Climate Surprises: Submission to Garnaut Review

The purpose of this submission is to draw attention to the potential for changes in climate to be much more rapid and extreme than is currently widely accepted. There are numerous positive feedback loops whose interactions cannot be modelled because of the complexity of doing so and because there is insufficient data to perform these calculations if such modelling were possible.

Optimism

The predictions of CSIRO [1] appear to be extremely optimistic in the light of what is known about emissions, the long-term climate record and our ability to predict climate change. “By 2030 we expect temperatures will rise by about 1°C over Australia compared with the climate of recent decades,” says one of the report’s authors, Dr Penny Whetton. This is notwithstanding the fact that the planet has warmed at ten times this rate in the past (in the absence of human interference).

The authors were relying on the IPCC third assessment report which has some drawbacks, dealt with below. There is also reference to temperature rises under low and high emission scenarios. However, the data indicate that there is very little likelihood of anything but the high-end IPCC emission scenarios becoming reality, or underestimating reality.

Furthermore, there is a current lull in some of the natural climate forcing, as noted by Hansen (2008). “The Southern Oscillation and the solar cycle have significant effects on year-to-year global temperature change. Because both of these natural effects were in their cool phases in 2007, the unusual warmth of 2007 is all the more notable. It is apparent that there is no letup in the steep global warming trend of the past 30 years.

"Global warming stopped in 1998," has become a recent mantra of those who wish to deny the reality of human-caused global warming. The continued rapid increase of the five-year running mean temperature exposes this assertion as nonsense. In reality, global temperature jumped two standard deviations above the trend line in 1998 because the "El Niño of the century" coincided with the calendar year, but there has been no lessening of the underlying warming trend.

Solar irradiance will still be on or near its flat-bottomed minimum in 2008. Temperature tendency associated with the solar cycle, because of the Earth's thermal inertia, has its minimum delayed by almost a quarter cycle, i.e., about two years. Thus solar change should not contribute significantly to temperature change in 2008.” [2]

Nevertheless, while 2008 is set to be cooler globally than recent years, but is still forecast to be one of the top-ten warmest years.[3] So accelerated warming can be expected when El

Niño returns and when the solar cycle reaches its next maximum, particularly if these coincide.

The central argument of this submission is that a deeper examination of the available research is required to avoid complacency in the planning of emission reduction and adaptation. The matter would seem to be more urgent than is generally accepted by policymakers.

Emissions are growing

Matthews and Caldeira (2008) [4] found that "to hold climate constant at a given global temperature requires near-zero future carbon emissions. Their results suggest that future anthropogenic emissions would need to be eliminated in order to stabilize global-mean temperatures. As a consequence, any future anthropogenic emissions will commit the climate system to warming that is essentially irreversible on centennial timescales."

However, the opposite is the case. A recent paper published by CSIRO researchers shows that not only have emissions grown in recent years, but that the planets ability to absorb CO_2 is decreasing. When the 1990s are compared to 2000-2006 emissions have grown from 1.3% to 3.3% per annum. This is due to the rapid growth in the world economy combined with an increase in its carbon intensity (the carbon produced for each dollar of wealth). Moreover the airborne fraction (AF) of CO_2 emissions has been increasing for 50 years. This indicates that there has been a decline in the efficiency of CO_2 sinks on land and oceans in absorbing anthropogenic emissions. [5]

Lead author, Dr Canadell says the results have major implications for the current and future growth of atmospheric CO_2. "What we are seeing is a decrease in the planet's ability to absorb carbon emissions due to human activity." [6]

Models underestimate change

Pointing out the implications for modelling climate, Dr Canadell stated, "The majority of current emission scenarios for modelling climate through the 21st century assume sustained decreases in the carbon intensity of the global economy, which have not occurred since 2000." [6]

Dr Mike Raupach, a co-chair of the Global Carbon Project, and co-author of the above mentioned paper, says "The carbon cycle is generating stronger-than-expected and sooner-than-expected climate 'forcing' - that is, mechanisms that 'force' the climate to change. In turn, climate change itself is feeding back to affect the carbon cycle, decreasing land and ocean sinks."[6]

Recent observed climate trends for carbon dioxide concentration, global mean air temperature, and global sea level, have been compared to model projections in the 2001

IPCC assessment report. In the period since 1990 the data indicate that the climate system, in particular sea level, may be responding more quickly to climate change than the current generation of models indicates. [7]

Stroeve et al (2007) concluded that "…current models struggle to encompass the suite of causes and feedbacks in the GHG-induced decline." They found that models greatly underestimated Arctic ice melting. In the period 1953-2006, the observed September trend is -7.8 + 0.6 %/decade, compared to the multi-model mean trend of -2.5 + 0.2%/decade. For 1979-2006, the numbers are -9.1 +1.5 % (observed) and -4.3 + 0.3% (modeled). Even larger differences are found for the last 10 years. [8]

The Antarctic situation is similar. "We knew what was left would collapse eventually, but the speed of it is staggering," said Dr David Vaughan, a British Antarctic Survey glaciologist. "[It is hard] to believe that 500 billion tonnes of ice sheet has disintegrated in less than a month." [9] This was a response to the 2002 collapse of the Larsen B ice shelf. The prior collapse of the Larsen A and the current disintegration of the Wilkins shelf also provoked surprise amongst researchers.

Change can be rapid

Multiple research groups, for instance Dansgaard,W. et al (1989) have established an accurate record of the last glacial period, the Younger Dryas, which ended abruptly 10,700 years ago.

Briefly, the data indicate that cooling into the Younger Dryas occurred in a few prominent decade(s)-long steps, whereas warming at the end of it occurred primarily in one especially large step of about 8°C in about 10 years. [10]

In a review of the literature, Alley et al (2003) concluded that, "Large, abrupt, and widespread climate changes with major impacts have occurred repeatedly in the past, when the Earth system was forced across thresholds. Although abrupt climate changes can occur for many reasons, it is conceivable that human forcing of climate change is increasing the probability of large, abrupt events." [11] They recommended that policymakers seriously consider the possibility of rapid transformations (and the consequent serious economic and ecological impacts) when assessing the magnitude of action to tackle climate change.

Non-linear Behaviour/Surprises

The term "tipping point" has been widely adopted to describe a threshold, which when exceeded, throws the climate into a completely different state of equilibrium. Lenton et al (2008) [12] introduce the term "tipping element" to describe large-scale components of the Earth system that may pass a tipping point. They evaluated potential policy-relevant tipping elements in the climate system under anthropogenic forcing and compiled a short list, ranking their sensitivity of these elements to global warming and the uncertainty about the underlying physical mechanisms. Figure 1 illustrates what were determined to be major tipping elements. Refer to Table 1 of the article [12] for specific data regarding timescales, sensitivites, etc.

