Scientific Uncertainties
From the IPCC Second Assessment Report
Working Group I

The role of the IPCC; current IPCC projections are judgemental (depends on authors and reviewers); formal methods of analysis are needed to achieve more consistency.

"The IPCC function is to assess the state of our understanding and to judge the confidence with which we can make projections of climate change and its impacts. These tentative projections will aid policy makers in deciding on actions to mitigate or adapt the anthropogenic climatic change, which will need to be re-assessed on a regular basis. It is recognised that many remaining uncertainties need to be reduced in each of the above-named disciplines, which is why IPCC projections and scenarios are often expressed with upper and lower limits. These ranges are based on the collective judgement of the IPCC authors and the reviewers of each chapter, but it may be appropriate in the future to draw on formal methods from the discipline of decision analysis to achieve more consistency in setting criteria for high and low range limits." (WG1 FSM, section 11.1).

Economic and environmental assessments are important

What is the best pathway toward stabilization ? "Wigley et al. (1995) stress the need for a full economic and environmental assessment in the choice of pathway to stabilisation." (WG1 FSM, section 2.1.3)

Limitations in Tropospheric Ozone / Chemistry

"An intercomparison of tropospheric chemistry/transport model using a short-lived tracer showed how critical the model description of the atmospheric motions is, finding a high degree of consistency between three dimensional models, but distinctively different results among two dimensional models. This finding, illustrating the low degree of confidence we should have in numerical solutions involving gases such as tropospheric ozone and its precursors, still holds.

Our ability to model tropospheric ozone is not restricted solely by the limitations of our chemistry/transport models. Equally important is our lack of quantitative knowledge of the global sources and distribution of tropospheric ozone and its short-lived precursors (NOx, hydrocarbons and CO). For example, even the relative importance of the anthropogenic NOx sources (transport of surface pollution out of the boundary layer, direct injection by aircraft) and natural sources (lightning, soils, stratospheric input) is unknown." (WGI FSM, section 2.2.1).

The average stratospheric ozone depletion over the last decade, as well as the large, but transient loss probably associated with Mount Pinatubo's injection of sulphur dioxide into the stratosphere, are expected to have affected various chemical cycles in the atmosphere. several groups have modelled increases in tropospheric OH due to enhanced fluxes of solar ultraviolet radiation reaching the troposphere. Others have speculated on more involved mechanisms linking stratospheric changes to tropospheric effects: changes in cloud radiative properties; changes in troposphere-stratosphere turn-over. While such mechanisms have been identified, there is not yet a consensus regarding the changes in tropospheric chemistry that occurred during this period. (WGI FSM, section 2.2.2.6)

referring to background concentrations of NOx, ozone and water vapor: "As a result, the ability of chemical transport models to simulate these background concentrations in the upper troposphere remains untested and the modelled impact of aircraft NOx on ozone remains quite uncertain." (WG1 FSM, section 2.2.3.3

Aerosol effects on clouds cannot be quantified. Current effects are probably overestimated. Results are preliminary and should be used with caution.

"The problem of the influence of aerosol particles on cloud lifetime and extent, and hence on the spatially and temporally averaged cloud optical thickness, was recognized but could not be quantified. (WG1 FSM, section 2.3.1)

"...the source and strengths of carbonaceous aerosol particles (organic as well as soot) are based on emission factors relating the mass of aerosol produced to the mass of carbon burned in the fuel...However, since the data on soot emissions have not been acquired with any standardisation of sampling or analysis techniques, the emission factors must be regarded as preliminary estimates...This, together with the fact that the atmospheric residence time of particles larger than 1 um is much shorter than that for small particles, suggests that the use of existing emission data is uncertain and likely to overestimate both particle mass concentration and light absorption." (WG1 FSM, section 2.3.3)

"In assessing these results, one should bear in mind the possible exaggeration of the sulphate aerosol concentrations under this scenario, the uncertainties in representing the radiative effects of sulphate aerosols and the neglect of other factors including the indirect effect of sulphates." (WG1 FSM, section 6.2.2.2)

"Including the effects of aerosols as well as greenhouse gases (based on IS92a) is simulations of future climate leads to a much reduced warming in mid-latitudes, not only in regions where the aerosol load is increasing, but also in some regions where the loading is decreasing. There are also marked changes in the hydrological cycle, principally in the northern hemisphere in summer. In particular, there is net reduction of precipitation in the Asian summer monsoon, and summer drying over Europe and North "America is weakened or even reversed. These preliminary results should be used with caution--they are based on two studies. These results are likely to be quite sensitive to the choice of scenario and the assumptions used in deriving the radiative forcing due to aerosols, both of which are subject to considerable uncertainty." (WG1 FSM, section 6.2.6).

Sulphate scenarios should not be considered realistic.

"The distribution of sulphate aerosols concentrations from 1990 in each case was derived using the MOGUNTIA sulphur cycle model (Langner and Rodhe, 1991) and sulphur emission scenarios under IS92a (IPCC, 1992)....Given the possible exaggeration of future concentrations, the uncertainties in converting from sulphate concentrations to forcing, and the neglect of other factors, including indirect forcing by sulphates, these experiments should be regarded as sensitivity studies which indicate the potential influence of sulphate aerosols rather than predictions which are likely to be realistic." (WG1 FSM, section 6.2.2.1)

"Recently the first coupled model integrations to include, although very crudely, the effects of tropospheric aerosols were completed (section 6.2.3). Only the so-called direct radiative effects of the aerosols were included in a simplistic way. This represents a first attempt to include some effects of tropospheric chemistry in a coupled model. To date, there have not been any coupled ocean-atmosphere model experiments performed which studied the effects on climate changes in tropospheric chemistry....The main problem is how to deal with the inclusion of large, complex tropospheric chemistry models in already very large and complex ocean-atmosphere models." (WG1 FSM, section 6.7.3).

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Unexplained drop in atmospheric methane growth

"During 1992/93 extremely low growth rates were observed, and during 1992 methane stopped growing at some locations...There has been considerable speculation and modeling of the possible cause(s) of this 1992-1993 anomaly...Many...factors contributed to the observed CH4 anomaly in 1992-93, but at present it is not clear what their relative contributions are, whether they can fully explain the observed anomalies in concentration and isotopic composition, or even whether we have identified all of the important processes." (WGI FSM, section 2.2.2.1)

"Although the concentration of methane in the atmosphere is well documented, the magnitudes of its sources and sinks and the processes invovled are poorly understood." (WG1 FSM, section 10.3.5.1).

Uncertainties / inadequacies in climate models

"There are still considerable uncertainties in the chemical models used to simulate possible future atmospheres...." (WG1 FSM, section 2.2.4).

"A major simplification of the IS92 scenarios is that we have chosen to ignore the changing emissions of the short-lived gases: CO, VOC (volatile organic compound), and NOx (nitrogen oxides). Although we would like to include complete atmospheric simulation with changing emissions of the major greenhouse gases and also these short-lived gases, there are two compelling reasons why this cannot be done at this time. First, there is not a strong enough consensus on how to treat the short-lived gases in the currently available coarse resolution global models, and on how the chemical feedbacks couple these highly reactive species with CH4. Second, the impact of these short-lived species depends critically on where and when these gases are emitted. For example, the IS92 scenarios do not differentiate between aircraft, urban combustion, and diffuse agricultural NOx emissions. The yield of ozone (a greenhouse gas) per emitted NOx molecule depends critically on these local conditions. Thus until we have a consensus on the tropospheric chemistry models and until the scenarios for short-lived gases include spatially resolved emissions (speciated in the case of VOC), the IS92 calculations cannot included these short-lived gases. This decision is not a recommendation to use the extremely simplified representation of atmospheric chemistry in integrated models." (WG1 FSM, section 2.2.4)

"As pointed out in IPCC (1994) there are difficulties associates with the determination of the scattering efficiency of sulphate aerosol. The difficulties have not been fully resolved. Some measurements of aerosol properties in China have been made but it remains difficult to evaluate adequately the effects of the aerosol particles in the Asian region, where source strengths are increasing rapidly." (WG1 FSM, section 2.3.3)

"Because the bulk of methane destruction normally takes place in tropical latitudes while ozone depletion maximises in middle and high latitudes, the details of such estimates are dependent on the uncertainties in the latitudinal distribution of ozone depletion, as well a tropospheric transport characteristics." (WG1 FSM, section 2.4.13.).

"Fluxes at the ocean-atmosphere interface in coupled models have not yet been fully examined. In some cases there may be serious errors--for example, surface radiative fluxes depending on inadequately parameterized cloud processes, and high latitude inputs of fresh water depending on poorly characterised changes in the atmosphere-hydrological cycle." (WG1 FSM, section 4.3.8).

"Fluxes of heat and moisture between land and the atmosphere are central to the role of land processes in the climate system. These fluxes determine the overlying distributions of atmospheric temperature, water vapour, precipitation, and cloud properties...Solar fluxes at the surface are currently highlighted as being significantly in error compared to observations, in some and perhaps most climate models due to the inadequate treatments of clouds." (WG1 FSM, section 4.4).

"Fluxes between the atmosphere and land may be poorly simulated because of inadequacies in the atmospheric and land-surface models themselves." (WG1 FSM, section 5.3.2.1).

"The dearth of appropriate observations hinders land-surface parametrization improvement and model evaluation." (WG1 FSM, section 5.3.2).

"Biases and uncertainties in the surface energy balance, and radiation water budgets, are a significant source of error in simulations of regional climate." (WG1 FSM, section 4.4.4)

"Modelling of runoff has large uncertainty in global models, there are not convincing treatments of the scaling of the responsible processes over the many orders of magnitude involved, and in high latitudes of the effects of frozen soils. Global data on soils, topography, and water holding capacities at the relevant scales will be urgently needed to make progress on this issue." (WG1 FSM, section 4.4.4)

"The simulation of clouds and their seasonal variation remains a major source of uncertainty in atmospheric models." (WG1 FSM, section 5.3.1.1.7).

"Many of the deficiencies in coarse resolution models notes by Gates et al. (1992) are only starting to be effectively addressed. These problems include: (i) the representation of geometry and bathymetry; (ii) the parametrization of sub-grid scale processes such as convection, mixing and mesoscale eddies; (iii) errors in surface forcing for ocean-alone simulations; (iv) a thermocline that is often too deep and too diffuse; (v) weak poleward heat transport; (vi) distortion of upper ocean and deep boundary currents; and (vii) temperature and salinity errors in the deep waters." (WG1 FSM, section 5.3.3.1)

"The chemistry and biology of CO2, CaCO3, N20, DMS, and other radiatively-active gases that may alter the efficacy of the greenhouse effect or the concentration of atmospheric aerosols are not included explicitly in these coupled models. CO2 is included only in terms of how its atmospheric concentration alters the strength of the greenhouse effect. The ocean carbon cycle and how it affect the CO2 partial pressure difference across the air-sea boundary, and hence the air-sea transfer, is not included." (WG1 FSM, seciton 10.4).

"At present we do not know enough about the processes governing the production, degradation and sources of light-sensitive compounds in the upper ocean, particulr DOC and DMS, to parameterize their behaviour in these models." (WG1 FSM, section 10.4).

"As a final note of caution, in the ocean many algae, bacteria, viruses, protozoa and metazoa interact with the physico-chemical environment and with each other. There are interspecific differences both in responses to environmental conditions and in specific biogeochmical effects. It is from this almost infinite multiplicity of connections tha the climatic role of the marine biota emerges. A further complication is that these interactions may span a range of time scales from millisecond to millenia and beyond, as climate change affects the molecular biological consitution of the marine biota, and this in turn feeds back on climate. For an adequate understanding of the climate system thse fundamental aspects cannot be ignored. The fact that our present models oversimplify the issue by emphasising bulk effects and responses of the marine biota further illustrates our limited understanding of the climate system." (WG1 FSM, section 10.4).

