

CLIMATE CHANGE

A Natural Hazard

William Kininmonth
(Australasian Climate Research)

Abstract

The impacts of weather and climate extremes (floods, storms, drought, etc) have historically set back development and will continue to do so into the future, especially in developing countries. It is essential to understand how future climate change will be manifest as weather and climate extremes in order to implement policies of sustainable development. The purpose of this article is to demonstrate that natural processes have caused the climate to change and it is unlikely that human influences will dominate the natural processes. Any suggestion that implementation of the Kyoto Protocol will avoid future infrastructure damage, environmental degradation and loss of life from weather and climate extremes is a grand delusion.

Introduction

Human interest in recurring weather and climate extremes can be traced to the earliest records of civilisation. The discovery in the late nineteenth century that the earth had been through several periods of significant glaciation over the previous million years heightened attention toward climate change. In 1896, the Swedish chemist, and later Nobel Prize winner, Svante Arrhenius proposed that changing concentrations of atmospheric CO₂ might have caused these major fluctuations in global temperature. Colleagues later suggested that the burning of fossil fuels was increasing the atmospheric concentration of CO₂ and thus leading to global warming. Arrhenius is reputed to have responded that would be no bad thing, given the cold of Swedish winters! In the 1920s, the Serbian astrophysicist Milutin Milankovitch advanced the currently accepted hypothesis for the cause of ice ages, namely, that they are related to changing orbital characteristics of the earth relative to the sun.

But support for the proposal that increasing atmospheric concentrations of greenhouse gases is causing global warming has not gone away, especially as observational evidence of warming during the twentieth century has accumulated. In 1985, scientists meeting in Villach, Austria issued a statement claiming that the earth was warming due to increasing concentrations of greenhouse gases caused by human activities. They suggested a magnitude for future warming and sea level rises, and called for global action. In 1987, an international conference in Toronto, Canada endorsed the Villach Statement and called for stabilisation of greenhouse gas concentrations at then-existing levels.

The World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) established the Intergovernmental Panel on Climate Change (IPCC) process in 1988 to authoritatively review climate science and provide guidance to policymakers and governments. The first IPCC assessment report, in 1990, concluded:

- there is a greenhouse effect;
- atmospheric concentrations of CO₂ had increased as a result of human activities and were likely to enhance the greenhouse effect; and
- the timing, magnitude and regional characteristics of warming were uncertain, although IPCC did offer a range of global temperature and sea level rise scenarios.

The IPCC findings were endorsed at the Second World Climate Conference held in Geneva in 1990 and the accompanying Ministerial Declaration called for UN action to negotiate a convention that would establish international agreements necessary to avoid dangerous climate change. The UN Framework Convention on Climate Change (UNFCCC) and its Kyoto Protocol are the results of those negotiations. The objective of the UNFCCC is to prevent dangerous climate change.¹

Since 1990, IPCC has reviewed the science of climate change and its findings on two occasions. The Second Assessment Report was published in 1995 and the Third Assessment Report was published in 2001. The sequence of assessments has expressed increasing confidence that greenhouse gases will cause dangerous future climate change. The most recent report claimed that there is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities.

This article will focus on three aspects of the science underpinning IPCC assessments and hence the Kyoto Protocol:

- facts and myths surrounding the greenhouse effect and climate change;
- examination of the claims of the IPCC third assessment report, particularly as they relate to causes of recent global warming; and
- recent variability of the climate system not examined by IPCC.

The Science of Climate Change

The IPCC hypothesis for global warming assumes that, under normal circumstances, the earth's climate is stable. Therefore, at the top of the atmosphere, incoming solar radiation equals outgoing longwave radiation. It is also assumed that the climate system will adjust to changes of either incoming or outgoing radiation and restore the earth's radiation balance. Change in the earth's temperature is the primary mechanism to restore the earth's radiation balance.

Changes to the incoming or outgoing radiation can be due to natural effects (changes in solar radiation, volcanic dust clouds) or human activities (greenhouse gas concentrations, land-use changes, pollutant dust particles, etc). Processes that lead to changes in either

¹ In the UNFCCC, climate change is defined as human-induced climate change, whereas the IPCC includes human-induced and naturally occurring climate change. Here, we use the IPCC definition for climate change.

incoming or outgoing radiation are called ‘radiative forcing’. IPCC considers that human activities, particularly the build-up of concentrations of greenhouse gases in the atmosphere, are reducing the emission of longwave radiation to space and global warming is necessary to restore the radiation balance. Processes that require global warming to restore the earth’s radiation balance are referred to as positive radiative forcing. The radiative forcing model is very simplistic and ignores the complexity of the climate system, particularly its ability to store heat for long periods without significantly affecting internal energy exchanges.

Satellite measurements of incoming solar, outgoing longwave and reflected solar radiation are the only means to quantify the earth’s radiation budget. Unfortunately, the local four-times-per-day observations available from satellites are not sufficiently frequent to represent the diurnal cycles accurately. The satellite observations cannot confirm that there is radiation balance at the top of the atmosphere, nor can they accurately quantify the magnitude of radiation forcing (see Trenberth and Solomon (1994) for a discussion on satellite observations).

The greenhouse effect is an important process of the global energy cycle. However, there are also other important processes that contribute to the changing global temperature of the earth’s surface and these include regulation of:

- ocean heat storage,
- heat transfer from the ocean to the atmospheric boundary layer,
- deep atmospheric convection that converts boundary layer heat and latent energy (from water vapour) to potential energy,
- subsidence of clear air where potential energy is converted to atmospheric heat, and
- the cooling of the atmosphere as heat is radiated to space.

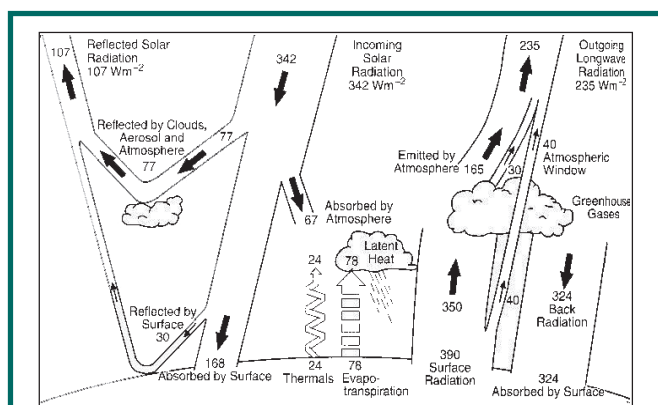
We will look at these processes and their potential significance to climate change. The IPCC ‘annual and global mean energy balance’ of the earth (see Box 1) is used as a starting point for this examination, recognising that the global climate system is only in approximate energy balance. The magnitudes of the rates of energy transfer in the climate system components identify the importance of each in maintaining the approximate energy balance of the earth.