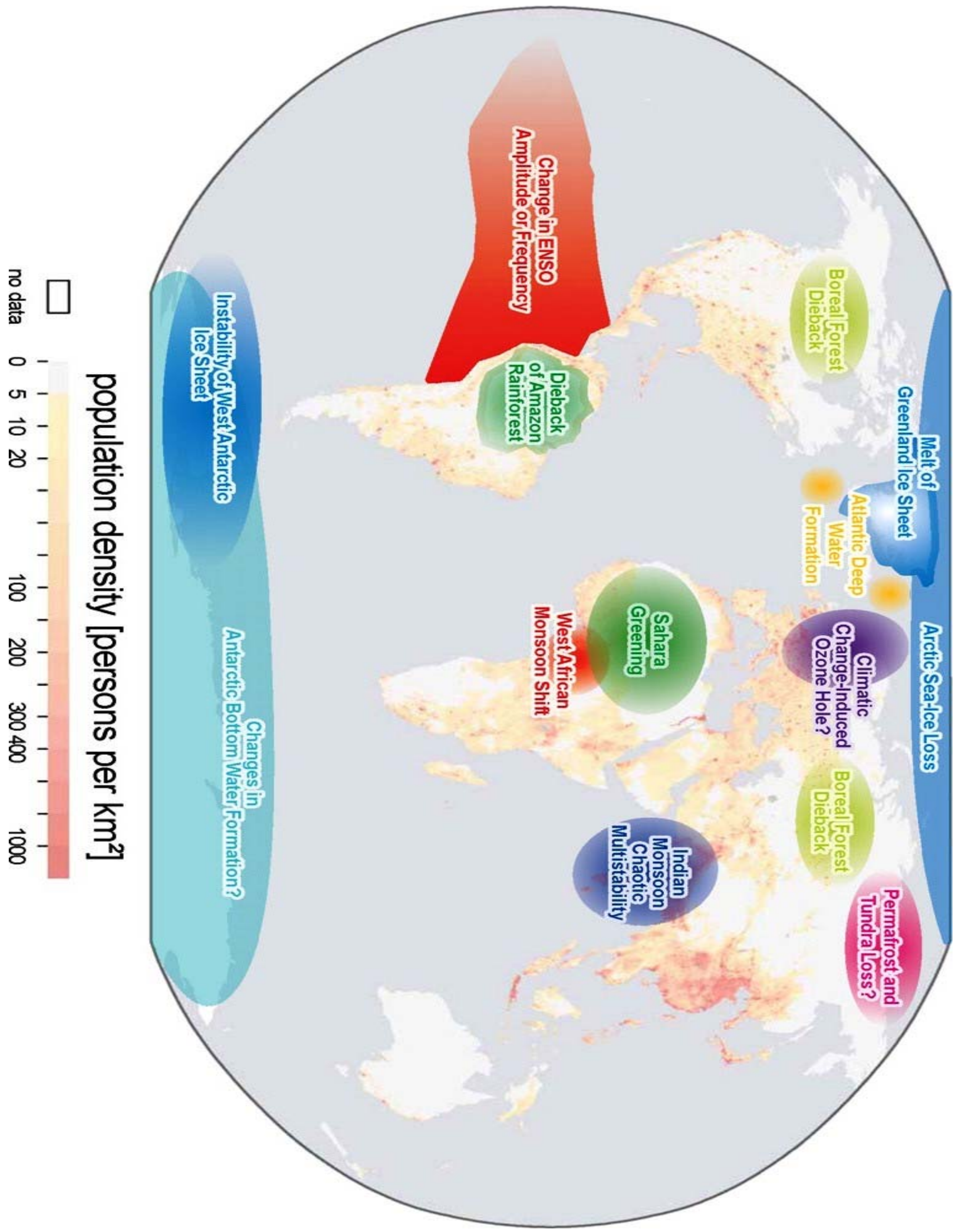

Fig. 1: Map of potential policy-relevant tipping elements in the climate system, and overlain on global population density. Subsystems indicated could exhibit threshold-type behavior in response to anthropogenic climate forcing, where a small perturbation at a critical point qualitatively alters the future fate of the system. They could be triggered this century and would undergo a qualitative change within this millennium. We exclude from the map systems in which any threshold appears inaccessible this century (e.g., East Antarctic Ice Sheet) or the qualitative change would appear beyond this millennium (e.g., marine methane hydrates). Question marks indicate systems whose status as tipping elements is particularly uncertain. (Lenton et al) [12]

The high probability of surprises (i.e. completely unforeseen changes in the climatic system) has been investigated by many research groups, particularly over the last decade. The reality of this feature of our climate system has, however, not been appreciated by the wider community of natural and social scientists and policy-makers. In the absence of any strategy setting research priorities, and the apparent reluctance of policy-makers to seriously consider the implications of abrupt climate change, the US Global Change Research Program asked the National Research Council to establish the Committee on Abrupt Climate Change. The aim of the group was to describe the current state of knowledge in the field and recommend ways to fill in the knowledge gaps. [13]

IPCC has suggested the range for climate sensitivity is a 1.5 to 4.5° C rise for a doubling of CO_2. This is serious enough, given that we are currently trending towards a high emission future. However several researchers (e.g. Forest et al, 2001) have found that, depending on the way that climate has been forced by human activities, the sensitivity could be up to 10°C. While this has a low probability, (see Figure 2) calculated on what is known, we are in uncharted territory. There is no method available to predict how a chaotic and extremely complex system will react.