Model resolution seriously affects regional climate models

"The key factors that affect the regional performance of global coupled models are their horizontal resolution and their physical parameterization. Coarse resolution atmospheric models are unable to realistically portray the extent and height of mountains, with consequent distortions in the simulation of orographic precipitation on regional scales, while coarse resolution ocean models suffer similar distortions in their simulation of boundary currents. A GCM's resolution may also introduce systematic errors in the depiction of coastlines, with consequent effects on the simulation of regional circulation and temperature." (WG1 FSM, section 5.2.5).

"While a given parametrization scheme may perform well in "off-line" tests, interactions with other parameterizations and with dynamics may not result in an improved simulation in a coupled model. A particular scheme may also perform well in one model but perform poorly when used in another model." (WG1 FSM, section 5.5).

"Climate models are also known to be sensitive to details of the parametrization of cloud microphysical processes." (WG1 FSM, section 5.5.3).

"The sensitivity of the surface climate to the parametrization of the land surface has been considered in Section 5.3.2....These results demonstrate the urgent need for further studies of the climate's sensitivity to land-surface processes in order to determine which schemes are the more realistic." (WG1 FSM, section 5.5.4)

"Confidence in climate models depends partly upon their ability to simulate the current climate and recent climate changes, and partly upon the realistic representation of the physical processes that are important to the climate system." (WG1 FSM, section 5.5.6).

Soil moisture parametrization is too simplistic.

"Soil moisture may be a more relevant quantity for assessing the impacts of changes in the hydrological cycle on vegetation than precipitation since it incorporates the integrated effects of changes in precipitation, evaporation and runoff through the year. However, simulation changes in soil moisture should be viewed with caution because of the simplicity of the land surface parametrization schemes in current models...." (WG1 FSM, section 6.2.2.3).

ENSO is not satisfactorily simulated in climate models

"...it is clear that ENSO must be considered part of the global climate system and should be accurately simulated. In order to simulate ENSO, the meridional resolution at the equator must be a fraction of a degree in order to simulate wave processes and the meridional extent of the upwelling, both crucial. To date, no coupled model used for projecting the response of greenhouse warming has such resolution." (WG1 FSM, section 4.3.7).

"ENSO processes have major effects on the tropical climate system, with a strong impact on hydrological processes and surface temperatures on interannual time scales. Some ocean-atmosphere coupled models appear to give reasonable simulations of this system and show promise for providing useful predictions. However, the current generation of models used for projection of greenhouse gas response do not satisfactorily simulate ENSO processes, in part because the spatial resolution required to do so is not computationally feasible for century-long climate simulations." (WG1 FSM, section 4.3.8)

"Debate continues over the most appropriate horizontal and vertical resolution to use in climate models....The sensitivity of ocean models to horizontal resolution is also an important issue in climate simulation with coupled models." (WG1 FSM, section 5.5.2).

Flux adjustments are too large in climate models

"The coupling of ocean and atmosphere models can highlight discrepancies in the surface fluxes that may lead to a drift away from the observed climate...Climate drift may be ameliorated by flux adjustment whereby the heat and freshwater fluxes (and possibly the surface stresses) calculated by the atmosphere model are modified before being passed to the ocean model by the addition of a 'correction' or 'adjustment'." (WG1 FSM, section 5.2.3)

"Flux adjustment is strictly justified only when the corrections are relatively small, and in fact the flux adjustments in some coupled models are comparatively large. The alternative is to avoid flux adjustment and to accept the resulting climate drift, a choice that is made in several of the models listed in table 5.1. However, confidence in a coupled models' simulation of transient climate change is not improved if the climate drift is large and/or if the feedbacks are seriously distorted by flux adjustment." (WG1 FSM, section 5.2.3)

"In a strict sense, the use of such corrections can only be defended if they are small. Although the adjustments are not small locally in current models, that is not proof the approach is invalid--it could be that model errors in the surface change negligibly with perturbations as small as that occurring with a doubling CO2." (WG1, FSM, section 6.2.3) **(This seems to says that a doubling of CO2 should be considered a *small* perturbationand therefore, it might be valid to use flux corrections. This statement sounds like the author is trying to defend an indefensible position.)**

"However, the errors which arise without flux adjustments (for example, lack of sea-ice in the Southern Hemisphere) can distort the simulated response, as seen earlier). (WG1 FSM, section 6.2.3).

"The need for flux adjustments arise from a variety of model shortcomings--it is not obvious if or how these shortcomings would alter qualitatively the main findings summarised above. Nor is it obvious whether they would enhance or diminish simulated changes. Thus eliminating the need for flux adjustments remains a high priority." (WG1 FSM, section 6.2.4)

"...when an atmospheric model is coupled to an ocean model and the implied heat and salt transports between the two models are incompatible, a drift in the ocean must occur....The use of flux adjustments may stabilise this drift, but they have the undesirable effect of being physically unfounded and often of large magnitude (in places) than the climatological mean fluxes..."") (WG1 FSM, section 6.7.1.3)

Flux Correction Problems

"Critics, however, note that the flux adjustments in some models can in certain regions greatly exceed the forcing expected from greenhouse gases. Such corrections are outward symptoms of underlying systematic errors in the uncoupled models. Their impact on the reliability of signals from anthropogenic change experiments and on the simulated natural variability is largely unknown. Some studies with simplified models suggest that flux correction may seriously affect the simulated signals and known variability noise...." (WG1 FSM, section 8.2.2).

Elimination of flux corrections is not enough to provide confidence in GCMs. Current weaknesses seriously affect confidence in GCM projections.

"Let us assume that a given CGCM realistically simulates the present climate without relying on any form of flux adjustment. Would this be a guarantee that the same model can predict the climate response to increasing GHG concentrations ? The answer is, 'probably not'. Successful simulation of the present climate is probably a necessary, but not sufficient condition to ensure successful simulation of future climate. To be confident hat a model has predictive skill on time scales of decades or longer, we would have to be sure that it incorporates all of the physics and feedback mechanisms that are likely to be important as greenhouse-gas concentrations or aerosol-producing emissions increase.

There are a number of reasons why it is difficult to feel confident that all important feedbacks have been included correctly in current CGCMs. Feedbacks involving clouds and the surface radiation budget are poorly understood (see chapter 4) and different schemes for parameterizing clouds processes can lead to substantially different results in greenhouse warming experiments (Mitchell et al., 1989; Cess et al., 1989). Other feedbacks that are either currently neglected or highly uncertain include interactions between the land biosphere and the carbon cycle, and between climate and atmospheric chemistry (see Chapters 2 and 4)." (WG1 FSM, section 8.2.3).

Effect of aerosols on cloud properties

"The problem of quantifying the relationship between aerosol source strengths and the droplet size distribution in low-level water cloud is complex because of the number of processes involved, including chemical processes in the emissions and the interaction between cloud dynamics and microphysics....It is clear however that the present results are not sufficient to provide global relationships which might be used with confidence in calculations of global forcing."(WG1 FSM, section 2.3.4).

"These studies continue to indicate that the effect of aerosols on cloud droplet effective radius may be substantial although it remains uncertain. We retain the range of 0 to -1.5 Wm^{-2} suggested in IPCC(94). Our quantitative understanding is so limited at present that no mid-range estimate is given." (WG1 FSM, section 2.4.2.4)

Importance of Volcanoes

"These studies continue to support the conclusion that volcanic activity may be important in explaining some of the interdecadal variation in surface temperature during the instrumental record." (WG1 FSM, section 2.4.3).

"Changes in cirrus cloud properties as a result of the incursion of stratospheric aerosols into the upper troposphere are a possible source of additional radiative forcing as mention in IPCC(1994). Sassent et al. (1995) and Wang et al. (1995) have provided further case-study evidence of cirrus modification by this mechanism. The extent of the effect, and even the sign of the resulting radiative forcing, remain unclear. (WG1 FSM, section 2.4.3)

"One aspect of atmospheric circulation variations considered recently is the possible impact of volcanic eruptions. The eruption of Mt. Pinatubo (Section 3.2.6) led to studies which suggested, based on geographic variations in temperature after major eruptions, that heating of the tropical stratosphere resulting from volcanic aerosols drives an enhanced zonal wind. This stronger wind advects warmer maritime air over continents, leading to warming, in the Northern Hemisphere winter, in higher latitudes. Such variations are limited to a year or two after a major eruption." (WG1 FSM, section 3.4.3).

"...cooling arising from the effects of Mt. Pinatubo's eruption in June, 1991, may have increased terrestrial carbon storage and contributed to the observed reduction in atmospheric growth rate druing the 1991 to 1992 period....Terrestrial carbon storage caused by climate anomalies may be spatially complex due to the potential for a spatial mosaic structure of the anomalies. In the near term, some regions may experience increases in carbon storage and others decreases." (WG1 FSM, section 9.2.3.1)

Comment: Although the effects of any one volcano seem to last only a few years, volcanic activity has occurred on a regular, and sometimes dramatic basis, during the last 150 years, suggesting that climate patterns have been regularly influenced by volcanoes.

There is no change in global temperature variability patterns

"In summary, temperature shows no consistent, global pattern of change in variability. Regional changes have occurred, but even these differ with the time scale considered." (WG1 FSM, section 3.5.2).

Long-term changes in solar radiation may be climatically significant

"Evidence suggests that the solar output was significantly lower during the Maunder minimum (mainly in the 17th century)..." (WG1 FSM, section 2.4.4). This means that the solar output *today* is significantly

greater than it was then. If the solar output is greater, then it stands to reason that the climate must be warmer as a result. The IPCC admits this:

"Extension of current understanding of the relationship between observed solar irradiance change and other indicators of solar variability indicates that long-term increase in solar irradiance since the 17th century might have been climatically significant." (IPCC(94), section 4.5.4).

Recent past warm period was due to orbital change, not to greenhouse gases

"At 6000yr bp (before present) there was more insolation than today in the Northern Hemisphere summer, and more total annual insolation (lending to warm year-round temperatures) at high latitutdes. 6,000 bp is not an analogue for the future, because the earth's orbital configuration was different from present, while CO2 concentration was similar to pre-industrial)." (WG1 FSM, section 9.3.4).

Urbanization does affect regional temperature data

"In specific regions, however, urbanisation influences may be significant. Portman (1993) found that the average warming of 0.22 C between 1954 and 1983 over northern China in the gridded data of Jones et al. (1986a) was nearly as large as the 0.25 C warming in this period averaged over seven uncorrected large urban stations. Portman's adjustments using rural stations, however, suggested that there was in fact a regional cooling of about 0.05 C." (WG1 FSM, section 3.2.2.1)

No evidence of a warming trend in the Arctic

"No systematic changes of minima or maxima and no general warming has been observed in the Arctic over the last 50 years or so." (WG1 FSM, section 3.2.2.4).

The observed warming is probably part of a long-term natural trend

"In France, Mareschal and Vasseur (1992) made independent analyses of two boreholes and derived similar GST [ground surface temperature] histories with peak warmth around 1000 A.D., cooling to a minimum at 1700 A.D., and warming starting at 1800 A.D.....Where no ice was present in western Siberia, analyses indicate the most recent warming started 400 years ago in the south, and much earlier in the north. " (WG1 FSM, section 3.2.5.2).