The greenhouse effect: Greenhouse gases absorb and emit longwave radiation. When averaged globally and annually, the atmosphere absorbs 350 Watts per

square metre (Wm^{-2}) of the emissions from the earth’s surface but itself emits 324 Wm^{-2} back to earth and 129 Wm^{-2} to space. This is a net deficit of 169 Wm^{-2} . The longwave radiation deficit of the atmosphere is partially offset by absorption of 67 Wm^{-2} of incoming solar radiation, leaving an overall radiation deficit (or atmospheric cooling) of 102 Wm^{-2} .

The greenhouse effect at the earth’s surface is the back radiation from the atmosphere to the earth that reduces net longwave radiation loss from 390 Wm^{-2} to 66 Wm^{-2} . It dramatically slows the rate of longwave radiative cooling of the earth’s surface from what it would otherwise be. Any increase in the atmospheric concentration of greenhouse gases will initially lead both to a reduction in radiation loss to space and to an increase in back radiation to the earth’s surface. This is because the emission to space would then be from a higher, colder altitude and the back radiation would be from a lower, warmer altitude. IPCC suggests that a doubling of the atmospheric concentration of CO_2 will lead to a reduction in longwave radiation to space of about 4 Wm^{-2} ; that is, a radiation forcing of the earth’s climate system of 4 Wm^{-2} .

As we have noted, the assumption that outgoing longwave radiation will adjust to balance net incoming solar radiation is the basis for the IPCC ‘radiative forcing’ hypothesis. Many natural changes in the climate system, including variability associated with ocean heat storage and internal energy exchange processes, also cause an adjustment to the outgoing longwave radiation. What is important for determining future global warming is the magnitude of human-



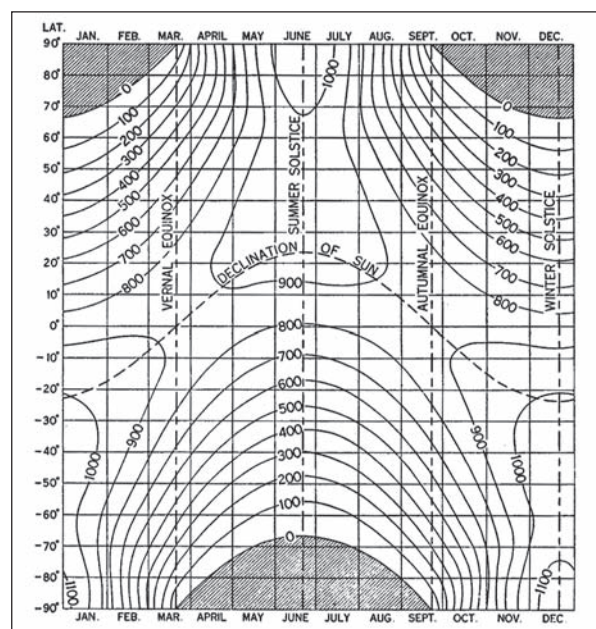
Box 1: The earth’s annual and global mean energy balance. At the top of the atmosphere, incoming solar radiation is assumed by IPCC to be balanced by outgoing longwave and reflected solar radiation. Thermals and evapotranspiration transfer 102 Wm^{-2} excess solar radiation absorbed at the surface to balance the radiation deficit of the atmosphere. Source: IPCC (2001).

induced changes compared with those resulting from natural processes.

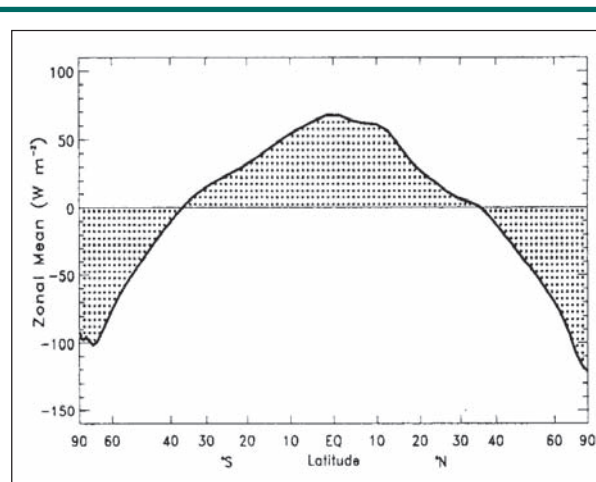
Surface heat storage: At the earth's surface, incoming solar radiation *does not* form an energy balance, as represented by IPCC. Seventy per cent of the earth's surface is ocean and solar radiation is absorbed in the top few hundred metres. Solar energy absorbed in the ocean surface layers is only given up by longwave radiation cooling at the surface and energy exchanges across the ocean-atmosphere interface. Surface currents also transport heat. The oceans have an enormous capacity to absorb heat when compared with the overlying atmosphere. A small increase in solar radiation may not be observed as a significant ocean surface temperature rise for decades, or even centuries, because of the thermal capacity of the ocean surface layer.

The assumption of negligible heat storage in the surface layers is only appropriate for land areas where solar radiation is absorbed at the surface and there are no processes for horizontal transport. When averaged over several years, it is assumed that there is no net heat storage. Even over land, however, the assumption breaks down where there is receding glaciers or shrinking permanent snow cover. Here, additional latent heat of fusion is being locally extracted from the atmosphere, transported by the melt-water and retained in the climate system. But more generally, there is also a capacity to change local energy storage and mean temperature if a changing climate is increasing or decreasing the eddy exchange with the overlying atmosphere.

