Climatic change in Western Australia

M A. Frahmand

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Climatic change in Western Australia

Division of Resource Management
1988

Notes prepared by:
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and
R.A. Nulsen
CLIMATIC CHANGE

IN

WESTERN AUSTRALIA

Notes prepared for the staff of the Western Australian Department of Agriculture by

M.A. Frahmand and R.A. Nulsen

DIVISION OF RESOURCE MANAGEMENT

1988
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INTRODUCTION

The greenhouse effect is now an established scientific fact. Evidence published in the US and Australia in 1987 leaves little room for doubt. Carbon dioxide sent into the air whenever fossil fuels are burnt traps reflected heat from the Earth's surface - just as a greenhouse traps heat on a summer's day.

The uncertainties currently present in any prediction of future regional climate are very large. This paper presents a synopsis of current literature related to the future climate of Western Australia.

What is the Greenhouse Effect?

The greenhouse effect is the name given to a global warming expected to be brought about by an increase in the atmospheric concentration of carbon dioxide and other gases which allow sunlight into the Earth's surface but prevent some of the infra-red or heat radiation given off by Earth from escaping to space.

This possibility was first suggested in 1896, but it is only since 1958 that accurate measurements of the increasing concentrations of CO₂ in the atmosphere have been made. These show a fairly regular annual rate of increase of about 0.4%, which is primarily due to the burning of fossil fuels (oil, coal and natural gas).

Measurements of past concentrations in bubbles of air trapped in ice cores from Antarctica and Greenland show that pre-industrial concentrations were about 270 parts per million by volume (ppmv) (Figure 1). The present concentration is about 348 ppmv, and a doubling of the pre-industrial level is expected by the latter half of the 21st century.
of the cloudiness. The effect of changing cloud cover depends on the height, latitude and season of the cloudiness. This warming effect is due to the relative opacity of CO$_2$ to infra-red radiation, so that less of the energy radiated from the earth escapes to space. A major uncertainty arises from the possibility of either positive (reinforcing) or negative (damping) feedbacks due to changes in cloudiness. The effect of changing cloud cover depends on the height, latitude and season of the cloudiness.

Figure 1. Carbon dioxide levels centuries ago. (Source: What air bubbles trapped in Antarctic ice tell us, 1986).

There is some uncertainty as to the probable effect of a given increase in CO$_2$ concentration on the climate, due to the complexity of the atmospheric circulation system. A doubling of CO$_2$ would, on theoretical grounds, lead to an average surface warming of about 2-4°C, with the greater increases occurring in winter and at high latitudes due to the reinforcing effect (positive feedback) of warmer temperatures leading to less snow and ice cover and thus to more sunlight being absorbed at the surface.
Ozone ($O_3$) is a form of oxygen that rarely occurs naturally in the cool reaches of the troposphere. It is created when ordinary oxygen molecules ($O_2$) are bombarded with solar ultraviolet rays, usually in the stratosphere. This radiation shatters the oxygen molecules, and some of the free oxygen atoms recombine with $O_2$ to form $O_3$. The configuration gives it a property that two-atom oxygen does not have; it can efficiently absorb ultraviolet light. In doing so, ozone protects oxygen at lower altitudes from being broken up and keeps most of these harmful rays from penetrating to the...
Earth's surface. The energy of the absorbed radiation heats up the ozone, creating warm layers high in the stratosphere that act as a cap on the turbulent troposphere below.

**How Ozone Diminishes?**

Ozone molecules are constantly being made. But they can be destroyed by any of a number of chemical processes, most of them natural. For example, the stratosphere receives regular injections of nitrogen-bearing compounds, such as nitrous oxide. Produced by microbes and fossil-fuel combustion, the gas rides the rising air currents to the top of the troposphere. Forced higher by the upward push of tropical storms, it finally enters the stratosphere.

Like most gaseous chemicals, man-made or natural, that reach the stratosphere, nitrous oxide (N$_2$O) tends to stay there. The nitrous oxide is broken down by ultraviolet radiation and the resulting fragments, called radicals, attack and destroy more ozone molecules (Figure 2).