"Recent studies have demonstrated that the two periods commonly known as the Medieval Warm Period and the Little Ice Age were geographically more complex than previously believed. It is not yet possible to say whether, on a hemispheric scale, temperatures declined from the 11-12th to the 16-17th century. However, it is clear that the period of instrument record began during one of the cooler periods of the past millennium. (WG1 FSM, section 3.6.4)

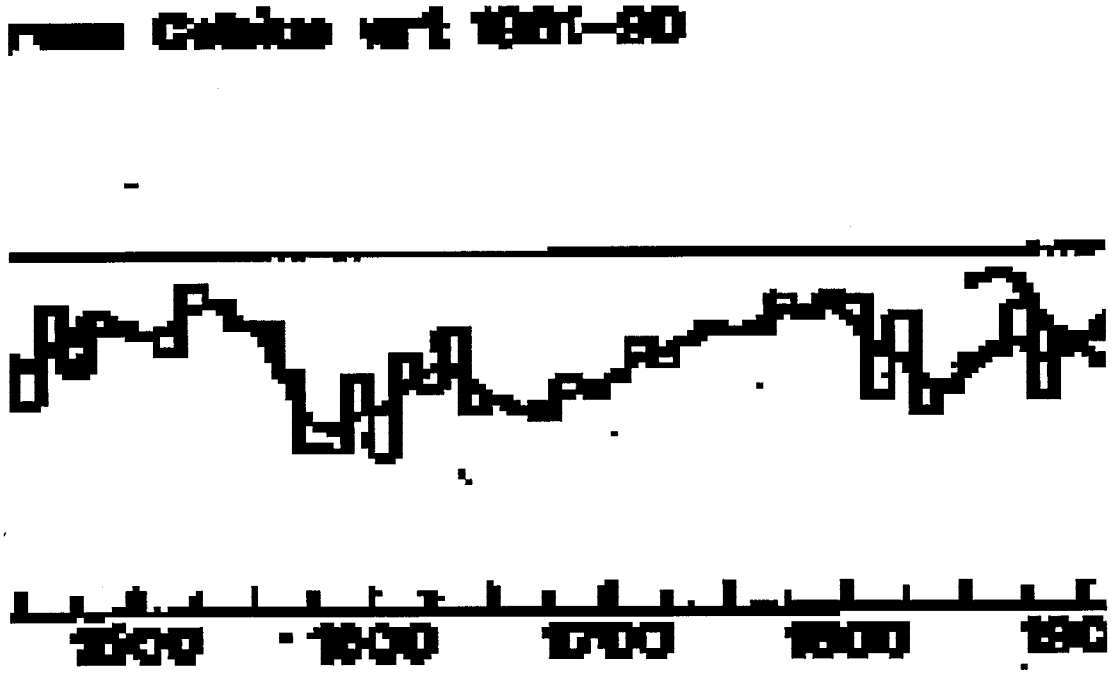
Two views of the temperature record of the last century are possible if this record is viewed with the longer perspective provided by the paleoclimatic data (figure 3.20). On the one hand, the long-term change of

temperature could be interpreted as showing a gradual increase from the late 16th century, interrupted by cooler conditions in the 19th century. Alternatively, one could argue that temperature fluctuated around a mean somewhat lower than the 1860-1969 averaged (punctuated by cooler intervals in the late 16th, 17th and 19th centuries) and then underwent pronounced, and precedented (since 1400) warming in the early 20th century. "(WG1 FSM, section 3.6.4)

The Little Ice Age doesn't sound much different from today, except that a warming trend seems to have replaced a cooling trend. The climatic question is : "Why did it get so cool 500 years ago ?

"The term Little Ice Age is often used to describe a 400-500 year long, globally synchronous cold interval, but studies now show that the climate of the last few centuries was more spatially and temporally complex than this simple concept implies. It was period of both warm and cold climatic anomalies that varied in importance geographically. For the Northern Hemisphere as a whole, the coldest intervals of summer temperature were from 1570-1730 (especially 1600-1609) and during most of the 19th century...Regional temperatures do not all, of course, conform to this pattern. For instance, spring temperatures during the period 1720-1770 appear to be warmer than the 20th century, in parts of China. Despite the spatial and temporal complexity, it appears that much of the world was cooler in the few centuries prior to the present century." (WG1 FSM, section 3.6.2). **This raises the question: If natural forces caused the climate to cool significantly, why should it be so unusual to find that we are now in a warming trend. It is simply coincidence that the industrial age began about the time the Little Ice Age ended.**

Figure 3.20: Global mean temperature anomalies from 1400 A.D. to present. (from WG1 FSM)



Note: the figure given above (while poor quality here) is <u>extremely important</u>. Environmentalist fought very hard in Rome to keep this out of the Synthesis Report. The reason is the clarity with which the message that "the current warming is long-term and natural" is very easy to discern. <u>It's essential that this graph be clearly reproduced, explained and presented to policymakers.</u>

Data regarding the hydrological cycle is very poor.

"Unfortunately, our ability to determine the current state of the global hydrological cycle, let alone changes in it, is hampered by inadequate spatial coverage, inhomogeneities in climate records, poor data quality, and short record lengths." (WG1 FSM, section 3.3.1)

"Changes of precipitation and/or evaporation may lead to changes in runoff or soil moisture storage. Thus changes in streamflow, lake levels, levels of inland seas, and soil moisture may provide information about changes in the hydrologic cycle. Data on many of these aspects of the hydrological cycle are suspect because of human influences, such as building of dams to regulate streamflow...." (WG1, FSM, section 3.3.5).

"No clear evidence of wide-spread change in the annual streamflow and peak discharges of rivers in the world was found." (WG1 FSM, section 3.3.5.1).

"Monitoring atmospheric moisture presents many difficulties....Measurement problems also make detecting trends of water vapour difficult....Another serious problem with radiosonde data stems from changes of instruments and reporting practices that have occurred through the period of record...These factors make it difficult to separate climate changes from changes in measurement programs." (WG1 FSM, section 3.3.7)

There is no consensus regarding the use of paleoclimatic data in estimating historical climate trends

"Climate from before the recent instrumental era must be deduced from paleoclimatic records. These include tree rings, pollen series, faunal and floral abundances in deep-sea cores, isotope analysis from coral and ice cores, and diaries and other documentary evidence...The difficulty of determining past climates can be illustrated by the case of tropical sea surface temperatures (SSTs) around the time of the last glacial maximum (around 22000-18000 years ago). The lack of consensus on this topic provides an indication of the problems of using proxy data. The topic is important partly because of the possible use of glacial data in validating climate models, and relating past climates to radiative forcings." (WG1 FSM, section 3.6.1).

Warming is not causing unusually heavy rainfall

"There has been a notable absence of very heavy monsoon onset (May-June) rains along the Yangtze River Valley of China since about 1970, although total warm season rainfall has changed little." (WG1 FSM, section 3.3.2.1)

Global wind speed has not changed

"Marine data show an increase of wind speed over the four decades since World War II, believed to be largely artificial...The notion of no global increase in wind speed is consistent with the calculations of Ward (1992, 1994) who used sea level pressure gradients to estimate changes in wind speed." (WG1 FSM, section 3.3.6.2)

Extreme Events are not getting worse

"Overall, there is no evidence that extreme weather events, or climate variability, has increased, in a global sense, through the 20th century, although data analyses are poor and not comprehensive. On regional scales there is clear evidence of changes in some extremes and climate variability indicators. Some of these changes have been toward greater variability; some have been toward lower variability." (WG1 FSM, section 3.5.4).

"A significant trend to increased percentages of rainfall falling in heavy events is evident in the USA, largely due to a strong increase in extreme rainfall events during the warm season...Trends to more extreme rainfall events were not apparent in the other regions." (Soviet Union and China) (WG1 FSM, section 3.5.3.3)

"Across the USA a spatially complicated pattern of variations in extreme maximum temperatures is evident, with no evidence of a country-wide increase in extremes." (WG1 FSM, section 3.5.3.4)

Possible future changes in extreme events cannot be assessed.

"In the few analyses available, there is little agreement between models on changes in storminess that might occur in a warmer world. Conclusions regarding extreme storm events are obviously event more uncertain. The formation of tropical cyclones depends not only on sea surface temperature (SST), but also on a number of atmospheric factors. Although some models now represent tropical storms with some realism for present day climate, the state of the science does not allow assessment of future changes." (WG1 FSM, section 6.0).

Current drought patterns in the Sahel are not unusual.

"Just as important as temperature are variations in the hydrological cycle during the last millennium. Global-scale records do not exist, but useful information has been derived for several continents. Especially relevant, because of the recent low rainfall in the Sahel (Section 3.3.2.1) is the evidence from Africa. From the 10th to the 13th centuries the evidence suggests a much wetter climate over much of North Africa...Interspersed in this moderately wet era were extreme droughts in the Sahel in the 1680s and the 1740s to 1750s...Nicholson (1989) has documented several previous dry regimes also lasting on the scale of a decade or two, particularly the 1680s, 1740s, and 1750s, and 1820s and 1830s, that mirrored the recent period in the Sahel. So, the recent past has exhibited periods of comparable dryness to the last few decades." (WG1 FSM, section 3.6.2). **The point is that recent droughts in the Sahel cannot be attributed to global warming. They are a natural feature of the area.**

No evidence of changes in extreme events (tornadoes, thunderstorms, dust storms and fire weather)

"Overall, there is no evidence that extreme weather events, or climate variability, has increased, in a global

sense, through the 20th century, although data analyses are poor and not comprehensive. On regional scales there is clear evidence of changes in some extremes and climate variability indicators. Some of these changes have been toward greater variability; some have been toward lower variability." (WG1 FSM, section 3.5.4).

"The final type of extreme weather events considered here consists of events normally subject to visual reports. Identification of trends in such data is likely to be problematic, because of doubts about consistency of observer behaviour. There is little or no evidence of consistent increases in such events. For instance, Ostby (1993) found no evidence of increased occurrence of strong or violent tornadoes in the USA, although the numbers of reports of less severe tornadoes appears to have increased, perhaps due to increased population, eagerness in reporting, or improved reporting procedures. Grazulis (1993) reported a drop in damaging tornadoes in the 1980s, over the USA." (WG1 FSM, section 3.5.3.5)

"Current climate models lack the accuracy at smaller scales and the integrations are often too short to permit analysis of local weather extremes. Except maybe for precipitation, there is little agreement between models on changes in extreme events." (WG1 FSM, section 6.5.7).

Climate in a warming world may be more stable than previously thought.

"Since the diurnal range of temperature is related to cloud cover and humidity, decadal decreases in the variability of the diurnal range may reflect a decrease in variability of cloud cover, soil moisture, humidity or wind." (WG1 FSM, section 3.5.2.2)

"Doubts about the quality and consistency of the data on maximum wind speeds in most cyclone basins preclude convincing analysis of how peak cyclone intensity might have changed in recent decades. Only in the Atlantic do the data seem of sufficient quality to allow such an analysis...Mean maximum wind speed appears to have decreased. However, the peak intensity reached by the strongest hurricane each year has shown no trend in the five-decade period." (WG1 FSM, section 3.5.3.1)

The potential severity of droughts may actually be as great as projected.

"Evaporation potential has decreased (since 1951) over much of the former Soviet Union (and possibly also in the USA).(WG1 FSM, section 3.3.9)

"As atmospheric CO2 increases, stomatal conductance declines, so that the effectiveness of water conservation by plants in increased and the effects of drought on plant growth ameliorated." (WG1 FSM, section 9.0).

"This latter effect of CO2 could mitigate or even reverse the mid-latitude drying seen in some 2xCO2 simulations with fixed surface conductance (Chapter 6)....Thus the net "physiological" effect of CO2 on climate would be to reduce evapotranspiration and increase soil moisture, relative to the scenarios based on radiative forcing alone." (WG1 FSM, section 9.7.2).

The current warming trend is well within the range of natural variability

"It seems unlikely, given the smaller regional changes, that global mean temperatures have varied by 1 C or more in a century at any time during the last 10,000 years" (WG1 FSM, section 3.6.3). **Global mean temperature is estimated to have changed only between 0.3 to 0.6 C during the last century.**

Great caution must be used when discussing regional climate change

"Concerns are often expressed that the climate may be more variable (i.e., more droughts and extended wet periods) or extreme (i.e., more frequent severe weather events). A possible source of confusion in any discussion of variability is that variability of the climate can be defined and calculated in several ways. Apparently contradictory conclusions may be reached from the different definitions....Care needs to be taken in the comparison of variabilities calculated and defined in different ways." (WG1 FSM, section 3.5.1).