The seasonal cycle: The annual average global model of the energy budget used by IPCC to support its explanation of radiative forcing ignores processes that respond to the seasonal cycle and are necessary for poleward transport of heat. Solar radiation at the top of the atmosphere varies with latitude and with season (see Box 2). The zonal average net radiation at the top of the atmosphere highlights the equator-to-poles imbalance and the need for the climate system to transport excess heat from the tropics to the polar regions (see Box 3). In particular, the need to transport excess energy from the tropics, especially in the winter hemisphere, forces meridional overturning of each of the atmosphere and ocean fluids. The atmosphere and the oceans interact at the interface and each influences the motions of the other, despite their significantly different inertial characteristics. The prevailing temperature, humidity and wind speed at each location regulate the exchanges of heat, moisture and momentum across the interface.



Box 2: Solar Radiation at the top of the atmosphere. Daily solar radiation (shown here in $\text{cal.cm}^{-2}\text{day}^{-1} = 0.484 \text{ Wm}^{-2}$) has its maximum variability over polar regions. In addition to the six months of polar darkness of the winter hemisphere, the total daily insolation over each pole in mid-summer exceeds that of the tropics. This seasonal variability over middle and high latitudes has an enormous forcing on the internal variability of the climate system. *Source: List (1966)*



Box 3: Zonally Averaged Net Radiation. The annual average zonal net radiation at the top of the atmosphere, based on satellite observations is positive over the tropics (excess radiation) and negative over the polar regions (radiation deficit). An inability to adequately capture the diurnal variation introduces errors, estimated at up to 6 Wm^{-2} at each zonal band. Excess solar radiation over tropical latitudes causes equator to pole near surface temperature gradients. The meridional temperature gradients drive the atmospheric and ocean circulations and transport excess energy to middle and high latitudes. *Source: Trenberth and Caron (2001)*

The annual average rate of meridional transport of energy by the atmosphere has been calculated from the global observations processed and archived in support of weather prediction, both in the US (National Center for Atmospheric Research—NCAR) and Europe (The European Centre for Medium Range Weather Prediction—ECMWF). The ocean transport is the difference between the required transport, as assessed from the top of the atmosphere satellite measurements, and the computed atmospheric transport. Trenberth and Caron (2001) have calculated the annual average heat transports for the oceans and atmosphere over the period 1985-1989. The peak atmosphere energy transport in each hemisphere is near 40 degrees latitude and was calculated as 5.0 PW with an estimated error range of 0.14 PW (equivalent to an error range for net radiation of about 4 Wm^{-2} over the area poleward of 40 degrees). This error is the same magnitude as IPCC has estimated for radiative forcing from doubling atmospheric CO_2 concentration.

As water in the surface layers moves poleward, it is cooled and increases in density. Near the polar regions the surface waters of the ocean reach their maximum density and sink, forming the cold deep water of the ocean. The sinking of near freezing and highly saline waters is the thermohaline circulation that drives the overturning of the oceans. Trenberth and Caron (2001) have calculated that the oceans transport about 15 per cent of the excess solar energy from the tropics, with a larger percentage in the northern hemisphere than the southern hemisphere.

Temperatures over middle and high latitudes are strongly affected by the strength of the ocean and atmosphere energy transport.

Convection and meridional heat transport: The ocean communicates to the atmospheric boundary layer by eddy exchange of heat, moisture and momentum across the interface. IPCC suggests that the excess solar radiation at the surface is mixed into the atmosphere by 'thermals and evapotranspiration' and is available to balance the radiation deficit of the atmosphere. This is physically impossible, as Riehl and Malkus (1958) have explained. The potential temperature of the atmosphere increases with height and eddy transport will mix heat downward, not upward from the boundary layer.

Deep tropical convection is the essential process for releasing boundary layer heat and latent energy to the atmosphere. The protected updraughts of deep convective clouds provide a channel for mass to rise buoyantly from the surface to the high troposphere.

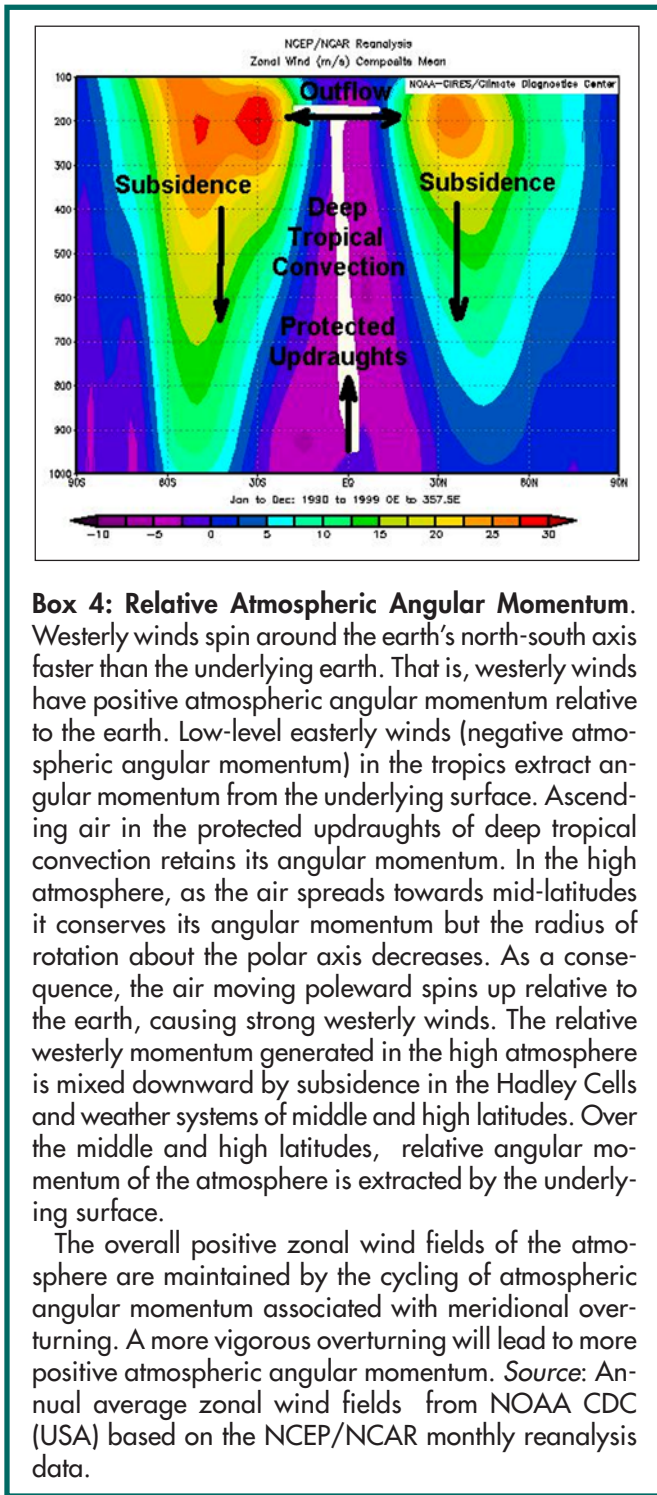
During the buoyant ascent heat and latent energy are converted to potential energy. In the subsiding clear air, away from convection, potential energy is converted to heat during compression. Overall, heat and latent energy accumulating in the tropical boundary layer are available to offset radiation cooling, but only indirectly through deep convection and overturning of the atmosphere.