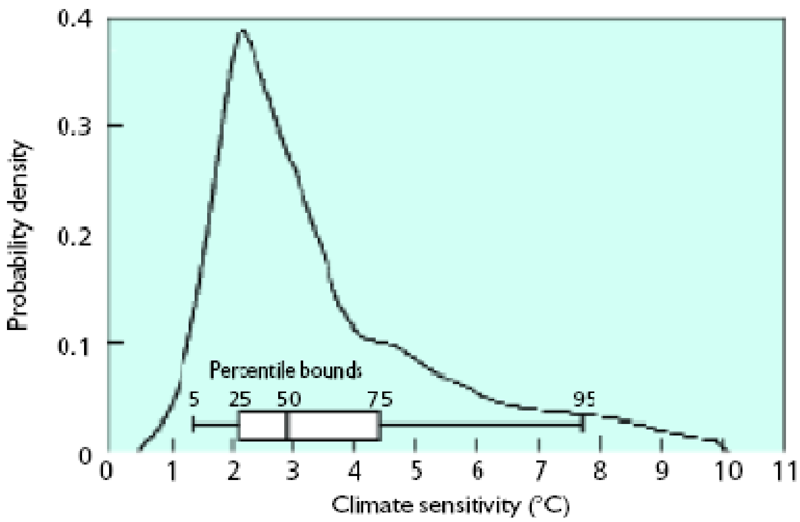

Fig. 2: The likelihood of a change in equilibrium global mean surface temperature caused by a doubling of atmospheric carbon dioxide shows a mean of 3.5 °C and a median of 2.9 °C. (Forest et al) [14]

In an OECD background paper for policy-makers, Schneider (2003) deals with attributes of complex systems. One of these is *emergent properties*, which are not initially discernable in the system, but arise unpredictably from the complexity. He noted, "…real-world coupling between sub-systems can cause the set of interacting systems to exhibit new collective behaviours - called "emergent properties" - that are not clearly demonstrable by models that do not also include such coupling. Furthermore, responses of the coupled systems to external forcing can become quite complicated. For example, one emergent property increasingly evident in climate and biological systems, is that of irreversibility or hysteresis -

changes that persist in the new post-disturbance state even when the original forcing is restored." [15]

He concluded that, "…the reliability of time-evolving, regional climatic projections is difficult to assess, as the added complexity taxes our capacity to validate the new results. Therefore, considerable uncertainty will remain in all climate model projections for some time to come." [15]

In addition to tipping points, and the uncertainty surrounding the climate's reaction to forcing, the Committee on Abrupt Climate Change points out that, "Regime transitions can occur spontaneously in a chaotic system. In this case, external triggers for transitions are not required, so a series of regime changes could continue indefinitely or until slow changes in external forcing or system dynamics removed the chaotic behaviour."[13]. The Committee also referred to the rapid warming coincident with the end of the last ice age, and further noted that, "Similar events, including local warmings as large as 16°C, occurred repeatedly during the slide into and climb out of the last ice age. Human civilizations arose after those extreme, global ice-age climate jumps. Severe droughts and other regional climate events during the current warm period have shown similar tendencies of abrupt onset and great persistence, often with adverse effects on societies… The abrupt changes of the past are not fully explained yet, and climate models typically underestimate the size, speed, and extent of those changes. Hence, future abrupt changes cannot be predicted with confidence, and climate surprises are to be expected." [13]

Feedback Loops

Within the climate system there is a number of sub-systems. Each one of these exerts influence on other sub-systems through various mechanisms. This eventually produces feedback which either reduces climate forcing or enhances it. The majority of these appear to be in the latter group, i.e. are positive feedbacks. Some of these are dealt with below.

Oceans

Circulation

Differences in density (due to temperature and salinity) of seawater drive the global thermohaline circulation, otherwise known as the ocean conveyor belt or meridional overturning circulation (MOC). It links surface and deep water of all the oceans. All other currents are in some way linked to it, and all ocean ecosystems are adapted to it. One of the outcomes of MOC is the transfer of heat from the Tropics to higher latitudes in the North Atlantic. Computer simulations predicted that global warming would weaken this current (which moderates European climate). Observations by Quadfasel (2005) have detected that effect. [16]

Bryden’s team (2005) also found a reduction (30%) in the warm currents that carry water north from the Gulf Stream [17]. It is not clear whether or not this is a natural perturbation, since it is only since 2006 that the Atlantic circulation has been properly monitored [18]. If it is a real trend and a product of global warming, then it is one of the first signs of a catastrophic collapse of the MOC.

A key element of the MOC is overflow and descent of cold, dense water from the sills of the Denmark Strait and the Faroe–Shetland channel into the North Atlantic Ocean (Figure 3). Dickson et al (2002) “…described a widespread, sustained, rapid and surprisingly uniform freshening of the deep and abyssal North Atlantic, south of the Greenland–Scotland Ridge, over the past four decades.” [19] The reduced salinity, due to melting Arctic ice, implies reduced density and consequent slow down of this element of the MOC, which main source for the deep water of the North Atlantic Ocean. Hansen et al (2001) measured this phenomenon. They found “…a decrease [in the Faroe–Shetland channel] by at least 20 per cent relative to 1950.” They further note, “If this reduction in deep flow from the Nordic seas is not compensated by increased flow from other sources, it implies a weakened global thermohaline circulation and reduced in flow of Atlantic water to the Nordic seas.[20] No such compensatory flow has been found.

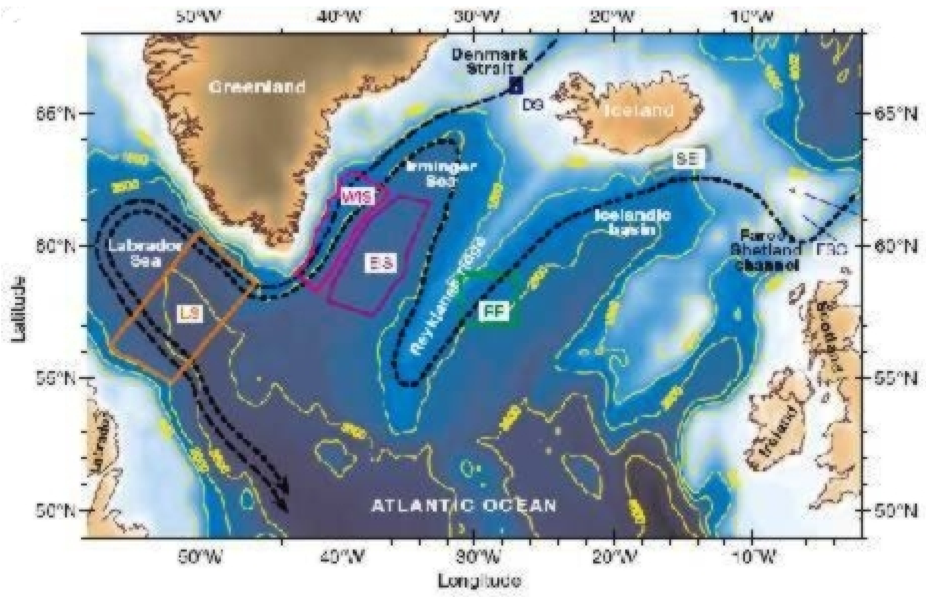

Fig 3: The two main overflows across the Greenland–Scotland ridge, the Denmark Strait and the Faroe–Shetland channel (black dashed lines).[19]

The have been dramatic changes in ocean currents closer to home. Hill et al (2005) have been studying the East Australian Current. They found that here has been a strengthening of the current over the last 60 years. It has warmed waters off Tasmania by 2°C in that time. Salinity has also increased. This has changed the species composition in those waters. Sea urchins native to the NSW coast are causing the loss of kelp forest (important habitat for rock lobster & abalone). 34 species of fish have either extended their range in Tasmania or become newly established south of Bass Strait. Tropical phytoplankton blooms are also occurring. [21]

Acidification, Ecosystems & Productivity

Some results with at least an optimistic aspect have been produced by Tortell et al (2008). They showed that elevated CO_2 led to a measurable increase in Antarctic phytoplankton productivity, promoting the growth of larger chain-forming diatoms. "Our results suggest that CO_2 concentrations can influence biological carbon cycling in the Southern Ocean, thereby creating potential climate feedbacks." [22] However it should be observed that the effect was selective for some species, so unknown modifications to the Antarctic ecosystem are taking place.