"Analysis of surface air temperature and precipitation results from regional climate change experiments carried out with coupled GCMs indicates that the biases in present day simulations of regional climate and the inter-model variability in the simulated regional changes are still too large to yield a high level of confidence in simulated change scenarios. The limited number of experiments available with statistical downscaling techniques and nested regional models has shown that complex topographical features, large lake systems, and narrow land masses not resolved at resolution of current GCMs significantly affect the simulated regional and local change scenarios, both for precipitation and (to a lesser extent) temperature. This adds a further degree of uncertainty in the use of GCM-produced scenarios for impact assessments". (WG1 FSM, section 6.6.3)

Scientific information is inadequate; sustained research is needed.

"current data and systems are inadequate for the complete description of climate change. Virtually every monitoring system and data set requires better data quality and continuity. New monitoring systems, as well as improvements on current systems and studies to reduce quality problems from historical data are required...Karl (1995) note, for instance, that the introduction of a new maximum-minimum thermistor in the USA Co-operative observing network has introduced a systematic bias. Oceanic data suffer from a lack of continuity. Conclusive detection and attribution of global climate change will require an ongoing homogenous, globally representative climate record." (WG1 FSM, section 3.7).

"There is justifiable concern over consistency of some data sets, which may need reanalysis." (WG1 FSM, section 11.9).

More ocean data is needed before climate change can be attributed to human activities

"In general, the ocean is so poorly observed and the instrumental record so incomplete that there are regions of the ocean for which no observations exist...Since there are now continuous long-term measurement sites in the deep ocean, the establishment of such a system is important for the evaluation of climate models and for the measurement of the natural variability that is necessary for the unambiguous detection of a climate response to anthropogenic forcing (see Chapter 8)." (WG1 FSM, section 5.3.3.4.3).

"The observational data sets on which the evaluation of ocean models rests have significant spatial and temporal shortcomings, with many regions of the global ocean not sampled and many others have only short sampling records (see Chapter 3.3.4.1). This means it is difficult to form a reliable estimate of the ocean climate and its variability." (WG1 FSM, section 5.3.3.5).

"The thermohaline circulation in the world oceans is an important feature which effects the coupled system. It transports large amounts of heat and water from the Southern Hemisphere to high latitudes of the Northern Atlantic Ocean. It also plays an important role in determining the vertical structure of the world oceans (Manabe and Stouffer, 1988) and it may response to any climate change. Many models show a weakening in the thermohaline circulation in response to increase Greenhouse Gases (Section 6.2). However, we do not have confidence in the simulation and structure of this circulation because of the lack of observations. It is very important that observational programs be developed to study this global circulation." (WG1 FSM, section 6.7.1.2).

Subtle errors can produce profound effects in attempts to attribute climate change to human activity and in quantifying potential impacts of climate change.

"Predictions of the rate of climatic change over the next few decades are of particular importance, both for the detection and attribution of climate change, and the estimation of climate impacts....Climate drift is another source of error in estimating initial rates of change in transient experiments. This can occur if the ocean and atmosphere are not brought into full equilibrium before starting an experiment, and results in a systematic trend in the simulation of present climate as the model 'drifts' toward its long term equilibrium state. This lack of initial equilibrium may affect the evolution of a perturbed climate differently from that of present day climate, and hence distorts the estimated rates of climate change." (WG1 FSM, section 6.2.4).

Clouds are a major source of error in attempting to attribute climate change to human activity. Current models cannot produce realistic estimates of the radiative fluxes from clouds.

"The single largest uncertainty in determining the climate sensitivity to either natural or anthropogenic change are clouds and their effects of radiation and their role in the hydrological cycle. Although there are many important unresolved issues relating to the basic physics of cloud-radiation interactions and their parametrization in climate models, even perfect parametrizations of radiation and cloud optical properties cannot produce realistic radiative fluxes and heating rates unless they are provided with a realistic distribution of cloudiness. At the present time, weaknesses in the parametrization of cloud formation and dissipation are probably the main impediment to improvements in the simulation of cloud effects on climate....There is a great need for observations of cloud-scale dynamics and of the radiative properties of clouds, so that the parametrizations of the physical processes can improve." (WG1 FSM, section 6.7.1.1).

Unlikely that the West Antarctic Ice Sheet will collapse

"Concern has been expressed that the West Antarctic Ice Sheet might 'surge', causing a rise in sea level. The current lack of knowledge regarding the specific circumstances under which this might occur, either in

total or in part, limits the ability to quantify the risk. Nonetheless, the likelihood of a major sea level rise by the year 2100 due to the collapse of the West Antarctic Ice Sheet is considered low." (WG1 FSM, section 7.0).

"In Antarctica, recent break-ups of the Larsen and the Wordie Ice Shelves in the Antarctic Peninsula and discharges of enormous icebergs from the Fichner and Ross Ice Shelves, and the discovery of major recent changes in certain Antarctic ice streams, have focused public attention on the possibility of 'collapse' of this ice reservoir within the next century, with potential impacts on sea level. Changes in floating ice shelves, of course, cannot affect sea level directly." (WG1 FSM, section 7.3.1)

"A contrary view is that the short response of ice streams removes the flux imbalance at the grounding line so that the purported instability may not exist." (WG1 FSM, section 7.5.5)

"On the other hand, there is evidence that does not support the notion of WAIS instability...Given our present knowledge, it is clear that while the ice sheet has had a very dynamic history, estimating the likelihood of a collapse during the next century is not possible. If collapse occurs, it will probably be due more to climate change of the last 10,000 years rather than to greenhouse warming." (WG1 FSM, section 7.5.5)

Sea level was increasing and began accelerating before the 1850s. Poor records make estimates of sea level trends highly uncertain.

"The conclusions given in Woodworth (1990), Gornitz and Solow (1991), and Douglas (1992) imply that the acceleration probably began before the 1850s. But data for the pre-instrumental period is sparse, at best. There is as yet no evidence for any acceleration of sea level rise this century....The evidence, or lack of it, for sea level accelerations over the past century depends critically on a small number of long tide gauge records which is unlikely to be supplemented significantly in the future...The main difficulties in determining a more robust estimate for sea level trends (let alone acceleration) are the unequal geographical distribution of historical tide gauge data and the considerable amount of typically decadal variability present in all records." (WG1 FSM, section 7.2.2).

"As most of our observations extend over a few decades only, this immediately poses a problem: how can we decide from observations whether a small change in ice sheet configuration is a response to a short-term climatic fluctuation or an ongoing process of slow adjustment to changes that happened a long time ago ? " (WG1 FSM, section 7.3.3.2).

Major disagreements exist in the contribution of changes in Greenland and Antarctic ice sheets to sea level rise. Current uncertainties suggest sea level could have actually dropped in the last 100 years.

"Most of the non-oceanic water on Earth resides in the two great ice sheets...." (WG1 FSM, section 7.3.3.1)

"The paucity of relevant data does not allow a meaningful judgement of the current state of balance of the Greenland and Antarctic ice sheets. Different workers claim changes with even different sign, up to (and

perhaps exceeding) 25% of the annual mass turnover (even more for south Greenland). A major problem is the use of data on the decadal time-scale to infer long-term changes. At present it can be concluded that an imbalance of up to 25% cannot be detected in a definite way by current methods/data." (WG1 FSM, section 7.3.3.2).

"With respect to the Greenland and Antarctic ice sheets, there is simply insufficient evidence, either from models or data, to say whether the mass balances have been positive or negative....In total, based on models and observations, the combined range of uncertainty regarding the contributions of thermal expansion, glaciers, ice sheets and land water storage to past sea level change is about -19 cm to +35 cm--a very wide band of uncertainty which easily embraces the observed sea level rise (10-25 cm). The major source of uncertainty relates to the current mass balance of the polar ice sheets." (WG1 FSM, section 7.4)

GCM estimates of sea level rise have limited reliability

"The initial conditions for coupled GCMs are never really known. This alone would be sufficient to prevent a prediction of the state of the ocean over several decades....These problems, and others like the consequences of differences in spin-up techniques, obviously limit the reliability of the conclusions presently resulting from these coupled GCM transient experiments." (WG1 FSM, section 7.3.1)

"Even GCMs, which fare well on average are not entirely reliable for polar climate studies." (WG1 FSM, section 7.3.3.3).

"Improvement is also needed in the ice-dynamics models. Short-term transient behaviour has been observed in major ice streams. The fact that these changes exist means that the physics incorporated in contemporary ice-sheet models is not completely realistic....Another key aspect, currently not well understood and therefore impossible to model with confidence, is the rate of iceberg calving. These are the key elements in defining the interactions between ice sheets, ice streams and ice shelves. These, together with changes of snow accumulation, are the most uncertain aspects of predicting changes in the ice sheets over the next decades to centuries, and need major improvement." (WG1 FSM, section 7.74).

Radar altimetry results should be viewed with caution

"Radar altimetry has become a major tool for studying sea level changes over most of the world ocean....Indeed, results from the first 2 years of the mission suggest an apparent sea level rise of approximately 3 mm per year....Given the number of potential altimeter errors at the millimetre level, it is premature to attach major significance to this result." (WG1 FSM, section 7.7.1).

Many factor s influence estimates of sea level

"It is also clear that the global average sea level change is not a good indicator of local changes at any particular place....If the ocean were homogeneous and at rest, with a uniform atmospheric pressure field above it and no wind, the sea surface would correspond to the geoid (i.e., an equipotential of the gravity field). However, it does not; it differs from the geoid by +/- one meter. Ocean and atmosphere are non-homogeneous and continuously moving within a variety of time and space scales, under gravitational

forcing (for tides) and thermal forcing from the sun (including variable wind stress and heat and fresh water exchanges at the sea surface)." (WG1 FSM, section 7.6.2).

Sea level rise by the year 2100 may be much smaller than projected by the IPCC.

"In present the revised IPCC projections of sea level rise in section 7.5.2, intra-model uncertainties were examined by selecting sets of model parameters to give high, middle and low projections of sea level change." (WG1 FSM, section 7.5.3).

"In general, the projections of future sea-level rise from this set of models are substantially lower than the revised IPCC projections presented in section 7.5.2 for the identical set of IS92 forcing scenarios...For the IS92a middle projections, sea level is estimate to rise by 27 to 34 cm for the cases including and excluding increases of aerosols, respectively, by the year 2100. These middle projections are about 50% lower than the corresponding projections in Section 7.5.2, while the highest projection (49 cm is less than half)...For the Antarctic ice sheet, the dynamic model gives relatively larger negative contributions to sea level by the year 2100 than the constant sensitivity values used in Section 7.5.2 (-7 cm as compared to about -1 cm)..In summary, the uncertainties in sea-level projections attributed to inter-model differences appear to be quite large. To date, no comprehensive model inter-comparisons have been carried out to identify and quantify the factors responsible for differences in results...." (WG1 FSM, section 7.5.3.2).

Stabilizing greenhouse gas concentrations will have little impact on sea level rise for several centuries

"In all but the lowest projections, sea level continues to rise at a scarcely unabated rate for many centuries after concentration stabilisation...Thus, even if greenhouse gas concentrations were stabilised, sea level would continue to rise for many decades--even centuries--because of the large inertial in the ocean-ice-atmosphere climate system." (WG1 FSM, section 7.5.4).

(note: this suggests that *adaptation measures* are already unavoidably necessary, and hence should be considered high on the priority list of "no regrets" measures. Stabilization measures will have little impact on sea level impacts for several centuries, but adaptation measures could have immediate impacts. Clearly, the policy priority should be given to adaptation over stabilization of GHG concentrations.)

Detection of a climate change and attribution to human influences are different. Attribution is not a simple 'yes' or 'no'

"In summary, "detection of change" is the process of demonstrating that an observed change in climate is highly unusual in a statistical sense, but does not provide a reason for the change. 'Attribution' is the process of establishing cause and effect--i.e., that changes in anthropogenic emissions are required in order to explain satisfactorily the observed change in climate. Attribution is feasible only in the sense of demonstrating that the observed change is consistent or inconsistent with the climate responses to a given set of external forcing mechanisms". (WG1 FSM, section 8.1.1)

"Statements regarding the detection and attribution of an anthropogenic effect on climate are inherently probabalistic in nature. They do not have simply 'yes-or-no' answers." (WG1 FSM, section 8.1.1).

