (ed) (1987) Toward Understanding Climate Change: the J.O.Fletcher Lectures on problems and prospects of climate analysis and forecasting Westview Press Boulder and London. pp.200

Ramanathan. V. (1988) "The Greenhouse Theory of Climate Change: A Test by an Inadvertent Global Experiment" in Science Vol 240 April 1988 p. 293 - 299.

Raschke. E. (ed) (1996) Radiation and Water in the Climate System: remote measurements Springer. Published in cooperation with NATO Scientific Affairs Division. Heidelberg. pp.614

Rignot. E.J. (1998) "Fast recession of a West Antarctic Glacier" in Science vol. 281 p. 549 - 551.

Rind. D. (1995) "Drying out the Tropics" in New Scientist 6 May 1995 pp. 36 - 40

Rintoul. S, Meyers. G, Church. J, Godfrey. S, Moore. M, Stanton. B. (1994) "Ocean Processes, Climate and Sea Level" in Greenhouse 94: Coping with Change p. 127 - 164.

Robin. G. de Q (1979) "Formation, flow and disintegration of Ice Shelves" in Journal of Glaciology vol.24 no. 90 pps 259 - 271.

Rothrock. D.A. (1979) "Modelling sea-ice features and processes" in Journal of Glaciology vol.24 no. 90 pps 359 - 375.

Rott. H, Skvarca. P, Nagler. T (1996) "Rapid collapse of Northern Larsen Ice Shelf, Antarctica" in Science vol. 271 p. 788 - 792

Rubin. M.J. (1962) "Atmospheric advection and the Antarctic mass and heat budget" in Wexler et al., Antarctic Research p. 149 - 159.

Santer. B.D, Taylor. K.E, Wigley. T.M.L, Johns. T.C, Jones. P.D, Karoly. D.J, Mitchell. J.F.B, Oort. A.H, Penner. J.E, Ramaswamy. V, Schwarzhopf. M.D, Stouffer. R.J, Tett. S. (1996) "A search for human influences on the thermal structure of the atmosphere" in Nature vol. 382 p. 39 - 46.

Sassower. R (1993) Knowledge without expertise: on the status of scientists State University of New York Press. New York. pp. 158

Scharpenseel. H.W. (et al) (eds) (1990) Soils on a Warmer Earth: effects of expected climate change on soil processses, with emphasis on the tropics and sub-tropics. Elsevier Science Publishers B.V. Amsterdam. pp.274

Schmitt. R.W. (1995) "The ocean's salt fingers" in Scientific American May 1995. p. 50 - 55.

Schumacher. E.F. (1977) A Guide for the Perplexed Jonathan Cape. London pp. 166

Schneider. S.H. (1990) "The Science of Climate Modelling and a Perspective on the Global Warming Debate" in Leggett. J. (ed) Global warming: the Greenpeace report Oxford University Press. Oxford pp 44 - 67

Schneider. S.H. (1996) Laboratory Earth: the planetary gamble we can't afford to lose Weidenfeld and Nicholson. London. pp. 184

Schneider. S.H, Mesirow. L.E. (1976) The Genesis Strategy: climate and global survival Plenum Press. New York. pp. 419

Schnell. R.C, Liu.S.C, Oltmans. S.J, Stone. R.S, Hofman. D.J, Dutton. E.G, Deshler. T, Sturges. W.T, Harder. J.W, Sewell. S.D, Trainer. M, Harris. J.M (1991) "Decrease of summer tropospheric ozone concentrations in Antarctica" in Nature 351: 726 - 729.

Shabtaie.S, Bentley. C.R. (1979) "Investigation of bottom mass-balance rates by electrical resistivity soundings on the Ross Ice Shelf, Antarctica" in Journal of Glaciology vol.24 no. 90 pps 321 - 343.

Siegenthaler. V, Wenk. Th (1984) "Rapid atmospheric C02 variations and ocean circulation" in Nature vol. 308 p. 624 - 626.

Stockdale. T.N, Anderson. D.L.T, Alves. J.O.S, Balmased. M.A (1998) "Global seasonal rainfall forecasts using a coupled ocean-atmosphere model" in Nature vol. 392 p. 370 - 377.

Stocker. T.F, Wright. D.G. (1991) "Rapid transitions of the ocean's deep circulation induced by change in surface water fluxes" in Nature 351: 729 - 732.

Thomas. R.H. (1979)(a) "The dynamics of marine ice sheets" in Journal of Glaciology vol. 24 no. 90 p 167 - 177.

Thomas. R.H, Sanderson. T.J.O, Rose. K.E (1979) "Effects of climatic warming on the West Antarctic ice sheet" in Nature 277: 355 - 358.

Thomas. R.H. (1979)(b) "Ice shelves: A Review" in Journal of Glaciology vol.24 no. 90 pps 273 - 286.

Thwaites. T. (1994) "Are the Antipodes in hot water" in New Scientist 12 November 1994.

Treguer. P (1994) "The Southern Ocean: biogeochemical cycles and climate changes" in Hempel.G (ed) Antarctic Science p. 110 - 125.

Trenberth. K.E. (1997) "The use and abuse of climate models" in Nature 386: 131 - 138.

van der Veen. C.J, Oerlemans. J (eds) (1987) Dynamics of the West Antarctic Ice Sheet D. Reidel Publishing Co.

Vaughan. D. (1993) "Chasing the rogue icebergs" in New Scientist 9 January 1993 pp.24 - 27

Vaughan. D.G, Doake. C.S.M. (1996) "Recent atmospheric warming and retreat of ice shelves on the Antarctic Peninsula" in Nature 379: 328 - 330

Wadhams. P. (1994) "The Antarctic sea ice cover" in Hempel.G (ed) Antarctic Science p. 45 - 59

Walker. G. (1995) "Diluted ocean threatens Western Europe's weather" in New Scientist 11 November 1995. p. 20

Warrick. R.A, LeProvost. C, Meier. M.F, Oerlemans. J, Woodworth. P.L (1995) "Changes in Sea Level" in Houghton.J.T. et al (eds) Climate Change 1995 363 - 405

Weaver. A.J, Hughes. T.M.C (1994) "Rapid interglacial climate fluctuations driven by North Atlantic ocean circulation" in Nature vol. 367 p. 447 - 450.

Weertman. J. (1976) "Glaciology's grand unsolved problem" in Nature vol. 364 p. 215 - 218.

Weertman. J (1974) "Stability of the junction of an ice sheet and an ice shelf" in Journal of Glaciology vol. 13. no. 67 p. 3 - 11.

Weiler. C.S, Penhale. P.A. (eds) (1994) Ultraviolet radiation in Antarctica: measurements and biological effects Antarctic Research Series. vol. 62 American Geophysical Union. Washington. pp. 257.

Wexler. H, Rubin. M.J, Caskey. J.E. Jnr. (eds) Antarctic Research National Academy of Sciences.

White. R.M (1990) "The Great Climate Debate" in Scientific American vol. 263. no. 1 July 1990 p. 18 - 25.

Whorf. B.L. (1956) Language, thought and reality M.I.T. Press. Massachusetts. U.S. pp. 278.

Ziman. j. (1987) Knowing everything about nothing Cambridge University Press. Cambridge U.K. pp. 196

Zumberge. J.H, Swithinbank. C (1962) "The dynamics of ice shelves" in Wexler. H, Rubin. M.J, Caskey. J.E. Jnr. (eds) Antarctic Research National Academy of Sciences. p. 197 - 208

Zwally. H.J (1994) "Detection of change in Antarctica" in Hempel.G (ed) Antarctic Science p. 126 - 143.