An examination of current research results indicates that this specific positive effect will be overwhelmed by deleterious effects of increased CO_2. For instance, a massive team encompassing researchers from 18 institutions (Orr et al, 2005) has examined the effect of CO_2-induced ocean acidity on marine organisms. Many ocean animals depend on the presence of a form of carbonate (aragonite) in the water to build shells or exoskeletons. As CO_2 increases the acidity of the oceans, aragonite becomes more soluble and harder to extract. Affected animals include pteropods (a large group of molluscs), corals and some plankton. Orr's team used models to predict acidity trends. They also conducted onboard experiments showing pteropod shells beginning to dissolve after only 48 hours in water undersaturated with aragonite. They predict that, "…Southern Ocean surface waters will begin to become undersaturated… by the year 2050. By 2100, this undersaturation could extend throughout the entire Southern Ocean and into the subarctic Pacific Ocean… Our findings indicate that conditions detrimental to high-latitude ecosystems could develop <u>within decades, not centuries</u> as suggested previously. [23] (My emphasis)

Pteropods also contribute to the diet of diverse carnivorous zooplankton, baleen whales and fish including salmon, mackerel, herring and cod. They also occur in such large numbers that they are considered key species of polar ecosystems. In the Ross Sea, for example, the prominent subpolar-polar pteropod *Limacina helicina (L. helicina)* sometimes replaces krill as the dominant zooplankton, and is considered an overall indicator of ecosystem health. [23]

L. helicina also plays a major role in the findings of Seibel and Dierssen (2003). They found a significant reduction in phytoplankton biomass in the Ross Sea in the summer of 2000–2001, a possible consequence of a disruption in sea-ice retreat due to the presence of an immense iceberg, B15. *L. helicina* populations were greatly reduced. The following season, for the first time on record, *L. helicina* was absent from McMurdo Sound. As noted above, many important predators, including whales and fishes, rely heavily on L. helicina for food. However, most obviously impacted by its absence was *Clione antarctica*, an abundant pteropod that feeds exclusively on *L. helicina*. In the summer of 2002–2003, sea-ice extent was much higher and phytoplankton stocks were dramatically lower than any reported previously [24].

Polovina et al (2008) have more alarming news. Using remote sensing data over 9 years, they have found that in the North and South Pacific, North and South Atlantic, outside the equatorial zone, the areas low surface chlorophyll waters have expanded at average annual rates from 0.8 to 4.3%/yr. *Low surface chlorophyll* means no phytoplankton, thus no herbivores, no carnivores, some would say a dead sea.

"It is estimated that the [non-productive] areas in these oceans combined have expanded by 6.6 million km^2 or by about 15.0% from 1998 through 2006… The expansion of the low chlorophyll waters is consistent with global warming scenarios based on increased vertical stratification in the mid-latitudes, but the rates of expansion we observe already greatly exceed recent model predictions." [25]. Note again, the juxtaposition of reality and model predictions. This is over and above the findings of increased productivity by Tortell et al (2008) already mentioned.

Since we do not understand any of the planet's ecosystems, the effect of changes in any of them, even of apparently insignificant organisms should not be assumed trivial. For instance, the reduction in phytoplankton will reduce krill populations. These humble crustaceans are not only a key food for most Antarctic carnivores (penguins, seals, whales, etc.), they have been found by Tarling and Johnson (2006) to be a key species in the carbon cycle. "We estimate that krill in the Southern Ocean sequester 2.3×10^{13} grams carbon each year through releasing faeces below the mixed layer, adding 8% to previous estimates of global active flux." [26]

Meanwhile Hoegh-Guldberg et al (2007) warns that CO_2 concentrations of over 500 parts per million and global temperatures rising by more than 2°C by 2050 to 2100, will destroy coral reefs. "These are values that significantly exceed those of at least the past 420,000 years during which most extant marine organisms evolved." [27]

The above effects produce feedbacks which reduce the oceans' capacity to remove carbon from the atmosphere, and also their ability to regulate the planet's heat balance.

Ozone Depletion

Hartmann et al (2000) have identified mechanisms by which ozone depletion and tropospheric warming synergistically reinforce each other. [28] There are also several well known connections between these two climatic processes. Several major greenhouse gases for instance contribute to ozone depletion.

In addition, Kodera, K.et al (2008) identified a positive feedback between the stratosphere and the troposphere. "This suggests that the stratospheric cooling effect due to increased CO_2 manifests in the troposphere through nonlinear interaction with solar cycle." [29]

Kovalenok, S. et al (2008) showed that increased UV resulting ozone depletion from damaged krill populations. [30]

Melting Ice

Any melting of ice produces two feedbacks: (1) it reduces the planet's ability to reflect heat and light (it's albedo); and (2) terrestrial ice melts will raise sea levels, which amongst other things will increase melting of ice in contact with the ocean. In addition, melting of permafrost raises the possibility of massive methane release in Arctic and sub-Arctic regions. This is a much more powerful greenhouse gas than CO_2.