**Ozone Killer**

° Methane

A carbon hydrogen compound produced by microbes in swamps, rice paddies and the intestines of sheep, cattle and termites.
For every chlorine atom released, 100,000 molecules of ozone are removed from the atmosphere (Time Australia, 1987).

Chlorofluorocarbons (CFC's)

In 1928 a group of chemists at General Motors invented a non-toxic, inert gas that was first used as a coolant in refrigerators. By the 1960's, manufacturers were using similar compounds, generically called Chlorofluorocarbons, as propellants in aerosol sprays. CFC's in aerosol cans are sprayed directly into the air, they escape from refrigerator coils, and they evaporate quickly from liquid cleaners and slowly from plastic foams.

For every chlorine atom released, 100,000 molecules of ozone are removed from the atmosphere (Time Australia, 1987).

Figure 2. How ozone is destroyed. (Source: Time Australia, 1987)
In the troposphere, CFC's are immune to destruction. But in the stratosphere, they break apart easily under the influence of ultraviolet light. The result: free chlorine atoms, which attack ozone to form chlorine monoxide (ClO) and O\textsubscript{2}. The ClO then combines with a free oxygen atom to form O\textsubscript{2} and a chlorine atom. The chain then repeats itself and causes the depletion of the ozone shield in the stratosphere (12-50 km above the Earth's surface).

Figure 3. Satellite image recorded October 5, 1987, showing ozone hole over Antarctica.
This depletion allows more ultraviolet radiation to penetrate to the surface. The recent discovery of an extensive "ozone hole" over Antarctica each spring raises the question of whether the quantity of ultraviolet light reaching Antarctic surface waters might reduce the phytoplankton production. If so there will be a reduced uptake of carbon dioxide thus leaving more CO₂ in the atmosphere (Chittleborough, 1985). Although field data are lacking, it is expected that the marine food chain in surface water would be reduced by 16-30 per cent (Pitock, A.B. et al., 1981). In 1985 the reduction in the ozone over Antarctica was 50% (Ember, L.R. et al., 1986) - sufficient to have a positive feedback on the greenhouse effect.

**How will it effect Western Australia?**

Global climatic models can reasonably predict gross climatic changes but regional impacts are more speculative. Impacts in Western Australia of the primary climatic factors of temperature and rainfall have been attempted.

**Physical Effects**

- **Temperature**

  At a doubling of atmospheric carbon dioxide, mean annual air temperature is expected to rise by about 2°C in the north and by some 4°C in the south of the State (Pitcock and Salinger, 1982).

- **Rainfall**

  The summer monsoonal rainfall regime is expected to intensify and push further south. Thus in the lower Kimberley, Great Sandy Desert and Pilbara regions, rainfall may increase by up to 50 per cent. In the south-west region, however, winters will be generally drier by 20 per cent or more (Pitcock, 1983), though there may be more frequent summer downpours from the remnants of tropical cyclones.
Pittock (1975) described the change in mean annual precipitation between the period 1913-1945 and 1946-1974 which showed a large area in south-western Australia where decreases of 10% or more occurred. The data have been updated by Pittock to 1978 and the changes examined in terms of true seasons (Pittock, 1983), viz. JJA (winter), SON (spring), DJF (summer) and MAM (autumn). The result for Western Australia is shown in Figures 4a-4d respectively.
in these areas are not well determined. (Source: Pittock, 1983)

-9-

seasonal rainfall less than 50 mm, have not been plotted as changes

Figures (a) to (d) respectively. Areas having district mean

December-January-February (Summer) and March-April-May (Autumn) in

Figures (a) to (d) respectively. Areas having district mean

seasonal rainfall less than 50 mm, have not been plotted as changes

in these areas are not well determined. (Source: Pittock, 1983)

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Figure 4. Changes in seasonal mean district precipitation, in percent of the

66-year average between 1913-45 and 1946-78. Seasons are

June-July-August (Winter), September-October-November (Spring),

December-January-February (Summer) and March-April-May (Autumn) in
In Figure 4 regions where changes exceeded ± 20% have been shaded. The main features are as follows:

(a) In winter there is a decrease in mean rainfall in the later period in south-west of Western Australia.
(b) In spring there is a decrease of about 10% occurring in the south-west of Western Australia.
(c) Summer shows a small decrease along the south coast of Western Australia.
(d) Autumn is dominated by a large inland area with a decrease greater than 20%, but seasonal rainfall there is below 100 mm and very variable.