An important consideration, not recognised by IPCC, is the role of convection and overturning of the atmosphere in regulating the release of boundary layer heat and latent energy to the atmosphere. If heat and moisture accumulate more rapidly in the boundary layer (for example by warmer sea surface temperatures) the buoyancy of the deep tropical convection will increase and there will be more vigorous overturning. More vigorous overturning, however, will release more heat in the subsiding air, leading to atmospheric warming and a loss of convective buoyancy. A new steady rate of overturning will become established but at a higher mean atmospheric temperature.

The Hadley Cells, with ascending air concentrated in convection of the intertropical convergence zone and descent extending to the subtropics, are essential for distributing excess energy from the tropical boundary layer to the atmosphere. Part of the energy is used to offset local atmospheric cooling and part is transported poleward by the largescale planetary waves and weather systems. The transported energy offsets atmospheric cooling over middle and high latitudes, especially during winter.

Atmospheric Angular Momentum: The air of the tropical boundary layer has high angular momentum (related to the spin about the north-south axis) acquired from contact with the underlying surface. As it rises buoyantly in the updraughts of the deep tropical convective clouds and moves poleward in the high atmosphere, the air conserves its absolute angular momentum. As the air moves away from the equator it speeds up relative to the underlying surface and the winds are primarily westerly. Over the middle and high latitudes the relative westerly momentum of the atmosphere is mixed downward to the surface where eddy stresses cause the atmosphere to give up angular momentum to the earth.

Overall, the magnitudes of the meridional overturning and angular momentum of the atmosphere are related to the rate of energy cycling from the tropical boundary layer to the atmosphere. A more rapid overturning will result in an accumulation of angular momentum in the atmosphere and, on average, the



Box 4: Relative Atmospheric Angular Momentum.

Westerly winds spin around the earth's north-south axis faster than the underlying earth. That is, westerly winds have positive atmospheric angular momentum relative to the earth. Low-level easterly winds (negative atmospheric angular momentum) in the tropics extract angular momentum from the underlying surface. Ascending air in the protected updraughts of deep tropical convection retains its angular momentum. In the high atmosphere, as the air spreads towards mid-latitudes it conserves its angular momentum but the radius of rotation about the polar axis decreases. As a consequence, the air moving poleward spins up relative to the earth, causing strong westerly winds. The relative westerly momentum generated in the high atmosphere is mixed downward by subsidence in the Hadley Cells and weather systems of middle and high latitudes. Over the middle and high latitudes, relative angular momentum of the atmosphere is extracted by the underlying surface.

The overall positive zonal wind fields of the atmosphere are maintained by the cycling of atmospheric angular momentum associated with meridional overturning. A more vigorous overturning will lead to more positive atmospheric angular momentum. *Source:* Annual average zonal wind fields from NOAA CDC (USA) based on the NCEP/NCAR monthly reanalysis data.

atmosphere will spin faster relative to the earth (see Box 4).

If the instability of the atmosphere increases, either through higher boundary layer energy (especially warmer sea surface temperature) or more rapid atmospheric cooling (longwave radiation divergence) the atmosphere will overturn faster. The relationship between atmospheric overturning and angular momentum can be observed in the seasonal cycle. In each hemisphere, as the atmosphere and underlying surface of the middle and higher latitudes cool during

winter the meridional transport of energy increases and the atmospheric angular momentum also increases. During an El Niño event, when the warmer tropical oceans are exchanging more energy with the overlying atmosphere, there is also generally an increase in global atmospheric angular momentum.

In summary, the IPCC concept of radiative forcing of the climate system does not reflect adequately the processes of the earth's energy cycle, except in the most general sense. Ocean storage, ocean-atmosphere energy exchange, convective overturning and the meridional energy transport are a few of the processes that each act to slow the negative feedback working to bring about top-of-the-atmosphere energy balance. In addition, no discussion has been given here of changing wind stresses on the oceans that alter the strength of upwelling and downwelling in the oceans' surface layer. The coupling between the atmosphere and the oceans is expected to excite internal variability of the climate system that is manifest on interannual to multi-decadal timescales.

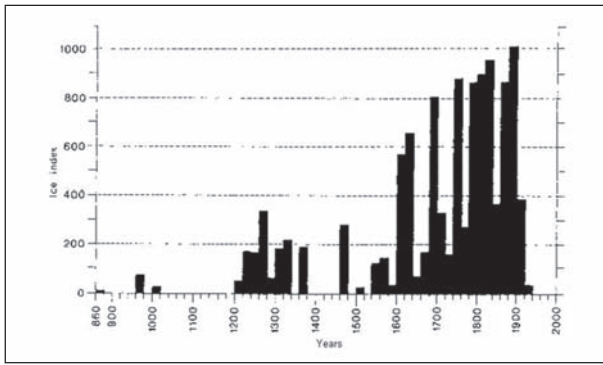
The IPCC's Third Assessment

The IPCC's Third Assessment Report (2001) makes the claim that, based on 'new and stronger evidence', the global warming of the second half of the twentieth century is attributable to human activities. The claim is based, essentially, on three factors:

- Recent warming is unusual in terms of the climate record.
- The climate system has limited internal variability (based on model studies) and so recent global temperature changes must be due to radiation forcing.
- Climate models, that include natural and anthropogenic forcing, reproduce the global temperature trends of the twentieth century and this gives confidence to their predictions for the future.