Polar Ice

The recent breakout of the Wilkins ice shelf is yet another indication that global warming is taking place, and happening more rapidly than expected. The breakout is the latest drama in a region of Antarctica that has experienced unprecedented warming over the last 50 years. Several ice shelves have retreated in the past 30 years - six of them collapsing completely (Prince Gustav Channel, Larsen Inlet, Larsen A, Larsen B, Wordie, Muller and the Jones Ice Shelf.) David Vaughan of the British Antarctic Survey "Wilkins is the largest ice shelf on the Antarctic Peninsula yet to be threatened. I didn't expect to see things happen this quickly…" [31]

Measurements by Rignot et al (2008) found massive losses. "In West Antarctica, widespread losses along the Bellingshausen and Amundsen seas increased the ice sheet loss by 59% in 10 years to reach 132±60 Gt yr-1 in 2006. In the Peninsula, losses increased by 140% to reach 60±46 Gt yr-1 in 2006." [29] In other words, West Antarctica and the Antarctic Peninsula lost nearly 200 billion tonnes of ice in 2006 alone. That is 75 per cent more than losses in 1996. According to Dr Rignot, the results showed that the IPCC had underestimated the impact of polar melting in its predictions of possible sea level rises next century. "Each time I look at some new data, I am astonished," he said. [32]

Hobart glaciologist Ian Allison (Australian Antarctic Division and the Antarctic Climate and Ecosystems Co-operative Research Centre) agrees, "This work suggests that the ice flow is accelerating," Dr Allison said. "It's worrying because ... the changes are happening due to processes we don't understand." [33]

The Arctic situation is similarly concerning. The inability of the models to predict the melting rate has been noted above [8]. Arctic sea ice during the 2007 melt season plummeted to the lowest levels since satellite measurements began in 1979. This is obvious in Figure 4.

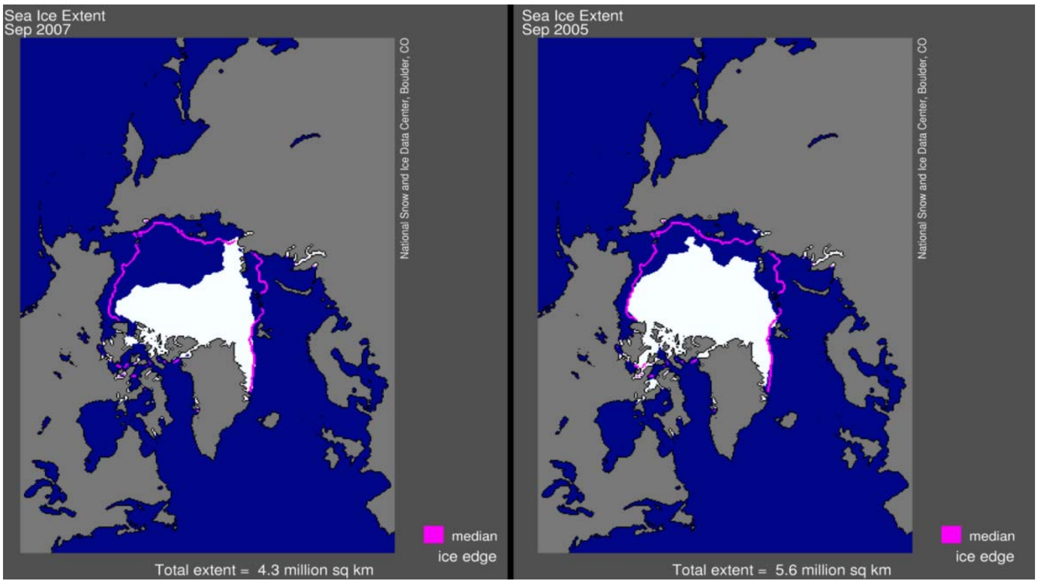

Fig 4: Arctic Sea Ice. 2007 compared with 2005 and the long term median (1979-2000).[34]

Glaciers

Climate sceptics like to argue that because some glaciers are growing, there is no warming signal to be derived from glacier study.

There is much research continuing into specific glaciers, like Nesje et al (2008). Their "…long-term weather 'forecast' for western Norway indicates a rise in the summer temperature of 2.3 C and an increase in the winter precipitation of 16% by the end of the 21st century. This climate scenario may, if it occurs, cause the equilibrium-line altitude (ELA) to rise 260 ± 50 m. As a result, about 98% of the Norwegian glaciers are likely to disappear." [35]

There is also Oerlemans' (1997) work on the Nigardsbreen glacier in Norway. He found a long-term trend of retreat. [36]

The conclusive data, however, comes from the World Glacier Monitoring Service (Haeberli et al ,2007). Results from 30 glaciers and 9 mountain ranges show a consistent downward trend (Figure 5). They add that "Preliminary figures for 2006 continue the trend in accelerated ice loss during the past two and a half decades." [37]

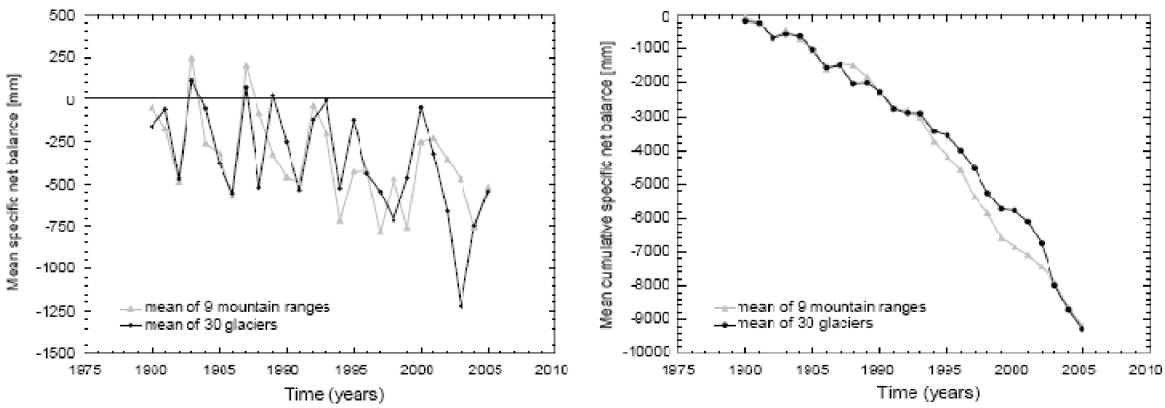

Fig. 5: Mean specific net balance (left) and mean cumulative specific net balance (right) of 30 (29 in 2005) glaciers and 9 mountain ranges since 1980. [37]

Permafrost

The work of Beloloutskaia and Anisimov (2003) gives an indication of how models are evolving. They compared actual permafrost loss with modelled predictions. They concluded, "Divergences between the permafrost observations and modeling may be explained by the effect of changing vegetation that is not taken into account in the models. Immediate response of vegetation to warmer conditions, particularly in the northernmost locations may be associated with the enhanced growth of non-vascular plants mitigating the effect of climatic change on permafrost. In the longer term climate-induced replacement of lichens and mosses with shrubs may lead to enhanced warming of permafrost. Transition from non-vascular plant dominated biomes to biomes dominated by shrubs, grasses, and trees may cause abrupt degradation of discontinuous and sporadic permafrost. Vegetation scenarios are needed for the realistic assessment of the effects of changing climate on permafrost." [38]