Requirements for detecting a human effect on climate

"To detect any signal of human effects on climate, it must be distinguished from the background 'noise' of climate fluctuations that are entirely natural in origin....However, large uncertainties still apply to current estimates of the magnitude and patterns of natural climate variability, particularly on the decadal-to century-time scales that are crucial to the detection problem." (WG1 FSM, section 8.0).

"The attribution of a detected climate change to a particular causal mechanism can be established only by testing competing hypotheses....Unique attribution of a detected 'significant' climate change to human activities requires the elimination of all possible non-anthropogenic mechanisms." (WG1 FSM, section 8.1).

"A number of studies have claimed that the observed warming is statistically significant. The credibility of these claims depends on how they have estimated the magnitude of natural variability and/or assessed the statistical significance of any change or trend....Alternatively, several authors have shown that some noise models with correlation of the residuals are consistent with the data but lead to a non-significant result for the observed warming trend...Claims of non-significance of the global warming trend have also been made..."(WG1 FSM, section 8.4.1.1).

"Attribution of an observed climate change to a particular mechanism can only be established by testing competing hypotheses. Thus unique attribution of a 'significant' observed change requires specifying the signals of all likely alternative explanations, and statistical determination that none of these mechanisms is a satisfactory explanation for the observed change. This is a difficult task, and one that detection studies to date have not addressed in a rigorous statistical way." (WG1 FSM, section 8.7).

Requirements for estimating natural variability

"Furthermore, the instrumental records covers a period when both anthropogenic effects and natural variability have occurred together, making it very difficult to separate the two in an unambiguous way....Nevertheless, several attempts have been made to estimate the background natural variability by subtracting a model-estimated anthropogenic signal from the observed data....The reliability of such variability estimates depends critically on the correctness of the CGCMs climate sensitivity, on the correctness of any assumed lag between radiative forcing and temperature response in the simple model, on the reliability of the signal pattern, and the correctness of the assumed radiative forcing history." (WG1, FSM, section 8.3.1)

"To build confidence in the cade-to-century time-scale natural variability simulated by models, there is a need to compare model attempts to mimic the climate of the past 1000 years, with variability estimates from paleoclimatic data with comparable time resolution. Reconstructions of the near surface temperature of the past 1000 years based on such proxies as tree rings, ice cores and corals are valuable but have their own inherent deficients." (WG1 FSM, section 11.7).

note: this means that the simulations of the past 150 years or so given by the Hadley center are simply inadequate to build conficence in the model simulations of natural variability. Without this confidence, statements attributing recent changes to human influences cannot be relied upon.

Better data is need to make a convincing case for that anthropogenic climate change is real

"Without a better paleoclimatic data base for at least the past millennium, it will be difficult to rule out natural variability for recent observed changes, or to validate coupled model noise estimates on century time scales." (WG1 FSM, section 8.3.2)

"Unless paleoclimatic data can help to 'constrain' the century time scale natural variability estimates obtained from CGCMs, it will be difficult to make a convincing case for the detection and attribution of an anthropogenic climate change signal." (WG1 FSM, section 8.3.3.3)

The current warming trend probably has natural and anthropogenic components. A significant portion may be natural. A significant warming trend does not prove that the trend was caused by human activity.

"The conclusion that can be drawn from this body of work, and earlier studies reported in Wigley and Barnett (1990), is that the warming trend to date is unlikely to have occurred by change due to internally generated variability of the climate system, although this explanation cannot be ruled out. This, however, does not preclude the possibility that a significant part of the trend is due to natural forcing factors. Trend significance provides circumstantial support for the existence of an anthropogenic component to climate change, but does not directly address the attribution issue." (WG1 FSM, section 8.4.1.1)

"In essence, this results says that the most recent (20-30) year trends in global-mean temperature are significantly different from the estimated level of background noise. As noted for Stage 1 studies, this does not resolve the attribution issue." (WG1 FSM, section 8.4.2.1).

"The best available evidence suggests that observed near-surface air temperature has increased by 0.3 C to 0.6 C in the last 100 years (Chapter 3)....This agreement does not, however, constitute identification of an anthropogenic effect on climate and may be serendipitous....It is certainly feasible that qualitative agreement could be due to compensating errors, such as a climate sensitivity that is too high being partially offset by cooling due to a residual drift, or by an overestimated aerosol effect." (WG1 FSM, section 8.5.2).

No studies to date have been able to attribute any observed climate change to human activities.

"None of the studies cited above has shown clear evidence that we can *attribute* the observed changes to the specific cause of increases in greenhouse gases." (WG1 FSM, section 8.4.2.1).

"While some of the pattern-based studies discussed here have claimed a significant climate change, no study to date has positively attributed all or part of that change to anthropogenic causes. Nor has any study quantified the magnitude of a greenhouse-gas effect or aerosol effect in the observed data--an issue that is of primary relevance to policymakers.". (WG1 FSM, section 8.7).

Scientists do not know when the attribution issue will be resolved. The issue will remain controversial.

"Finally, we come to the most difficult question of all: 'When will the detection and unambiguous attribution of human-induced climate change occur? ' In the light of the very large signal and noise uncertainties discussed in this Chapter, it is not surprising that the best answer to this question is 'We do not know'. Some would and have claimed, on the based of the results presented in Section 8.4, that detection of a significant climate change has already occurred. Few if any would be willing to argue that unambiguous attribution of this change to anthropogenic effects has already occurred, or was likely to happen in the next several years." (WG1 FSM, section 8.6).

"Any claims of positive detection and attribution of significant climate change are likely to remain controversial until uncertainties in the total natural variability of [the] climate system are reduced." (WG1 FSM, section 8.7).

The burden of proof is on the scientists

"The signal and noise data used in past detection studies are subject to large uncertainties. Although model improvements and more relevant simulations have helped to gain a better understanding of issues that are important for detection, they have also expanded our 'uncertainty horizons'....Furthermore, the differences between the internally-generated noise estimates from different CGCMs translate into important uncertainties in estimates of detection time, even for a perfectly-known time-evolving anthropogenic signal. These noise estimates are the primary yardstick that must be used to judge the significance of correspondences between modelled and observed changes. They may be flawed on the century time scales of interest for detection of a slowly-evolving anthropogenic effect on climate. The burden of proof that this is not the case lies with climate modellers, experts in the analysis of paleoclimatic data, and with the scientists engaged in detection studies." (WG1 FSM, section 8.7).

The ecosystem has a puzzling ability to adapt to climate change

"... the role of the terrestrial biosphere in controlling past atmospheric CO2 concentrations is uncertain, and its future role is difficult to predict." (WGI FSM, section 2.1.1)

"Rates of species spread in response to Holocene climate changes have been reconstructed by mapping pollen data from networks of ^{14}C-dated cores. They range from 50-2000 m/yr for most woody species in Europe and North america (Davis, 1976; Huntley and Birks, 1983; Huntley, 1988). The puzzle is how species could spread so fast." (WG1 FSM, section 9.3.7).

Warming may increase carbon storage, thus offsetting a sizeable fraction of anthropogenic emissions

"These equilibrium model results suggest that the effect of CO2 in increasing carbon storage could dominate over any warming-induced reduction in carbon storage, but this result must be considered as preliminary." (WG1 FSM, section 9.4.2).

"The lesson is that a combined CO2 increase and global warming can lead to a substantial (in this case, about 25%) increase in the amount of carbon stored in terrestrial vegetation and soils." (WG1 FSM, section 9.4.4).

"Shifts induced by climate change in the phytoplankton community to a greater proportion of Oscillatoria (as observed by Karl et al. (1995a) during the 1991-92 warming event) could potentially increase the sequestering of anthropogenic CO2 by a sizeable fraction in less than a decade." (WG1 FSM, section 10.3.3.1).

Changes in land-use could be climatically significant

"Such sensitivity studies suggest that large biogeophysical effects of vegetation structure on climate could be brought into play by land use change." (WG1 FSM, section 9.7.2).

References

WG1 FSM = Working Group 1 Full Supporting Material:

Climate Change 1995: The Science of Climate Change. Draft Contribution of Working Group 1 to the IPCC Second Asssessment Report. Accepted by governments at IPCC Working Group 1, Fifth Session, Madrid, 27-29 November, 1995. Document: WGI/5th/Doc.3 (9.X.1995).

IPCC (94)

Climate Change 1994. Radiative Forcing of Climate Change and An Evaluation of the IPCC IS92 Emission Scenarios. Edited by J.T. Houghton, L.G. Meira Filho, J. Bruce, Hoesung Lee, B.A. Callander, E. Haites, N. Harris and K. Maskell. Cambridge University Press, 1995.

Scientific Uncertainties
From the IPCC Second Assessment Report
Working Group II

Definition of impacts. Basic requirements for confidence in impact assessments

"Impacts are estimated as the differences between two states: the environmental and socio-economic conditions expected to exist over the period of analysis in the absence of climate change and those expected to exist with climate change." (WGII FSM (Chapter 26, Technical Guidelines), section 6.0).

"Climate impact assessment must address an inherently global phenomenon affecting all nations, so it is desirable that assessments be conducted in a transparent manner, with comparable assumptions and internally consistent procedures. Comparability among assessments is of great importance in appraising the range of appropriate response actions at the international, national and regional levels. Decision makers must have confidence that, at a minimum, the basic assumptions are uniform (e.g., use of a common set of scenarios), that the various models and analytical tools are used correctly, and that the evaluation of impacts properly takes into account future impacts due to socio-economic and technological changes that would occur even in the absence of climate change." (WGII FSM (Chapter 26, Technical Guidelines), section 1.3).

"Two issues are of critical importance in communicating and evaluating research results among researchers: the reports of results and peer review.

Reporting of results. There is a burgeoning literature on the possible effects of future climate, but as yet there has been little attempt to coordinate or standardize either the approaches used or the reporting of results. It is critical that the methodology, assumptions and results of studies are transparent...."

Peer Review. The peer review of results is a vital element ensuring the quality control of published research. Proper vetting by expert reviewers is the only means by which non-specialists are able to evaluate the quality and significance of research." (WGII FSM (Chapter 26, Technical Guidelines), section 9.3.1).

note: the "Peer Review" statement helps makes the case for quoting from the underlying documents, which reflect the end result of a rigorous peer review, versus the Summaries for Policymakers which reflect the end result of a government negotiation.

Development of appropriate baselines to evaluate impacts is crucial.

"The development of a baseline describing conditions without climate change is crucial, for it is this baseline against which all projected impacts are measured. It is highly probable that future changes in other environmental factors will occur, even in the absence of climate change, which may be of importance to the exposure unit." (WGII FSM (Chapter 26, Technical Guidelines), section 6.3).

"Global climate change is projected to occur over time periods that are relatively long in socio-economic terms. Over that period it is certain that the economy and society will change, even in the absence of climate change. One of the most difficult aspects of establishing trends in socio-economic conditions without climate change over the period of analysis is the forecasting of future demands on resources of interest. Simple extrapolation of historical trends without regard for changes in prices, technology, or population will often provide an inaccurate base against which to measure future impacts." (WGII FSM (Chapter 26, Technical Guidelines), section 6.4).

"Impacts are estimated as the differences over the study period between the environmental and socio-economic conditions projected to exist without climate change (the future baseline), and those that are projected with climate change. This definition can be extended to include consideration of adaptation in

the estimation of impacts with climate change. Up to now, few climate impact studies have paid adequate attention to adaptation. Further, many studies have assumed a fixed baseline, often failing to recognize that conditions in the future will be quite different from those at present, even in the absence of climate change." (WGII FSM (Chapter 26, Technical Guidelines), section 7.0).