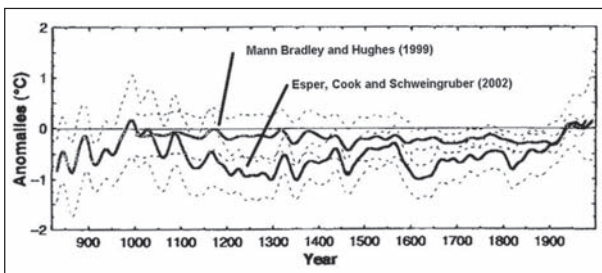
We will look at each of these factors in turn with a view to assessing the strength of the claim.

The paleo-temperature record for the northern hemisphere: IPCC denies the global extent of the Medieval Warm Period (MWP) (800-1300) and Little Ice Age (LIA) (1400-1850). Based on the paleo reconstructions (tree rings, corals, ice cores, etc) for the northern hemisphere temperature record made by Mann *et al.* (1999), IPCC claims that the MWP and LIA were regional phenomena that do not show up in hemisphere-averaged data.



Box 5: Icelandic Coastal Ice. Data on the incidence of coastal ice around Iceland is available from the ninth to the twentieth centuries. Koch's generalised ice severity index is based on the number of sections of coast (each of about 135 km) and the number of weeks when sea ice was noted on them. Not only does the index increase from the twelfth to the eighteenth century before decreasing rapidly but there is also significant shorter-period variability. The incidence of sea-ice can be related to Icelandic temperature, which has risen nearly 2°C since the nineteenth century. *Source: Grove (1988)*

The temperature of Iceland over the past millennium clearly demonstrates that the North Atlantic region, at least, endured significant temperature changes associated with the MWP and LIA (see Box 5). Iceland is sensitive to variations in the strengths of the warm North Atlantic Current and the cold East Greenland Current. A stronger North Atlantic Current will keep the shores ice-free in winter, while a stronger East Greenland Current will bring more



Box 6: Paleo-Temperature Trends. A comparison of the northern hemisphere temperature reconstructions from paleo-data by Mann *et al.* and Esper *et al.* as presented by Esper *et al.* (2002). The reconstruction of Esper *et al.* only uses tree ring data from the middle and high latitudes of the northern temperature and is able to reproduce the MWP and LIA, suggesting that these climatic episodes were not confined to the European region for those latitudes. The Mann *et al.* temperature trend is constructed from a variety of paleo-data obtained from all latitude zones and do not reproduce any long-term variability. *Source: Esper et al. (2002).*

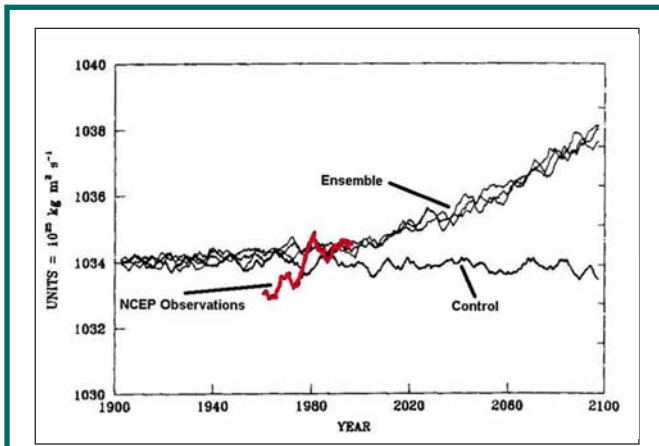
winter ice to the shores. Data on sea-ice incidence from Iceland over the past 1,000 years show the overall increase from 1200 to 1800 and the absence thereafter. It should also be noted that there are significant variations over shorter time periods. Sea-ice incidence can be related to Icelandic temperature and the temperature has risen nearly 2°C since the late nineteenth century (Bergthórsson, in Grove (1988)). The Icelandic sea-ice data provide quantitative evidence for the MWP and LIA whose effects are well documented in European literature.

A more recent paleo study, by Esper *et al.* (2002) using only tree ring data from 14 middle- and high-latitude sites of the northern hemisphere, reproduces the millennium-scale variability of which the MWP and LIA are part (see Box 6). The more recent reconstruction suggests that the MWP and LIA were characteristic of all middle and high latitudes of the northern hemisphere. A probable cause for the discrepancy between the two reconstructions is that the millennium scale changes in the tropics were small compared to the higher latitudes and inclusion of the tropical data smoothed the Mann *et al.* temperature record.

The strength of warming for the instrumental record covering the past century is not unusual in the context of the paleo-temperature record, given the relative sensitivity of thermometers.

Internal variability of the climate system: As part of the Atmospheric Model Intercomparison Project (AMIP), Hide *et al.* (1997) demonstrated that atmospheric models, driven by historical sea surface temperatures, have the ability to reproduce observed atmospheric angular momentum characteristics on seasonal and longer timescales. In contrast, Huang *et al.* (2001) demonstrated that fully coupled models have significantly less atmospheric angular momentum variability (internal variability) when compared to observations of the climate system. Huang *et al.* used the model of the Canadian Centre for Climate Modelling and Analysis, which was one of the better performing models of the AMIP intercomparison (see Box 7). Neither the control run nor the ensemble of 3 integrations forced by projected changes in greenhouse gas and aerosol concentrations could reproduce the variability of atmospheric angular momentum observed over 4 decades. This would suggest that the ocean component of the coupled model does not have the internal variability that is expected.