Figure 4. Key to the meteorological districts discussed in the text and data for which are plotted in Figures 6 and 7. (Source: Pittock, 1983)
A better idea of changed seasonal distribution of rainfall for Western Australia in the vicinity of Perth is given in Figure 6, which shows the mean annual cycle for the 33-year periods 1913-45 and 1946-78.

The seasonal distributions show an appreciable decrease in mean rainfall in the winter months from May through September, with decreases of 22% in August and 30% in September. The frequency distributions for August in the two periods are shown in Figure 7. Again, the change seems to be the result of a real shift in the whole distribution of rainfall rather than the result of a few extreme events.

Figure 6. Mean annual cycles in selected districts for the intervals 1913-45 (dotted lines) and 1946-78 (full lines). Increases are indicated by stippling, and decreases by hatching. (Source: Pittock, 1983).
but at the cost of local flash floods, sheet erosion and siltation of streams. Frequent summer downpours from tropical cyclones may afford some compensation for evaporation and lower winter rainfall, available water will decline. More frequent summer downpours from tropical cyclones may afford some compensation but at the cost of local flash floods, sheet erosion and siltation of streams.

Figure 7. Frequency distributions of monthly precipitation amounts in the vicinity of Perth and months as indicated, for the two data intervals 1913-45 (upper graphs) and 1946-78 (lower graphs). (Source: Pittock, 1983).

- Tropical cyclones

Tropical cyclones are expected to move some 200-400 km further south. The frequency of occurrence and maximum intensity may increase (Emmanuel, 1987).

- Soil moisture and water runoff

Soil moisture and water runoff available for urban and rural water supplies, river flow and flooding will change regionally as these depend on the delicate balance between rainfall and evaporation. In the south-west, with higher evaporation and lower winter rainfall, available water will decline. More frequent summer downpours from tropical cyclones may afford some compensation but at the cost of local flash floods, sheet erosion and siltation of streams.
Experiments under controlled environmental conditions show that photosynthesis and plant growth are enhanced increasing carbon dioxide concentrations (Idas, 1985). Gifford (1977) in his early experiments with wheat grown under favourable conditions found that carbon dioxide enrichment lead to a substantial increase in yield (Figure 8) because plants produce more tillers, more ears, and more grains per spikelet. Later enrichment experiments (Gifford, 1979), in which wheat was grown in denser stands at 19°C with limited water to stimulate field conditions, showed that grain yield may increase by 5-13 kg per hectare per year at the current global rate of increase of carbon dioxide. Counter to the simple interpretation of the "law of limiting factors" the percentage yield increase in wheat grown at high carbon dioxide concentrations, (compared with that at a normal concentration) was greater in plants that had less water available to them than in plants with ample water - an important consideration in Western Australia.

Sea level rise

Estimates of sea level rise, due almost entirely to thermal expansion of surface waters of the oceans, indicate a rise of 80 ± 60 cm. The wide variability of the estimates reflect the inadequacy of data on aspects such as the rates and depths of mixing of upper layers in the oceans.

Changes in the watertable

Changes in the watertable will result from the interaction of the factors outlined above. In localities where rising watertables are indicated, this could lead to increasing problems of soil salinity.

Biological Effects

Photosynthesis and plant growth

Experiments under controlled environmental conditions show that photosynthesis and plant growth are enhanced increasing carbon dioxide concentrations (Idas, 1985). Gifford (1977) in his early experiments with wheat grown under favourable conditions found that carbon dioxide enrichment lead to a substantial increase in yield (Figure 8) because plants produce more tillers, more ears, and more grains per spikelet. Later enrichment experiments (Gifford, 1979), in which wheat was grown in denser stands at 19°C with limited water to stimulate field conditions, showed that grain yield may increase by 5-13 kg per hectare per year at the current global rate of increase of carbon dioxide. Counter to the simple interpretation of the "law of limiting factors" the percentage yield increase in wheat grown at high carbon dioxide concentrations, (compared with that at a normal concentration) was greater in plants that had less water available to them than in plants with ample water - an important consideration in Western Australia.
Under extremely arid conditions (equivalent to less than 100 mm of rainfall available to the crop), wheat plants could produce grain only if they received extra carbon dioxide - an infinite percentage yield response! So more carbon dioxide may extend the boundaries of wheat zones towards arid regions. Some of the improved water-use efficiency of wheat at high carbon dioxide concentrations is due to stomatal control of water vapour and carbon dioxide. At elevated carbon dioxide concentrations, the stomata tend to close thus reducing the loss of water by transpiration, and incidentally helping the plant to survive periods of water stress (Gifford, 1985). However, there is now some evidence that plants grown for generations under increased carbon dioxide levels have a lower number of stomates per unit leaf area. This essentially negates the above enhancement effect.