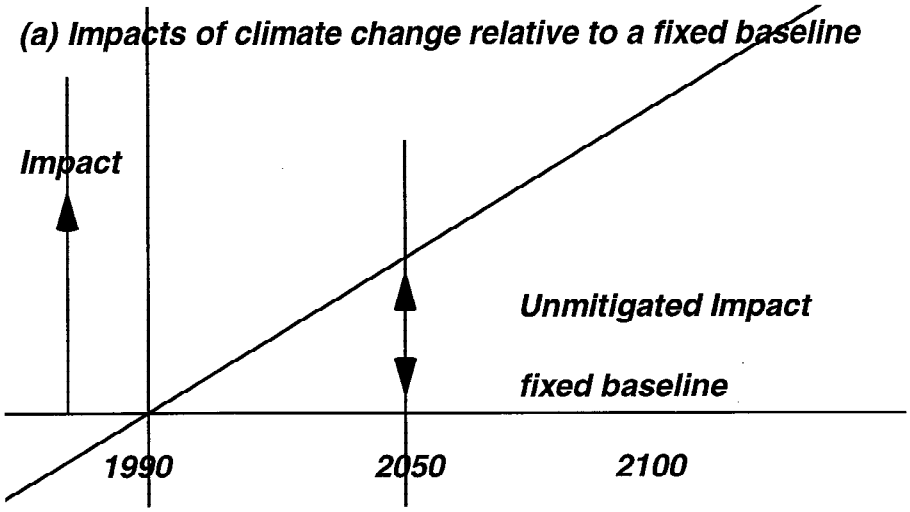
The following illustration and explanation is very useful in explaining the importance of adaptation and "no regrets" measures before strong mitigation policies are considered.

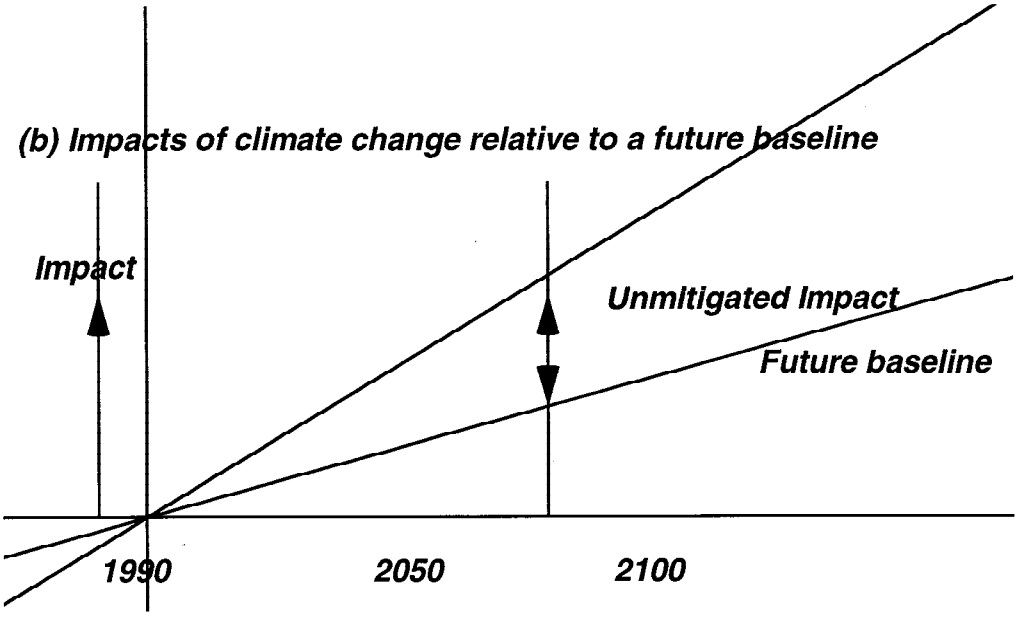
Illustration showing different approaches to the assessment of impacts (adapted from WGII FSM (Chapter 26, Technical Guidelines), section 7.0).

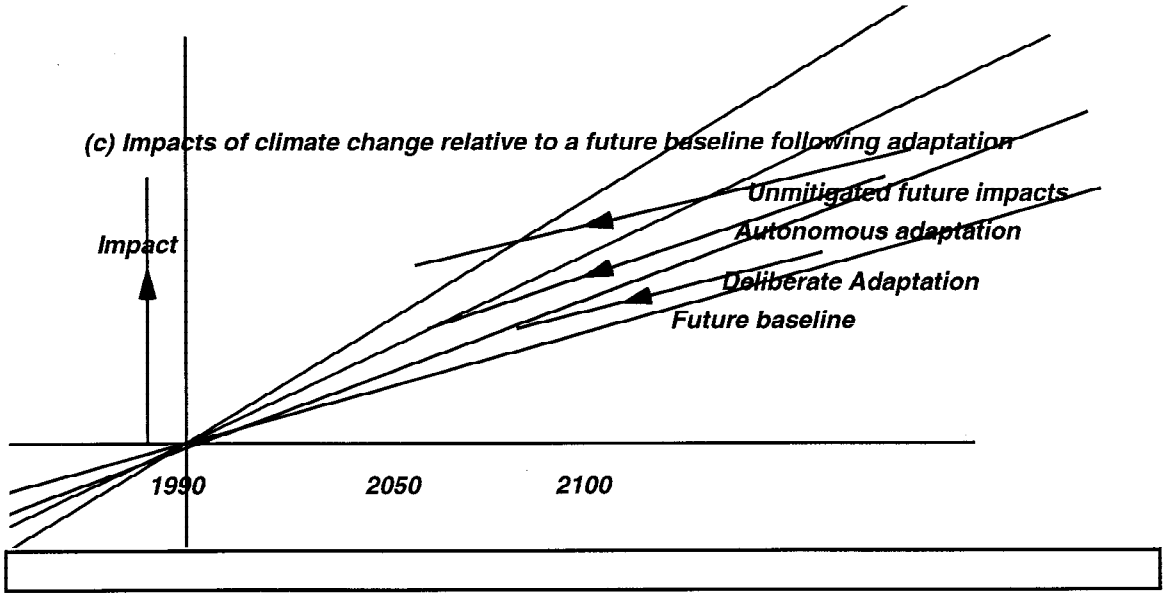
"The three figures illustrate schematically how differing degrees of realism in assessing impacts result from alternative assumptions about the baseline and from consideration of various types of adaptation. In Figure (a), impacts in the year 2050 ... are portrayed as the cumulative effects of future climate change on an exposure united, assuming a fixed baseline (i.e., no concomitant changes in the environmental, technological, societal and economic conditions relative to the present). This unrealistic, though readily application of the future climate is characteristic of many early impact assessments.

Figure (b) shows how more realism is introduced if impacts of future climate change are evaluated relative to a future baseline without climate change.....

However, this approach still ignores the many adjustments and adaptations that would occur either in expectation of or in response to impacts of climate change. These are shown in figure (c), which distinguishes between two types of adaptation: autonomous adjustment , which is implemented immediately (often unconsciously) as part of the normal package of measures available to organisms or systems for coping with climatic variability; and deliberate adaptation, which involves conscious actions to mitigate or exploit the effects of climate change. In most cases (as in Figure (c)), the objective of adaptation is to reduce the negative impacts of climate change...." (WGII FSM (Chapter 26, Technical Guidelines), section 7.0).


(a) Impacts of climate change relative to a fixed baseline
Impact
Unmitigated Impact
fixed baseline
1990
2050
2100


(b) Impacts of climate change relative to a future baseline
Impact
Unmitigated Impact
Future baseline
1990
2050
2100


(c) Impacts of climate change relative to a future baseline following adaptation
Impact
Unmitigated future impacts
Autonomous adaptation
Deliberate Adaptation
Future baseline
1990
2050
2100

Confident projections of future climate do not yet exist.

"In order to conduct experiments to assess the impacts of climate change, it is first necessary to obtain a quantitative representation of the changes in climate themselves. No method yet exists of providing confident predictions of future climate. Instead, it is customary to specify a number of plausible future climates." (WGII FSM (Chapter 26, Technical Guidelines), section 6.5.)

"One of the problems with adopting any single climatic scenario is that it represents only one of an infinite number of plausible future conditions. Even the more common practice of specifying a range of scenarios is limited in that first, the range may be modified in the light of new knowledge and second, the full range of projections for one variable may not coincide with the full range of another." (WGII FSM (Chapter 26, Technical Guidelines), section 6.5.1).

Doubts about GCM regional output.

General Circulation Models (GCMs) produce estimates of climatic variables for a regular network of grid pints across the globe. Results from about 20 GCMs have been report to date (e.g., see IPCC, 1990a and 1992a). However, these estimates are uncertain because of some important weaknesses of GCMs. These include:

- Poor model representation of cloud processes.
- A coarse spatial resolution (at best employing grid cells of some 200 km horizontal dimension in model runs for which outputs are widely available to impact analysis).
- Generalized topography, disregarding some locally important features.
- Problems in the parameterization of sub-grid scale atmospheric processes such as convection and soil hydrology.
- A simplified representation of land-atmosphere and ocean-atmosphere interactions.

As a result, GCM outputs, though physical plausible, often fail to reproduce even the seasonal pattern of present-day climate observed at a regional scale. This naturally casts some doubt on the ability of GCMs to provide accurate estimates of future regional climate. Thus GCM outputs should be treated, at best, as broad-scale sets of possible future climatic conditions and should not be regarded as predictions." (WGII FSM (Chapter 26, Technical Guidelines), section 6.5.3).

"The interpretation of transient simulations is complicated, however, by two important problems associated with the coupling of atmospheric and ocean models. First, the models commonly exhibit drift in the control simulation, such that the global mean temperature at the end of the simulation deviates from that at the start. This may be an expression of natural climatic variability, or a result of poor initialization of the ocean model or errors in the coupling of the ocean and atmosphere models. Second, transient simulations exhibit the so-called 'cold start' problem (Hasselmann etl al., 1993). This refers to the assumption that the climate is in equilibrium at the start of a simulation, with GHG concentrations representative of conditions in recent decades. However, this is not the case, as there has been a considerable build-up of GHGs since pre-industrial times, and the recent climate is certainly not in equilibrium." (WGII FSM (Chapter 26, Technical Guidelines), section 6.5.3).

"Additional problems with transient simulations include the inability of current ocean models adequately to

resolve boundary currents and deep convection, and their poor performance in reproducing the El Nino/Southern Oscillation (ENSO) phenomenon." (WGII FSM (Chapter 26, Technical Guidelines), section 6.5.3).

"Although some of the principal linkages between climate and the hydrological system are well understood, predicting the effects of global warming is very uncertain. Current general circulation models (GCMs) work at a spatial resolution that is too coarse for hydrological purposes, producing weather averaged over too large a geographic area and producing average conditions rather than changes in ranges, frequencies, seasonal distributions and so forth. They do not yet include all of the relevant feedbacks between the land surface and the atmosphere. There is considerable uncertainty in the translation of climate changes into hydrological effects through hydrological models and an inability to maintain consistency between GCM and hydrological model water balances, particularly for evaporation. Different models give different sensitivities to change, and a model calibrated under current conditions may not be appropriate under a changed climate. There still are major uncertainties over the effects of increased CO2 concentrations on plant water use--and hence transpiration rates--in natural settings at the catchment scale." (WGII FSM, section 10.1).

"The direct use of GCM output to drive hydrological models is considered inappropriate due to the coarse resolution of the spatial grids used by current GCMs (relative to the scale of river basins); the simplified GCM representations of topography, land surface and cloud processes, and energy transfer within the oceans; and the simplified coupling of the atmosphere and the ocean." (WGII FSM, section 10.2.3.1)

"The current generation of transient GCMs, while much improved, does not offer the degree of watershed-specific information or of anticipated variability in future climate required to allow robust estimates to be made regarding changes in water availability." (WGII FSM, section 14.0).