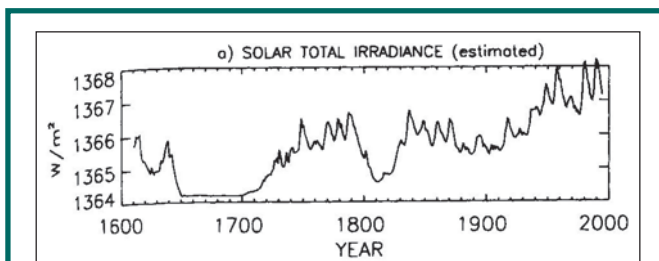
Simulating the recent global climate: Solar radiation variability and volcanic dust are the principal



Box 7: Variability of the Climate System. Atmospheric angular momentum (AAM) is used as a measure of the variability of the climate system. The AAM of a climate model is shown for the control run and each of an ensemble of three runs forced by changing greenhouse gases and aerosols. The same quantity from NCEP re-analyses (over the period 1958-98) is shown for comparison. Note that the models, until late in the integration, do not reproduce the magnitude of the trend of AAM in the observations. *Source:* Huang et al. (2001).

natural forcing components and greenhouse gas concentrations and aerosols are the human-induced forcing components. Values of solar irradiance reaching earth have been estimated for the period since 1600 (see Box 8). IPCC claims that it is ‘only with a combination of natural and anthropogenic forcing’ that the climate model will reproduce the observed global temperature trend of the twentieth century (see Box 9).

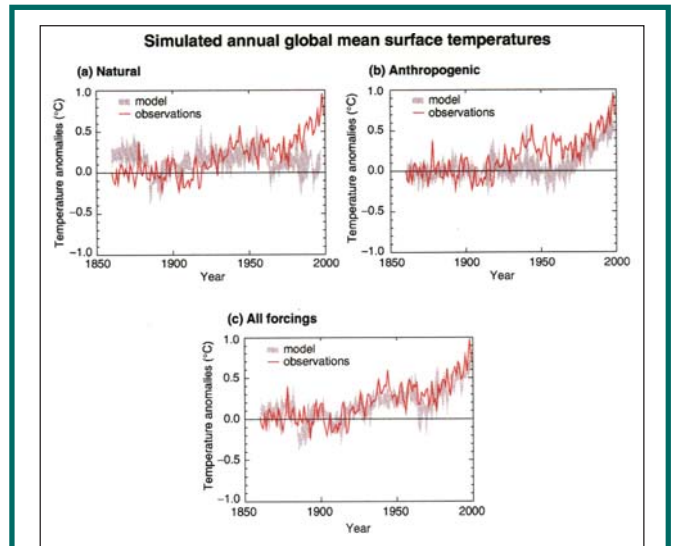
Although plausible, the natural and anthropogenic forcing of the climate model as cited by IPCC is not unique in reproducing the recent global temperature trends. An atmospheric model forced by historical sea-surface temperatures will also reproduce the global temperature trend (see Box 10). Indeed, this capability has been used to substantiate corrections made to early



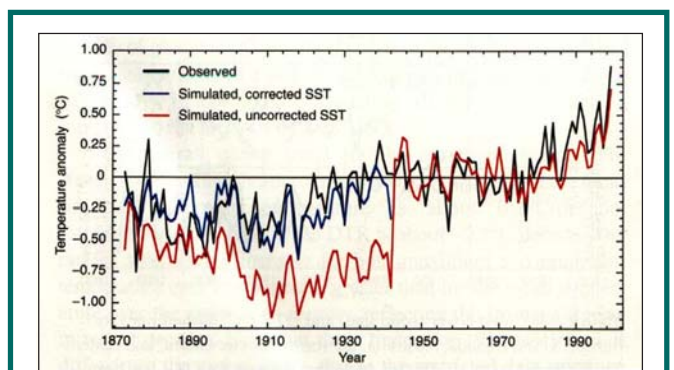
Box 8: Historical Solar Irradiance. Overall, since 1700 there has been an estimated increase of nearly 4 Wm^{-2} in the solar radiation reaching the earth. This is comparable in magnitude to estimated greenhouse gas radiative forcing from a doubling of CO_2 concentration, but over a longer interval. *Source:* Lean and Rind (1988)

observations of sea-surface temperature. When these corrections were made to the observations then an atmospheric model forced by the adjusted historical sea-surface temperature data also reproduces the global temperature trend of the twentieth century.

A more fundamental conclusion is that it is the changing sea-surface temperature characteristics, through energy processes of the climate system, that are regulating near surface global air temperatures.



Box 9: Simulated Near-Surface Temperature Trends. A comparison of global temperature trends obtained from model climate simulations using a) natural forcing (solar and volcanic), b) anthropogenic forcing (greenhouse gases and aerosols) and c) a combination of natural and anthropogenic forcing. The combination reproduces the trend better than either natural or anthropogenic alone. *Source:* IPCC (2001)

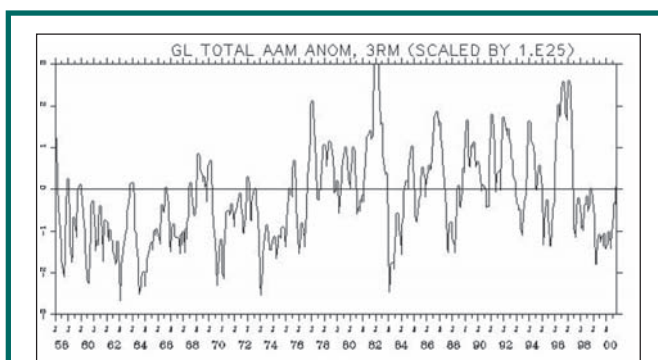


Box 10: Ocean Forcing of Global Temperature. Simulations of global near-surface air temperature (black line - observed) using an atmospheric general circulation model forced by uncorrected (red) and corrected (blue) historical sea surface temperature data. Accurate representation of sea surface temperature is crucial for modelling the climate system. *Source:* IPCC (2001)