Figure 8. Enhanced photosynthesis at the high carbon dioxide concentration promoted both total crop growth and grain yield in the glasshouse experiment. (Source: Gifford, 1985).

Chittleborough (1987) suggests that the enhanced photosynthesis and plant growth due to higher carbon dioxide concentration might lead to changes in
Net primary productivity (NPP) (tonne/ha/yr) was calculated using the Miami Model (Lieth, 1975 and 1978) and the results are shown in Figures 9, 10 and 11. Figure 9 shows the values of NPP for forest and pasture production in Western Australia. Values generally reflect those observed. For example, simulated NPP at or close to the margins of the wheatbelt is close to 5 tonnes/ha/yr which is in good agreement with actual values based on grain yield and the known harvest index (Nix, 1975).
Figure 10 shows the NPP for a doubling of carbon dioxide. There is an increase in NPP over most of Western Australia with little change in the relative productivity between different regions. Highest NPP continues to be in the south-west.
in winter rainfall is the dominating factor, Albany. This is an area with almost no summer rainfall so that the decrease in productivity is along the extreme south-west coast from Carnarvon to Albany. The only area showing a decrease relatively small increase in temperature has little or no effect, but the very maximum increase exceeding 40% occurring in the Kimberley. Here the rainfall areas of northern and north-western Western Australia with the greatest changes are predicted to occur in the predominantly summer rainfall areas of northern and north-western Western Australia with the maximum increase exceeding 40% occurring in the Kimberley. Here the relatively small increase in temperature has little or no effect, but the very significant increase in precipitation does. The only area showing a decrease in productivity is along the extreme south-west coast from Carnarvon to Albany. This is an area with almost no summer rainfall so that the decrease in winter rainfall is the dominating factor.

Figure 10. Net primary productivity for Australia as calculated with the Miami Model for a climate scenario roughly as might be expected for a doubling of atmospheric carbon dioxide.

Figure 11 shows the percentage change in NPP when carbon dioxide is doubled. The greatest changes are predicted to occur in the predominantly summer rainfall areas of northern and north-western Western Australia with the maximum increase exceeding 40% occurring in the Kimberley. Here the relatively small increase in temperature has little or no effect, but the very significant increase in precipitation does. The only area showing a decrease in productivity is along the extreme south-west coast from Carnarvon to Albany. This is an area with almost no summer rainfall so that the decrease in winter rainfall is the dominating factor.
surrounded by cleared agricultural land will be at greatest risk of extinction.

Species diversity may decline as a result of changed habitats caused by the greenhouse effect. Those species confined to "island" parks and reserves surrounded by cleared agricultural land will be at greatest risk of extinction.

Plant disease and insects

The incidence and distribution of plant diseases and insect pests can be expected to change with climate. For example, occasional summer downpours in the south-west are known to greatly increase the destruction of jarrah forest by dieback disease, Phytophthora cinnamomi (Shea, S.R. et al., 1984).

Species diversity

Species diversity may decline as a result of changed habitats caused by the greenhouse effect. Those species confined to "island" parks and reserves surrounded by cleared agricultural land will be at greatest risk of extinction.

Figure 11. Percentage change in net primary productivity to the present for a climate scenario roughly equivalent to a doubling of atmospheric carbon dioxide.
Socio-Economic Effects

Both Chittleborough (1987) and Pittock (1987) have suggested that the changing climate is likely to have a number of socio-economic effects.

- Urban and rural water supply
Urban and rural water supply will present major problems as water balances change regionally. In the south-west, while rainfall over the catchments decreases and evaporation increases, per capita demand for water can be expected to rise unless patterns of usage can be changed dramatically.