"A third form of model conspicuously absent is a climate model that could provide *regional* estimates of the climatic change implied by increasing GHG concentrations. The existing climate models are not able to generate reliable estimates on regional temperature, precipitation, and hydrology. Yet much of the forest response that is relevant to socioeconomic assessment varies significantly from one locale or region to another. In addition, in order to assess the quantitative implications of ecophysiological processes under chronic climatic change, climate models must describe the regional and seasonal changes of temperature and precipitation." (WGII FSM, section 15.7.2)

Model testing is the most critical step for establishing credibility of impact projections

"The testing of predictive models is, arguably, the most critical stage of an impact assessment. Most studies rely almost exclusively on the use of models to estimate future impacts. Thus, it is crucial for the credibility of the research that model performance is tested as rigorously as possible. Standard procedures should be used to evaluate models, but these may need to be modified to accommodate climate change. Two main procedures are recommended--validation and sensitivity analysis--and these should always precede more formal impact analysis.

Validation involves the comparison of model predictions with real world observations to test model performance....Climate change introduces some additional problems for validation, since there may be little local data that can be used to test the behaviour of a modelled system in conditions resembling those in the future....Sensitivity analyses evaluates the effects on model performance of altering the model's

structure, parameter values, or values of its input variables....

It is worth noting here that while predictive models offer the most promising means of obtaining estimates of possible future impacts of climate change, in some sectors these are not yet sufficiently developed to be used for this purpose. Where the system are complex and/or poorly understood (e.g., marine ecosystems), considerable efforts are still required to obtain an understanding even of variations in the present-day system. Only after such basic research is completed can meaningful projections be made in the future." (WGII FSM (Chapter 26, Technical Guidelines), section 5.3).

Selection of an appropriate time scale for projections is important

"The only prediction horizon of proven reliability is that provided by weather forecast models extending for days or, at most, a few weeks into the future (Lorenz, 1968). In general few accurate projections of rates of change in socio-economic factors such as population, economic development and technological change can be made for periods beyond 15-20 years into the future). (WGII FSM (Chapter 26, Technical Guidelines), section 3.4.)

"Of course, long time scale projection periods may be wholly unrealistic for considering some impacts (e.g., in many economic assessments where projections may not be reliable for more than a few years ahead)....Caution must be exercised, therefore, in ensuring that the projection period is both relevant for policy but also valid within the limitations of the approach).(WGII FSM (Chapter 26, Technical Guidelines), section 6.2.1.)

IMPACTS ON FORESTS

Land-use changes are as important as climatic changes in determining future forest changes.

"In summary, all models suggest that the world's forest are likely to undergo major changes in the future....This is partly due to the fact that some regions are likely to lose forests for climatic reasons, while climatic gains in other regions might not be realized due to land-use pressures." (WGII FSM , section 1.3.4).

"Tropical forests are likely to be more affected by changes in land use than by climate change as long as deforestation continues at it current high rate (High Confidence)" (WGII FSM , section 1.0).

"One of the most important anthropogenic effects on forest product availability in temperature zones in the past has been intensive land use." (WGII FSM, section 15.4.2).

Models do not agree on climatic impacts.

"Global vegetation models do not agree on whether climatic change (in the absence of land-use change) will increase or decrease the total area of tropical forests....") (WGII FSM , section 1.4.3.1).

In the temperate zone, forested area would change little; types of trees growing may change.

"Compared with latitudinal zones, the potential area for temperature forests is projected to change the least; however, many existing forests will still undergo significant changes in their species composition (High Confidence)." (WGII FSM , section 1.0)

The productivity of boreal forests is likely to increase .

"The net primary productivity of forests not limited by water availability is likely to increase in response to warming, partly mediated by increased nitrogen mineralization." (High Confidence)." (WGII FSM , section 1.0)

"The productivity of boreal forests--except those at the warmer and drier edge of their species ranges--is likely to respond favorably to increases in temperature....".(WGII FSM , section 1.6.4.2)

Accuracy of projected changes in forests is limited

"However, current understanding of the physical and biological interactions between environment and organisms is still rather limited, so these techniques enable us only to project future response as consequences of given assumptions and scenarios and not to make precise forecasts." (WGII FSM , section 1.3)

Many forests can adapt to climate change. Human assistance can be beneficial

"Forests themselves may to some extent acclimate or adapt to new climatic conditions, as evidence by the ability of some species to thrive outside of their natural ranges. Also, elevated CO2 levels may enable plants to use water and nutrients more efficiently....Consideration may, therefore, be given to human actions that minimize undesirable impacts."(WGII FSM , section 1.3.7)

Large-scale forest fires are expected to be rare in the temperate zone. Fires are normal in the boreal forest.

"However, large-scale fires may continue to be rare in the temperate zone and confined to drier parts of North America, Australia, and the Mediterranean region because temperature forest most occur in dissected landscapes in countries that can afford fire-control measures." (WGII FSM , section 1.5.4.5)

"Natural wildfires are ubiquitous throughout the boreal region because of the buildup of large amounts of litter, much of which is not only resistant to decomposition but is also highly flammable. In the absence of fire-suppression measures, the interval between fires (the fire cycle) ranges from 50 to 200 years from south to north but may be over 1,000 years in wet northern ecosystems." (WGII FSM , section 1.6.2)

IMPORTANCE OF MANAGEMENT DECISIONS

Non-greenhouse gas activities may have greater impacts than climate change.

"In rangelands, the amount and timing of precipitation are the major determinants of community structure and function....Most rangelands do not exist in a state of equilibrium, nor do they exhibit linear successional trends; rather, they fluctuate from one state to another depending on rain, fire, grazing, and other anthropogenic factors....However, in managed rangeland systems, management is likely, at present, to maintain the systems in the desired state. In many areas, however, poor management of rangelands enhances the changes likely to be caused by climatic/atmospheric change--for example, by increasing the ratio of woody to herbaceous vegetation." (WGII FSM , section 2.1)

"The impacts of climate change on the health of the land should be considered in parallel with the effects of existing pressures caused by unsustainable land management--because it is often impossible to separate the effects of these impacts and because the cumulative impact on soils is often greater than a simple summation." (WGII FSM , section 4.1)

"Because humans have influenced mountain ecosystems in many different ways throughout history, anthropogenic impacts generally cannot be dissociated from climate change impacts. Climatic influences are often obscured by the impact of change in land use." (WGII FSM, section 5.2.4).

"Human activities--such as the conversion of wetlands to agricultural and forest lands, construction of dams and embankments, and peat mining--already pose a serious threat to wetlands worldwide. Mainly as a result of these activities, it is estimated that more than half of the world's wetlands have disappeared during the last century. These anthropogenic effects are most notable in densely populated areas and are expected to increase, especially in developing countries....For wetland functions that are local in scale (habitat value, pollution trapping, and to some degree flood control), possibilities exist for adaptation, creation, and restoration." (WGII FSM, section 6.0).

"Apart from climate change, the most common disturbances to the hydrological regimes of wetland ecosystems are alterations n plant communities, storage of surface water, road construction, drainage of surface water and soil water, alteration of ground water recharge and discharge areas, and pumping of ground water. All of the anthropogenic activities and natural causes mentioned in Table 6-1 will, to various extents, impact the hydrology of wetlands." (WGII FSM, section 6.3.4).

"Many studies, however, have found that direct human reclamation of wetlands for a range of purposes is a much bigger threat than sea-level rise." (WGII FSM, section 9.5.2.2)

"Human activities are interfering with the hydrological cycle in many regions and catchments." (WGII FSM, section 10.2.2). This section contains a good summary of the non-climatic impacts of human activities on water. Shows there is much to do , without focusing on GHG emissions.

"...the human settlements most vulnerable to climate change are likely to be in locations already stressed by high rates of population growth, urbanization, and environmental degradation." (WGII FSM, section 12.0).

Factors other than climate change can overwhelm climate change

"Local environmental and socioeconomic situations are changing rapidly for reasons other than climate change. Worldwide, population growth, industrialization, urbanization, poverty, technological changes, and government policy could overwhelm any effects of climate change." (WGII FSM, section 12.0).

"A major difficulty in determining the impact of climate change on human habitat is the fact that many other factors, largely independent of climate change, are also important. In many cases, these others factors are far more important than climate change in terms of the risk they pose for human settlements. These non-climate factors will also increase the vulnerability of some regions to climate change. The most important of these factors include population growth, urbanization and industrialization, technology choices, and government policies. Other social factors, such as cultural clashes and warfare, also play a role." (WGII FSM, section 12.2).

"Most obviously, forces other than climate will probably overshadow the impact of ecosystem responses to climate early on (the next 50 years)." (WGII FSM, section 15.5.3).

"Globally, overfishing and diverse human stresses on the environment will probably continue to outweigh climate-change impacts for several decades." (WGII FSM, section 16.2.2.3)

"Future erosion risk is more likely to be influence by increases in population density, intensive cultivation of marginal lands, and the use of resource-based and subsistence farming techniques than by changes in climate. One can anticipate that erosion, mass movement, and landslides are most likely to increase in an near regions of high population density." (WGII FSM, section 4.2.5).

Adaptation strategies can protect against the impacts of climate change on rangeland

"By the time there is a detectable rise in mean temperature of a degree or two, pastoral societies may already have begun to adapt to climate change....One management option for the future is to actively change species composition of selected rangeland....In some grass dominated rangeland systems, improved pastures may help people to adapt livestock grazing strategies. In these systems, there is significant intervention--including selection of forage type, selective animal breeding, pasture renewal, irrigation, and other practices (Campbell and Stafford Smith, 1993). This intervention provides opportunities for graziers to adapt systems so they are protected against negative effects of global change and so that any potential benefits are realized." (WGII FSM , section 2.9)

"Practices listed in table 2.5 may prove useful in GHG mitigation".(WGII FSM , section 2.10)
note: table 2.5 provides an impressive list of options for the rangeland sector which do not require the elimination of GHG emissions

Management of the land is a more important issue in desertification than climate change.

"Human-induced desertification has the potential to counteract any ameliorating effect of climate change on most deserts unless appropriate management actions are taken." (WGII FSM , section 3.0)

"Even if wetter conditions were to prevail, the 'greening' of the deserts would often be negated by pressure from the expanding human population and the associated desertification problems (see chapter 4)." (WGII FSM , section 3.5)

"In essence, desertification results form a combination of drought and mismanagement of land--in particular, the disharmony between land use and management of land on the one hand and the soil and prevailing climate on the other." (WGII FSM, section 4.4).

"Currently, there is disagreement as to whether human impacts or climatic factors are the primary agents responsible for the desertification of the world's arid and semi-arid lands.

Some evidence suggests that human impacts arising from overstocking, overcultivation, and deforestation are primarily responsible for the process." (WGII FSM, section 4.4.2).

"The limited information that is available suggests that land degradation is a major global problem that urgently needs to be addressed." (WGII FSM, section 4.6.1).

Technological Solutions to Greenhouse Gas Reductions are significant

"In the energy supply sector, we conclude with a high degree of confidence that GHG emissions reductions can be achieved through technology options...It is not possible, however, to identify a least-cost future energy system for the longer term because the relative costs of options depend on resource constraints and technological opportunities that are imperfectly known, as well as on actions of governments and the private sector." (WGII FSM, section 19.0).

"The world energy supply system is huge, and many of the installations have economic lifetimes measured in decades. Annual worldwide investments are on the order of $150 billion. This means that changes will take considerable time to implement. However, within a period of 50-100 years, the entire energy supply system will be replaced at least twice. New investments to replace an old plant or to expand capacity are opportunities to adopt technologies that are more environmentally desirable at low incremental cost. Significant reductions in GHG emissions will not be achieved by a few scattered improvements. New technologies must become characteristic for all new investments to reduce net carbon emissions significantly." (WGII FSM, section 19.1).

"It is not realistic to probe the deep future by taking into account only currently available commercial technologies." (WGII FSM, section 19.3).