Results from an improved model (Anisimov and Reneva, 2006) indicate that by the mid-21st century ", …near-surface permafrost in the Northern Hemisphere may shrink by 15%–30%, leading to complete thawing of the frozen ground in the upper few meters, while elsewhere the depth of seasonal thawing may increase on average by 15%–25%, and by 50% or more in the northernmost locations. Such changes may shift the balance between the uptake and release of carbon in tundra and facilitate emission of greenhouse gases from the carbon-rich Arctic wetlands." [39]

Zimov et al (2006) concurs, "Climate warming will thaw permafrost, releasing trapped carbon from this high-latitude reservoir and further exacerbating global warming." [40]

Another large potential feedback is the melting of thermokarst lakes in the Tundra. Walter et al (2007) have established that "…CH_4 bubbling from newly forming thermokarst lakes comprised 33 to 87% of the high-latitude increase in atmospheric methane concentration and, in turn, contributed to the climate warming at the Pleistocene-Holocene transition [41]. This event marks the last major sea level rise.

Deforestation

The terrestrial biosphere and the atmosphere are two interacting subsystems of the Earth. This interaction is accomplished through the strong influence of the biosphere on land surface exchange processes on the one hand, and through the dominant control of climate on the phenology and physiological processes of the biosphere on the other hand. Specifically, vegetation influences the physical appearance and functioning of the land surface in terms of its radiative properties, its hydrological function, and its turbulent characteristics. Vegetation also affects the chemical composition of the atmosphere through its important role for the exchange of atmospheric trace gases such as carbon dioxide, methane and NOx.

Most of the research concerning the forested part of the biosphere has yielded concerning results (major disruption and/or positive feedback). Melillo et al (2002) though found that the long-term response to soil warming in a mid-latitude hardwood forest produced a negative feedback. They reported that, "…warming increases the availability of mineral nitrogen to plants. Because plant growth in many mid-latitude forests is nitrogen-limited, warming has the potential to indirectly stimulate enough carbon storage in plants to at least compensate for the carbon losses from soils." [42]. On the other hand, Reich et al (2006) found contrasting results in a long-term field study of perennial grassland. [43]

Thomson and Parker (2008) looked at Jack Pine forests of North America. Their trials showed that, "Future temperature increases are expected to cause a northward shift of the optimal habitat by approximately 2°. Northern sources are growing at temperatures below optimum and would benefit from warmer environments provided other environmental factors do not become limiting. Central sources are growing at close to optimum and will be negatively affected by increased temperatures in the future. Southern sources performed better in cooler environments, and warmer temperatures may cause significant height growth loss and the potential extirpation of these populations." [44]

In British Columbia, Carroll et al (2006) investigated the range expansion that climate change has provided for the Mountain Pine Beetle. They concluded, "This eco-system altering epidemic is causing widespread mortality of the lodgepole pine forests, the province's most abundant commercial tree species. At the current rate of spread, 50 per cent of the mature pine will be dead by 2008 and 80 per cent by 2013." [45]

Wildfire is even faster at knocking out forests as carbon sinks. "It took just one Siberian heatwave to temporarily wipe out most of the gains made by the Kyoto Protocol on climate change. In the summer of 2003, wildfires raced across the region, incinerating an area of some 22 million hectares." [46] Australians and North Americans are of course just as aware of this as Siberians.

When natural disturbances, such as wildfire and insect outbreaks, are taken into account Kurz et al (2008) calculated that Canadian forests become carbon sources rather than sinks, and that, "The effects of these are likely to be exacerbated by climate change." [47]

Increased intensity of cyclones in a warmer world is well established. For instance Emanuel 2005) [48]. This will entail more widespread and severe deforestation in tropical regions including those of Australia.

So climate change is expected to involve considerable unplanned deforestation. This is compounded by the increasing difficulty of reforestation. In the Amazon, Kleidon and Heimann (1999) found that the localised climatic consequences of deforestation made reforestation very difficult. “Most of the climatic effects occur during the dry season and are attributed to the reduction of rooting depth. Dry periods are found to last longer, being more intense with drier and warmer air, while the wet season remains fairly unchanged. The implications are that these climatic effects are antagonistic towards the re-establishment of the natural evergreen forest once it has been cleared.” [49]

Agriculture

Deforestation for agriculture has been a long-term human activity. Clearly it replaces a carbon sink with a source, particularly since fossil fuels have been part of the equation. DeFries and Bounoua (2004) investigated the implications of past and future land use change for two ecosystem services provided by terrestrial vegetation: net primary production (NPP), which is the basis of the food chain, and modulation of climate through exchanges of energy, water, and momentum between the land surface and atmosphere. They determined that, “ In the past, the effects of land use change on NPP and surface climate are not substantially outside the range of decadal-scale interannual variability. Future land use change alters these ecosystem services outside this range. The consequences of land use change in the coming decades are likely to be fundamentally different than in the past.” [50]

Most agriculture today is very carbon intensive. Clearly as climate change renders conditions more difficult, even more effort (involving increased emissions) will be needed for each unit of food production.

Clouds

Soden and Held (2006) modelled the behaviour of water vapour in the climate system. They found, “Water vapour is the largest feedback in the 14 model simulations. (As temperature rises, evaporation increases and more water vapour accumulates in the atmosphere. As a greenhouse gas, the water absorbs more heat, further warming the air and causing more evaporation.)” [51]

Some of this water vapour becomes cloud. It is generally presumed that high cloud produces positive feedback and low cloud produced negative feedback. But the climatic effect of clouds is still far from certain. Chen et al (2000) showed that different cloud types reflected different radiation (essentially heat or light) and had different effects on the planet’s radiation flux. [52]

Andrews and Forster (2008) summed all known direct and indirect cloud forcing and concluded that there was a slight positive feedback. [53] However Baker and Peter (2008) encapsulate the current state of research, “Clouds constitute the largest single source of uncertainty in climate prediction.” [54]

Recommendations

I have summarised and simplified positive feedback loops that I identified in Figure 6. Note that each of these loops drives warming and in the absence of a significant number of negative feedbacks, these will ratchet up the warming process by feeding each other. A significant number of negative feedbacks has not been identified and the pace of climate change indicates that they aren't present.

The Precautionary Principle is the hallmark of sound environmental policy. In the case of policy aimed at preserving the systems which support human civilization, I would recommend the Extremely Precautious Principle be applied.