- Pattern of land use
Patterns of land use will be altered considerably. Some rural communities will be better off, others may be able to adapt by changing farming strategies. In the south-west marginal land will become uneconomic unless production systems change. Significant shifts of population (both rural and urban) could result.

- Energy demand
Domestic energy demand could also change significantly, with less demand for winter heating and more for summer cooling.

- Coastal impacts
Coastal impacts will be diverse as sea level rises and the frequency of tropical cyclones reaching our lower west coast increases. Effects include:

  - accelerated recession of coastlines, coastal plains and deltas;
  - narrowed beaches;
  - intensified storm surge damage to waterfront structures, industries and resorts;
- enlargement and salinisation of inlets, embayments and estuaries, grossly altering ecosystems;
- flooding of low-lying coastal plains;
- rising watertable in coastal soils, with salt water intrusion.

Fisheries practices may have to be modified in the long-term, if, for example, as the warm Leeuwin Current strengthens the range of tropical species will extend southwards displacing some of the present species.

When Will it Affect Western Australia?

It is already affecting Western Australia! However, the doubling of the concentration of atmospheric carbon dioxide is applied as a benchmark for comparing the results from the various predictive models of global climate changes (Figure 12). If world-wide emissions of CO₂ from fossil fuels had continued at their pre-1973 rate of growth - more than 4 per cent annually (Postel, 1986) - atmospheric concentrations would have doubled in 40 years.
Figure 12. The recent increase in atmospheric carbon dioxide over south-eastern Australia. These levels have risen from about 280 ppm (parts per million) at the end of the 1700's. (Source: Weather and Climate, 1986).

Fortunately, for the decade following 1973 world-wide carbon emissions grew at an average of only 1 per cent per year, though the rate may now be rising again. These estimates do not take into account the cumulative effects of the other greenhouse gases, which although in much lower concentrations, exert a combined effect as great as that of carbon dioxide. Thus the net effect of the present rate of increase of all the greenhouse gases is estimated to be equivalent to the doubling of atmospheric carbon dioxide in 30 to 50 years.

However, such a benchmark does not mean that in a few decade's time, we will shift abruptly to a fresh plateau in global climate. The processes already in train are expected to lift the primary factors (air temperature and rainfall) above the background "noise" level in a decade or so. Nor will the greenhouse effect reach a new equilibrium at the point equivalent to a doubling of atmospheric CO$_2$. From the predicted energy requirements during the next
50 years, world-wide CO₂ emissions could rise to 35 billion tonnes of carbon per year (Pitlock, et al., 1981). Projected scenarios into the end of the next century include the prospect of atmospheric CO₂ increasing four-fold by that time (Ratty and Reister, 1986). Further acceleration would occur should the ocean sink for CO₂ in the southern ocean alter.

What Has Been Done So Far?

In October 1985, an international conference brought together experts from 29 countries at Villach, Austria to discuss the greenhouse effect and related atmospheric changes (Bolin, 1986). They agreed that on present trends the combined effects of all the greenhouse gases would be equivalent to a doubling of atmospheric carbon dioxide concentration as early as 2030, with a consequent surface warming of 1.5-4.5°C (increasing with latitude) and a rise of global sea level of 20-140 cm, due essentially to thermal expansion of surface water of the oceans.

The report of the Villach meeting, known as the "Villach Statement" opened by stating:

"As a result of the increasing concentrations of greenhouse gases, it is now believed that in the first half of the next century a rise of global mean temperature could occur which is greater than any in man's history".

The statement goes on to say:

"Many important economic and social decisions are being made today on long-term projects - major water resource management activities such as irrigation and hydro-power, drought relief, agricultural land use, structural designs and coastal engineering projects, and energy planning - based on the assumption that past climatic data, without modification, are a reliable guide to the future. This is no longer a good assumption .......".
In March, 1987 the world's industrial nations agreed in principle to cut production of chemicals that destroy the Earth's protective ozone layer. Officials of the United Nations said after a meeting in Geneva that they hope a treaty to protect the ozone would now be signed in September (Small comfort for the ozone layer, 1987). In September (1987) the world, or at least a part of it, finally did something.