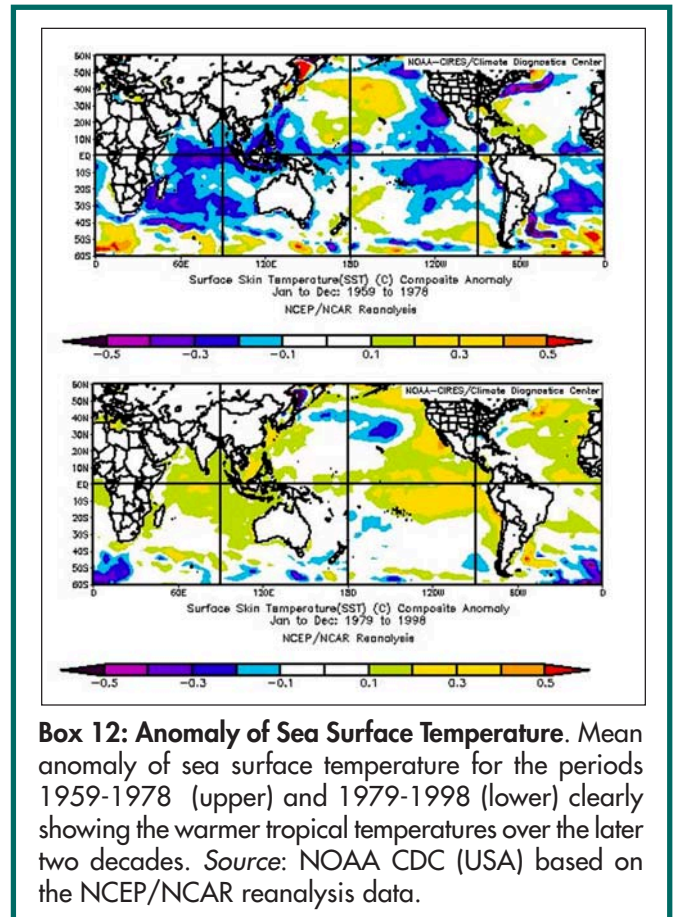
Recent Variations in the Climate System

The near-surface air temperature record is the most comprehensive climate data available and is accurate back to about 1860. In addition, there are very good data on other aspects of the climate system, including angular momentum and sea-surface temperature, for the past 45 years. These latter data have been collected and analysed in association with operational weather forecasting and have been reanalysed in a consistent manner for climate purposes. They give insights as to the true cause of recent global warming.

Global atmospheric angular momentum: The global total angular momentum of the atmosphere increased during the mid-1970s and remained generally at an elevated level until after the major El Niño event of 1997 (see Box 11). The increase was about $1 \times 10^{25} \text{ Kg m}^2 \text{ sec}^{-1}$, nearly a 10 per cent increase above normal values. We have previously noted that atmospheric angular momentum will increase when the circulation is forced either through enhanced atmospheric cooling (eg, over the winter hemisphere) or by warmer sea surface temperatures (eg, during an El Niño event). Enhanced cooling can be eliminated as the cause for the increase from the mid-1970s to the late 1990s because all the evidence points to warming of the atmosphere during this period. We therefore look for evidence of an increase in tropical sea surface temperatures as a source of additional boundary layer energy to force the atmospheric circulation.



Box 11: Atmospheric Angular Momentum Trend. The anomaly of global total atmospheric angular momentum (units $10^{25} \text{ kg m}^2 \text{ sec}^{-1}$) has been calculated over the period 1958-2000 based on reanalysis data. Atmospheric angular momentum was at enhanced levels over the period 1977-1998, particularly during the El Niño events of 1982 and 1997, but decreased during the La Niña event that developed during 1998. Source: NOAA CDC (USA) based on the NCEP/NCAR reanalysis data.

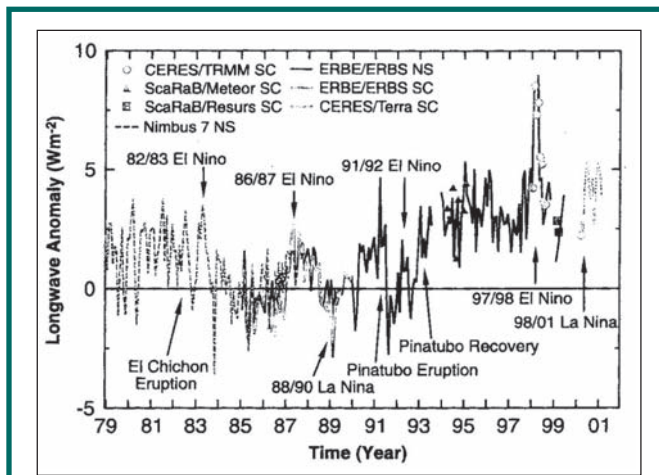


Box 12: Anomaly of Sea Surface Temperature. Mean anomaly of sea surface temperature for the periods 1959-1978 (upper) and 1979-1998 (lower) clearly showing the warmer tropical temperatures over the later two decades. Source: NOAA CDC (USA) based on the NCEP/NCAR reanalysis data.

Tropical sea surface temperatures: If we compare the anomaly of mean sea surface temperature for the period 1959-1978 with that for the period 1979-1998, the latter is clearly warmer than the former, particularly over tropical oceans (see Box 12). Over the later two decades, tropical sea-surface temperatures are about 0.4°C warmer than for the earlier two decades.

Care should be taken when interpreting the data over the Western Pacific warm pool. Here, sea surface temperatures are about 30°C and near the natural upper limit. The upper limit comes about because of the rapidly increasing rate of evaporation as temperatures rise toward 30°C (the saturation vapour pressure of water increases exponentially with temperature). Any additional convergence of heat at the ocean surface will be lost through latent heat of evaporation.

The higher sea-surface temperatures mean that the surface energy exchange to the atmosphere across the tropical Indian, Pacific and Atlantic Oceans is significantly more over the later two decades than the former. This additional energy exchange from the oceans provides the explanation for why the atmospheric circulation is stimulated and atmospheric angular momentum is anomalously high during the later period. The more active circulation also transports more heat to the poles.



Box 13: Top-of-the-Atmosphere Longwave Radiation. Various satellites have been used to measure longwave radiation to space. The satellite data have been calibrated and provide an estimate of tropical mean (20°N-20°S) anomalies of longwave radiation to space over the period 1979-2001. Various natural phenomena that have had short-term impacts on the record are identified. Overall, there is a trend of increasing longwave radiation to space. *Source:* Wielicki et al. (2002).

Longwave radiation to space: The IPCC hypothesis for global warming requires that longwave radiation to space is reduced as a result of the increased concentrations of atmospheric greenhouse gases. IPCC expects this radiative forcing to cause an accumulation of energy in the climate system and for the global temperature to rise. The IPCC hypothesis, however, does not accord with the observed trend of increasing tropical longwave radiation to space, as measured by satellites, over the past two decades (see Box 13).