Alan Watterson
(Ecosphere Consulting)

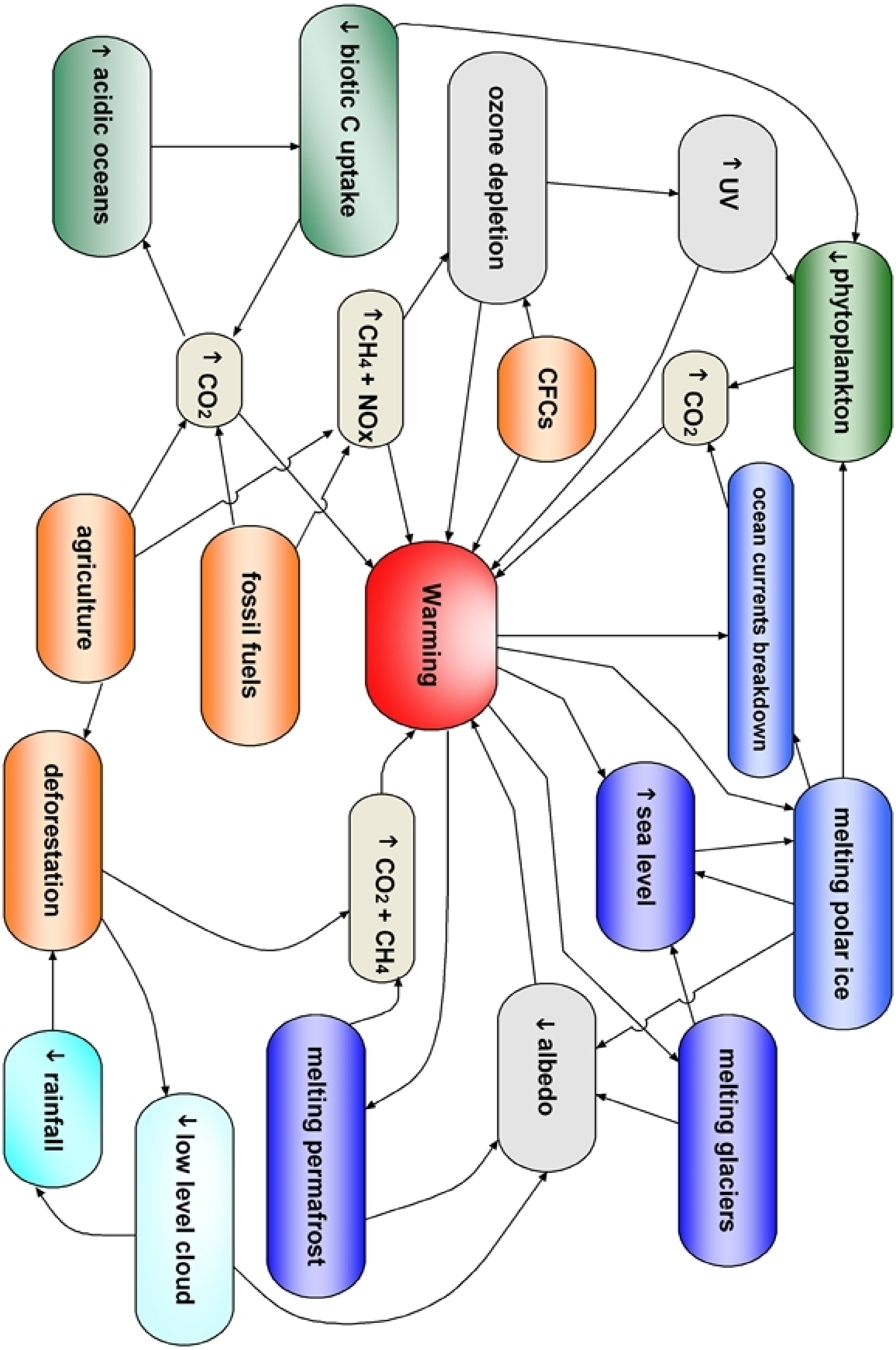

Fig. 6: A simplified diagram of some positive feedback loops.

References

1 CSIRO Australia (2007) New Projections For Australia's Changing Climate. ScienceDaily. http://www.sciencedaily.com/releases/2007/10/071003130920.htm

2 Hansen, J.E. (2008) GISS Surface Temperature Analysis: Global Temperature Trends: 2007 Summation. http://data.giss.nasa.gov/gistemp/2007/

3 Met Office, UK (2008) Global temperature 2008: Another top-ten year. http://www.metoffice.gov.uk/corporate/pressoffice/2008/pr20080103.html

4 Matthews, H. D., and K. Caldeira (2008), Stabilizing climate requires near-zero emissions, Geophys. Res. Lett., 35, L04705

5 Canadell J.G. (2007) Contributions to accelerating atmospheric CO_2 growth from economic activity, carbon intensity, and efficiency of natural sinks *PNAS* 104(47) 18866-18870

6 CSIRO Australia (2007) Decline in uptake of carbon emissions confirmed. Media Release 07/211, http://www.csiro.au/news/CarbonEmissionsConfirmed.html

7 Rahmstorf et al (2007) Recent climate observations compared to projections. Science 4 May 2007: 709 DOI: 10.1126/science.1136843

8 Stroeve J. et al (2007), Arctic sea ice decline: Faster than forecast, Geophys. Res. Lett., 34, L09501

9 BBC News (2002) Antarctic ice shelf breaks apart. http://news.bbc.co.uk/1/hi/sci/tech/1880566.stm

10 Dansgaard,W. et al (1989)The abrupt termination of the Younger Dryas climate event. Nature, 339(6225): 532-534

11 Alley, R.B. et al (2003) Abrupt Climate Change. Science 299(5615): 2005 - 2010

12 Lenton, T. M. et al (2008) Tipping Elements in the Earth System. PNAS,105(6): 1786-1793

13 Committee on Abrupt Climate Change (2002) Abrupt Climate Change: Inevitable Surprises. Ocean Studies Board, Polar Research Board, Board on Atmospheric Sciences and Climate, Division on Earth and Life Studies, National Research Council. National Academy Press, Washington, D.C. pp 75-76.

14 Forest, C.E. et al (2001) Quantifying uncertainties in climate system properties using recent climate observations, *Science*, 295(5552):113-117.