At a conference in Montreal sponsored by the United Nations Environment Programme 24 countries signed a milestone accord that promised to halve production and use of ozone-destroying chemicals by 1999. "There has never been an agreement like this on a global scale", claimed Winfried Lang of Austria, Chairman of the Conference. Said Lee Thomas, Administrator of the US Environmental Protection Agency: "The signing shows an unprecedented degree of co-operation among nations of the world in balancing economic development and environmental protection".

The Montreal Protocol is aimed at reducing the production and use of CFC's. The pact also limits the use of an ozone-destroying group of fire-suppressant chemicals called halons, which some scientists believe cause as much as 20 times the damage of CFC's (A Breath of Fresh Air, 1987).

In October 1986 a National Conference on Coastal Management brought together Australian experts who concluded that there was a need for more research, and careful definition of the local and regional climatic and sea level changes that could be expected. There was also a need for a systematic assessment of the impacts that predicted climatic changes might be expected to have.

More recently the CSIRO Division of Atmospheric Research in co-operation with the Commission for the Future brought together atmospheric physicists, agricultural scientists, engineers, geographers, marine biologists,
environment scientists, ecologists, meteorologists, planners, health authorities, sociologists and insurance specialists at a national conference in December 1987 under the title of "Greenhouse 87".

The objectives of the conference were:

* To have experts in the various potential impact areas assess the impacts of climatic change of the kind possible due to greenhouse warming.
* To communicate to the wider scientific and engineering community the current status of the greenhouse theory.

Conference speakers concentrated on reviews of the nature of the greenhouse effect, the methods by which its climatic effect are assessed and the anticipated changes for Australia. In addition, papers were presented reviewing some of the evidence that climatic changes have started to take place already; how sea level rise may manifest itself; how climatic change in the Antarctic may contribute to sea level rise and on what time scale. The final paper in this session reviewed the known effects of higher atmospheric CO₂ concentrations on plant growth.

Some outcomes of the conference have been:

* The stimulation of climatic-impact research throughout Australia.
* A clearer specification of the requirements of climatic modelling work by the wider community.
* Establishment of an awareness of the potential advantages and disadvantages of greenhouse climatic induced change in government instrumentalities and the community at large.
Anticipatory actions (adapting to the changes) range from shifting energy sources (e.g. natural gas emits 42 per cent less CO$_2$ than coal per unit of useful energy output (Postel, 1986)), strong policies for energy conservation including alternative energy sources, energy-efficient housing and public transport, and the phasing out of chlorofluorocarbons. Though these actions are vital, they will only buy us a little more time.

What Should We Do About It?

Planners need to be aware that climatic change is inevitable in the next three to five decades (Pearman, 1986). As the extent of local impacts are largely speculative there is an urgent need for more data and research towards a more precise definition of local and regional climatic changes that might be expected and a systematic assessment of the effects that these changes will bring about. Site-specific studies are needed in Western Australia to integrate the complex interactions into useful predictions for the near future.

At the same time there is a need for planners to develop strategies to adapt to the future changes. Some may counsel against pressing for major socio-economic changes until the climatic effects are more evident and the impacts more precisely defined. However, recognizing the long lead time necessary to effect major socio-economic changes, we cannot afford further delay (Ember, 1986, Rotty, 1986, and Pittock et al., 1981).

Anticipatory actions (adapting to the changes) range from shifting energy sources (e.g. natural gas emits 42 per cent less CO$_2$ than coal per unit of useful energy output (Postel, 1986)), strong policies for energy conservation including alternative energy sources, energy-efficient housing and public transport, and the phasing out of chlorofluorocarbons. Though these actions are vital, they will only buy us a little more time.
Under the World Conservation Strategy, the National Conservation Strategy for Australia, and the State Conservation Strategy for Western Australia we have a commitment to focus on causes as well as treating symptoms. A consumer society dedicated to maximizing growth will inevitably expand energy use and continue to add to the greenhouse gases. To treat the cause of the problem, then, requires a change to a more conserving society, with "reductions in the growth rates of population, production of goods, per capita income and many other factors" (Rotty, 1986). While that may be an unattainable goal, we can hardly afford to delay implementation of positive action.

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