Notwithstanding the problems of absolute accuracy of satellite observations, the evidence is for increased longwave radiation to space at the top of the atmosphere. These observations are in accordance with a warmer climate system. Whatever the reason for the warmer climate system, the increased radiation from the warmer temperatures dominates any tendency for a reduction that might arise from increased concentrations of greenhouse gases in the atmosphere.

Summary

A range of climate processes, including direct ocean storage of solar radiation, surface eddy exchange, buoyancy of convection and meridional transport, combine to regulate the flow of energy through the climate system. A range of negative feedbacks, including those related to meridional heat transport

by the atmosphere and oceans, work to adjust top-of-the-atmosphere longwave energy loss. However, over timescales of years to decades, or even centuries, there is no requirement for global energy balance at the top of the atmosphere, especially if solar irradiance at the top of the atmosphere is varying because of fluctuations of solar output or earth orbital variability. The concept of radiative forcing, including by increasing concentrations of greenhouse gases, was derived from a one-dimensional energy model and is an erroneous explanation for climate change. In particular, it does not take the thermal inertia of the climate system into account.

There are impediments to the IPCC claim that global warming over the second half of the twentieth century is due primarily to human activity, notwithstanding the results of model studies. The increase in atmospheric angular momentum over the period strongly suggests that there has been an increase in the atmospheric circulation and rate of meridional transport of heat. It is the increased rate of meridional transport of heat that has resulted in higher near surface air temperatures over middle and high latitudes. In addition, the limited observational data on longwave emission to space suggests that, at least over the tropics, this component has increased since the early 1980s.

Recent global warming can be directly linked to forcing by the tropical oceans. The increased downward emission of longwave radiation to the surface resulting from increasing greenhouse gas concentrations (the enhanced greenhouse effect) could not have caused the warming of the tropical oceans because the large thermal mass of the surface layer would not respond in such a relatively short timeframe. The magnitude of the response, however, is consistent with the estimated increase in solar irradiance operating over the past three hundred years. There has been a real climate change over the late nineteenth and twentieth centuries that can be attributed to natural phenomena.

Natural variability of the climate system has been underestimated by IPCC and has, to now, dominated human influences. The climate model studies that claim to reproduce the global temperature trend since 1860 need further assessment and development. Of particular concern are the internal feedback processes, including the specification of clouds and their radiative properties. It is these feedback processes that erroneously amplify the enhanced greenhouse effect, including predictions of future climate change.

The impacts of weather and climate extremes continue to be a barrier to sustainable development, particularly as they set back progress in developing countries. Therefore, there is a continuing and urgent need to predict the future direction of climate change and any likely change in intensity of local and regional

weather and climate extremes. Anticipating and adapting to these changes are fundamental to a sustainable future. Reducing emissions of CO₂, as proposed under the Kyoto Protocol, will not avert climate change.

References

- Esper, J., E.R. Cook and F.H. Schweingruber, 2002: 'Low-Frequency Signals in Long Tree-Ring Chronologies for Reconstructing Past Temperature Variability'. *SCIENCE* V 295, 2250-2253.
- Grove J.M., 1988: *The Little Ice Age*. Methuen, London
- Huang, H-P, K.M. Weickmann, and C.J. Hsu, (2001): 'Trend in Atmospheric Angular Momentum in a Transient Climate Change Simulation with Greenhouse Gas and Aerosol Forcing'. *J. of Climate* V 14, 1525-1534.
- Hide, R., J.O. Dickey, S.L. Marcus, R.D. Rosen and D.A. Salstein, 1997: 'Atmospheric Angular Momentum Fluctuations during 1979-1988 Simulated by Global Circulation Models', *J. Geog. Res.* V 102, No D14, 16, 423-16, 438.
- IPCC, 1990: *Climate Change – The IPCC Scientific Assessment*. Houghton J.T., G.J. Jenkins and J.J. Ephraums (Eds.). Cambridge University Press.
- IPCC, 1995: *Climate Change 1995 – The Science of Climate Change*. Houghton, J.T., L.G. Meira Filho, B.A. Callander, N. Harris, A. Kattenberg, and K. Maskell (Eds.). Cambridge University Press.
- IPCC, 2001: *Climate Change 2001 – The Scientific Basis*. Houghton, J.T., Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, X. Dai, K. Maskell and C.A. Johnson (Eds.). Cambridge University Press.
- Lean, J., and D. Rind, 1998: 'Climate Forcing by Changing Climate Radiation'. *J. of Climate* V 11, 3069-3094.
- List, R.J., 1966: *Smithsonian Meteorological Tables* (6th Rev. Edition). Smithsonian Institution, Washington
- Mann, M.E., R.S. Bradley and M.K. Hughes, '1999: Northern Hemisphere Temperatures During the Past Millennium: Inferences, Uncertainties and Limitations'. *Geophys. Res. Lett.* V 26, 759-762.
- Riehl, H. and J.S. Malkus, 1958: 'On the Heat Balance of the Equatorial Trough Zone'. *Geophysica* V 6, Nos. 3-4, 503-538.
- Trenberth, K.E. and J.M. Caron, '2001: Estimates of Meridional Ocean and Atmosphere Heat Transports'. *J. of Climate* V 14, 3433-3443.
- Trenberth, K.E. and A. Solomon, '1994: The Global Heat Balance: Heat Transports in the Atmosphere and the Ocean'. *Climate Dynamics* V 10, 107-134.
- Wielicki, B.A., T. Wong, R.P. Allan, A. Slingo, J.T. Kiehl, B.J. Soden, C.T. Gordon, A.J. Miller, S-K Yang, D.A. Randall, F. Robertson, J. Susskind, H. Jacobowitz, '2002: Evidence of Large Decadal Variability in the Tropical Mean Radiative Energy Budget'. *SCIENCE* V 295, 841-844.

About the Author

William Kininmonth headed the Australian National Climate Centre from 1986 to 1998 and now operates a meteorological consultancy. During 1998 and 1999 he coordinated a global review of the 1997-1998 El Niño event and its impacts for the World Meteorological Organization (WMO). He was principal Australian delegate to the WMO Commission for Climatology (1982-1998) and served for eight years on its advisory board. He was also an Australian delegate to the Second World Climate Conference (1990) and the intergovernmental negotiating committee for the UNFCCC (1991-1992).