15 Schneider, S. H. (2003) Abrupt Non-Linear Climate Change, Irreversibility and Surprise. OECD Workshop on the Benefits of Climate Policy: Improving Information for Policy Makers. Working Paper ENV/EPOC/GSP(2003)13/FINAL

16 Quadfasel, D. (2005) Oceanography:The Atlantic heat conveyor slows. Nature 438, 565-566

17 Bryden, H.L. et al (2005) Slowing of the Atlantic meridional overturning circulation at 25° N. Nature 438, 655-657

18 Schiermeier, Q. (2006) Climate change: A sea change. Nature 439, 256-260

19 Dickson, B. et al (2002) Rapid Freshening of the Deep North Atlantic Ocean Over the Past Four Decades. Nature, Vol. 416, 832-837

20 Hansen, B. et al (2001) Decreasing overflow from the Nordic Seas into the Atlantic Ocean through the Faroe Bank Channel since 1950. Nature, Vol. 411, 927-930

21 Hill, K. et al (2005) Dynamics and impacts of changes in the East Australian Current off the south east coast of Australia http://www.cmar.csiro.au/e-print/open/hillk_2005a.pdf

22 Tortell, P. D.*et al* (2008), CO_2 sensitivity of Southern Ocean phytoplankton, *Geophys. Res. Lett*., 35, L04605, doi:10.1029/2007GL032583

23 Orr, J.C. *et al* (2005) Anthropogenic ocean acidification over the twenty-first century and its impact on calcifying organisms. *Nature,* 437(29): 681-686

24 Seibel, B.A. and Dierssen, H.M. (2003) Cascading Trophic Impacts of Reduced Biomass in the Ross Sea, Antarctica: Just the Tip of the Iceberg? Biol. Bull. 205: 93-97

25 Polovina, J. J. *et al* (2008), Ocean's least productive waters are expanding, *Geophys. Res. Lett.,* 35, L03618

26 Tarling, G. A. and Johnson, M. L. (2006) Satiation gives krill that sinking feeling. *Current Biology,* 16(3), R83-R84

27 Hoegh-Guldberg, O. et al (2007) Coral Reefs Under Rapid Climate Change and Ocean Acidification. Science 318(5857):1737–1742

28 Hartmann, D.L. et al (2000) Can ozone depletion and global warming interact to produce rapid climate change? PNAS 97(4): 1412–1417http://www.pnas.org/cgi/reprint/97/4/1412.pdf

29 Kodera, K.*et al* (2008), Solar modulation of the Northern Hemisphere winter trends and its implications with increasing CO_2*, Geophys. Res. Lett*., 35, L03704, doi:10.1029/2007GL03195

30 Kovalenok, S. *et al* (2008) Antarctic total ozone distribution climatology in connection with possible impact to ecosystem. *Geophys. Res. Abs.*,Vol. 10, EGU2008-A-00387

31

British Antarctic Survey (2008, March 25). Huge Iceberg Breaks Away, Antarctic Ice Shelf 'Hangs By A Thread'. *ScienceDaily*. Retrieved March 30, 2008, from http://www.sciencedaily.com

/releases/2008/03/080325120714.htm

34 Renfrow, S. (2007) Arctic Sea Ice Shatters All Previous Record Lows. National Snow and Ice Data Center. http://nsidc.org/news/press/2007_seaiceminimum/20071001_pressrelease.html

35 Nesje, A. et al (2008) Norwegian mountain glaciers in the past, present and future. Global and Planetary Change 60(1-2): 10-27.

32 Rignot, E. *et al* (2008) Recent Antarctic ice mass loss from radar interferometry and regional climate modelling. *Nature Geoscience* 1, 106 – 110

33 Dayton,L. (2008) Antarctica's ice melting faster. The Australian January 15, 2008

36 Oerlemans, J. (1997) A flow-line model for Nigardsbreen: projection of future glacier length based on dynamic calibration with the historic record. Annals of Glaciology 24, 382-389.

37 Haeberli, W.,Hoelzle, M. & Zemp, M (Eds.) (2007) Glacier Mass Balance Bulletin No. 9 (2004–2005). World Glacier Monitoring Service. Staffel Druck AG,CH-8045 Zurich,Switzerland

38 Beloloutskaia, M. and O. Anisimov (2003) Feedbacks in Climate - Permafrost - Vegetation System: Predictive Modeling Approach. Amer. Geophys. U. Fall Meeting http://adsabs.harvard.edu/abs/2003AGUFM.C11E..04A

39 Anisimov, O. and S. Reneva (2006) Permafrost and Changing Climate: The Russian Perspective. *Ambio* 35(4): 169-175

40 Zimov, S.A. et al (2006) Climate change: Permafrost and the Global Carbon Budget Science 312:1612-1613

41 Walter, K. M. M et al (2007) Thermokarst Lakes as a Source of Atmospheric CH4 During the Last Deglaciation. Science 318: 633-636

42 Melillo, J.M. et al (2002) Soil warming and carbon-cycle feedbacks to the climate system. *Science* 298(5601): 2173 - 2176

43 Reich, P.B. et al (2006) Nitrogen limitation constrains sustainability of ecosystem response to CO2. Nature 440, 922-925

44 Thomson, A. M. and Parker, W. H. (2008) Boreal forest provenance tests used to predict optimal growth and response to climate change. 1. Jack pine. Canadian Journal of Forest Research, 38(1): 157-170(14)

45

Carroll, A.L. *et al* (2006) Impacts of Climate Change on Range Expansion by the Mountain Pine Beetle. *Mountain Pine Beetle Initiative Working Paper 2006-14.*Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, Victoria, BC.

46 Schiermeier, Q (2005) Climate change That sinking feeling. Nature 435: 732 - 73

47 Kurz, W.A. *et al* (2008) Risk of natural disturbances makes future contribution of Canada's forests to the global carbon cycle highly uncertain. *PNAS*, 105(5), 1551-1555

48 Emanuel, K (2005) Increasing destructiveness of tropical cyclones over the past 30 years. *Nature* 436: 686-688

49 Kleidon, A. and M Heimann (1999) Deep rooted vegetation, Amazonian deforestation, and climate: Results from a modelling study. Global Ecology and Biogeography, 8(5), 397-405

50 DeFries, R. and Bounoua, L. (2004) Consequences of land use change for ecosystem services: A future unlike the past. Geojournal 61(4): 345-351

51 Soden, B.J. & Held, I.M. (2006) An assessment of climate feedbacks in coupled ocean–atmosphere models. Journal of Climate 19: 3354-3360

52 Chen, T. et al (2000) Radiative Effects of Cloud-Type Variations. Journal of Climate 13(1):264–286

53 Andrews, T., and P. M. Forster (2008), CO2 forcing induces semi-direct effects with consequences for climate feedback interpretations, Geophys. Res. Lett., 35, L04802

54 Baker, M.B. & T. Peter (2008) Small-scale cloud processes and climate. *Nature* 451, 299-300