"It is important to have a government energy R&D strategy that does not attempt to pick winners. Fortunately, many of the technologies that can reduce emissions at costs comparable to those projected for conventional energy, such as fuel cells, and most renewable energy technologies, require relatively modest investments in R&D. This is a reflection largely of the small scale and modularity of these technologies

and the fact that they are generally clean and safe (Williams, 1995b). As a result, it should be feasible, even with the limited resources for R&D, to support a diversified portfolio of options. It has been estimated that research and development of a range of renewable energy technologies would require on the order of $10 billion (WEC, 1994). (WGII FSM, section 19.4).

"R&D programs are necessary but not sufficient to establish new technologies in the marketplace. Commercial demonstration projects and programs to stimulate markets for new technologies are also needed....Total investment for R&D and deployment would thus be $15-20 billion". (WGII FSM, section 19.4).

"Industrial GHG emissions can be achieved by good housekeeping (operational performance), additional investments in energy-efficient technologies (both conversion and end-use equipment), or redesigning the manufacturing process itself (process innovation and integration). (WGII FSM, section 20.5)

"Seeing is believing. Often, the amount of uncertainty associated with a new technology being applied to a new situation with untested goals and techniques is too great to convince managers to invest in it--even if theory indicates no only that the investment will be safe but also that it will return dividends throughout its lifetime. However, if those same managers see the technology successfully applied to a test bed under conditions that resemble their company's situation, they might be more convinced that it would work for them. Such demonstrations can be offered by government agencies, trade groups, developers of the technology, utilities, corporation or other institutions. Cooperative efforts often are most effective." (WGII FSM, section 20.5.7).

"Great use of available, cost-effective technologies to increase energy efficiency in buildings could lead to sharp reductions in emissions of CO2 and other gases contributing to climate change" (WGII FSM, section 22.5.1).

Industry has been improving greatly

"Regarding specific industry emissions, energy-intensive industries such as chemicals, cement, and steel have shown substantial improvements in energy efficiency during the past 20 years, albeit unevenly in different countries." (WGII FSM, section 20.0).

"Energy use in the industrial sector varies vastly among different countries." (WGII FSM, section 20.1).

"Given these energy-demand trends, and taking into account the industrial-fuel-composition changes toward natural gas, the general trend for GHG emissions from fuel combustion in the manufacturing sector of industrial nations in the past 2 decades has been downward. The overall decrease from 1973 to 1991 was about 15%)...."(WGII FSM, section 20.2.3.1).

Emissions from developed countries will rise gradually. Emissions from developing countries will rise rapidly.

"...Under business-as-usual conditions, emissions from industrial countries will continue to grow moder-

ately but with a gradual shift away from energy-intensive industries." (WGII FSM, section 20.2.3.1).

"Industrial energy use in developing countries is dominated by China, India and Brazil. The developing world as a whole is experiencing an upward and accelerating trend in industrial GHG emissions." (WGII FSM, section 20.2.3.3).

"The largest single additive impact in all respects will come from industrial growth in developing countries...Although the potential for reductions in specific energy use are large, they are likely to meet severe implementation problems, and they will be insufficient to counteract the other effects in a major way. The aggregate effect will lead to a relatively rapid increase in GHG emissions." (WGII FSM, section 20.2.3.3).

"Implementation problems for energy-efficiency improvements in developing economics are more severe than those in industrial countries. In addition to the problem areas already indicated, key problems in both developing and transitional economies concern the economy-wide lack of capital, foreign exchange, and industrial energy prices and tariffs that often are below those of the world market. Because energy-saving investments are often characterized by capital and foreign-exchange intensity rather than by labor and resource intensity, their cost-effectiveness tends to be less in those countries than in the industrialized countries. Moreover, developing and transitional economies, in general, are characterized by lower overall productivity, including energy productivity. One should not attempt to solve energy-efficiency problems in isolation from other efficiency problems. Problems related to vintage equipment, scarcity of management skills, small-scale production, or poor technological infrastructure will not be solved by addressing climate-change or energy goals only. (WGII FSM, section 20.5.3.2).

"The potential for the greatest growth in CO2 emissions--in both percentage and absolute terms--is in the developing world, where per capita energy consumption in human settlements is very low." (WGII FSM, section 22.0).

"Second, growth in both the number of households and in equipment stocks per household is increasing much faster in the developing countries than in the industrial countries, and the average efficiency of new equipment is lower because of the need to keep initial costs low...Thus, there is much potential to affect future CO2 emissions by improving the efficiency of residential buildings and appliances in these countries." (WGII FSM, section 22.4.1).

"In the developing countries, the most important appliance to target for efficiency improvement in the near term is the refrigerator, whose saturation is growing rapidly. In the longer term, air conditioners will be of great importance. The majority of refrigerators and air conditioners sold in the developing world are well below state of the art...." (WGII FSM, section 22.4.1.5).

Technology transfer is a crucial issue

"Because future global industrial growth will take place largely in the developing and transitional economies, the early transfer of advanced energy-conservation technology may be crucial to curb worldwide GHG emissions. Developing countries might even jump from an early stage of industrial development to an advanced stage in one step. Such leapfrogging makes sense only if the new technology is economically superior to the old technology over its life cycle and capital is available to purchase it." (WGII FSM, sec-

tion 20.5.2).

"In regard to technology transfer, two issues are still unclear. one is trade barriers in the form of import tariffs and legal barriers for the protection of intellectual-property rights. Such barriers affect the adoption of high-tech components of energy-efficient equipment. A balance between the interests of developing nations and the interests of industrial firms elsewhere must be struck....Nevertheless, joint implementation could potentially be viewed as a mechanism to make private capital available for the transfer of energy-efficient technology." (WGII FSM, section 2.5.2).

RAINFALL RELATED IMPACTS

Projected increase in global precipitation.

"GCMs suggest a globally averaged increase in precipitation of about 2.5% per degree of warming." (WGII FSM , section 1.3.1.1)

note: this means that the current 0.5 C warming over the past 100 years could, at most, have produced a 0.5% increase in precipitation.

Rainfall will increase in some desert areas and decrease in others

"....some desert regions will receive more rainfall than at present, most will remain extremely arid....Decreased rainfall is predicted for large parts of the Sahara, northern Arabian, Sonoran, and central and western Asian deserts. Rainfall in the Chihuahuan, southern Arabian, and Atacama deserts is predicted to increase slightly or remain the same, wile some of the arid regions of Central Australia are predicted to have significant increases in precipitation." (WGII FSM , section 3.4.2)

GCMs are poor predictors of changes in rainfall and surface wind speed.

"General circulation models (GCMs) can provide a range of climate scenarios, but these alone are not sufficient to predict future erosion risk, particularly because GCMs are currently poor predictors of changes in rainfall intensity and surface wind speed." (WGII FSM , section 4.2.1)

Decreased rainfall will not affect irrigated agriculture

"Irrigated farming may not suffer from increased aridity even if water availability becomes more difficult. Improved irrigation practices (e.g., generalized drip irrigation, underground irrigation) can save up to 50% water compared with conventional irrigation systems. Under more arid future conditions one could expect a very large increase in the use of irrigation, in addition to the expansion of controlled farming, crop genetic improvement, and the expansion of winter-growing crops that are much less demanding on water.

In most arid and semi-arid countries, wasted water is common, particularly in agriculture (due to inefficient irrigation systems). The amount of waste commonly reaches 50% in many countries, but such

waste often is easy to prevent with appropriate techniques." (WGII FSM, section 4.4.4.1)

Impact on wetlands of climate change is uncertain. Temperature effects may be limited.

"It is difficult to determine the vulnerability of specific types of non-tidal wetlands to climate change. One line of reasoning suggests that wetlands in naturally stressed environments appear to tolerate less additional stress than those located in favorable conditions....A second line of reasoning suggests that wetland types that have a large degree of inherent exposure to high spatial and temporal variation in environmental conditions may have a greater potential for adaptation to climate change." (WGII FSM, section 6.3.1).

"Some modeling studies have indicated that there may be a threshold temperature beyond which changes in precipitation become less important to wetland hydrology. In one study, Poiani and Johnson (1993) conclude that precipitation changes are much less influential on hydrological regimes under a +4C scenario than under a +2 C scenario." (WGII FSM, section 6.3.2.2).

"At present, regional scenarios do not provide adequate information to determine the direction or magnitude of change in the areal extent of wetlands (Gorham, 1991). It seems likely that some wetland regions will become moisture-limited, while other non-wetland areas will develop a climate conducive for wetland development. At this time, however, any estimation of the change in global areal extent would be very uncertain." (WGII FSM, section 6.3.3.1).

Water availability will be a problem in the future regardless of climate change

"The results show that in all countries with high population growth rates, future per capita water availability will decrease independently of the assumed climate scenario." (WGII FSM, section 14.2.3).

POSITIVE IMPACTS OF GLOBAL WARMING

"The potential effects of climate change on resources and products range from significantly negative to significantly positive." (WGII FSM, section 8.4) (see associated table for a nice listing of negative and positive effects).

"Some of the impacts of global climate change are beneficial, some are neutral, and some are adverse." (WGII FSM, section 8.5.3).

"Climate change does not directly lead to air, water, or soil-column pollution." (WGII FSM, section 12.3.3)

"One study (Stzepek et al., 1995) suggests that, although the global water conditions may worsen in 2025 due to population pressure, climate change could have a net positive impact on global water resources." (WGII FSM, section 14.2.3)

OFFSHORE OIL INDUSTRY RECOGNIZED

"For instance, offshore oil and gas platforms are now seen as having value for monitoring dimensions of climatic change." (WGII FSM, section

IMPACTS ON EXTREME EVENTS

Droughts are not getting worse.

"However, other than those areas under the influence of the (ENSO) and the few areas with longer-term droughts such as the Sahel, there is little evidence for recent changes in drought frequency or intensity in arid and semi-arid lands." (WGII FSM, section 4.4.1).

Not possible to say if tropical cyclones will get worse

"It is presently uncertain whether the frequency and severity of tropical cyclones will increase due to climate change." (WGII FSM, section 8.0)

"It is not possible to say if the intensity, frequency, or locations of cyclone occurrence would change in a warmer world (High Confidence)." (WGII FSM, section 9.0).

"Although there is uncertainty, the extent of damage caused by great windstorm catastrophes has expanded in recent years. The concentrations of people living in high-risk coastal regions must be considered the main reason for this alarming trend....It is therefore quite possible to get a scientific assessment of low injury to an ecosystem combined with high economic loss value, especially given that the value of waterfront real estate is normally high (see also chapter 17). The reverse is also true: major ecological damage might occur with little economic loss." (WGII FSM, section 8.3.1.5)

"At present, there is no evidence of any systematic shift in storm tracks." (WGII FSM, section 9.3.2)

"Despite the often repeated assertion that climate variability could increase in a warmer world, there is little evidence from climate models to support this notion." (WGII FSM, section 9.3.2).

Storm damages are rising for non-climatic reasons. Extreme events are not increasing in severity.

"There are several reasons for the escalation in the cost of severe weather. Developed countries have become wealthier. Many more people now live in coastal areas with costly infrastructures. Personal goods and business processes are generally more vulnerable to water damage. The built environment also contributes through inappropriate or incorrect design and construction. The insurance industry has compounded matters by extending the basis of coverage. It is a common perception in the insurance industry that there is a trend towards an increased frequency of severity of extreme climate events. The meteorological literature fails to substantiate this in the context of long-term change, though there may have been a shift within the limits of natural variability." (WGII FSM, section 17.0).

"These authors failed to find any trend that could not be explained by data inhomogeneities. A related insurance study failed to find any trend in UK storminess over 60 years...but other studies show a correlation between winter storms and temperature...Again, it has been suggested that this is due to inhomogeneities in compiling weather maps." (WGII FSM, section 17.4.1).

"The recognized source of information on future climate change is the General Circulation Model, or GCM...but at present GCMs are of limited use to the financial sector, for the following reasons:

- The length of the model run is generally too short for statistical analysis of extreme events....
- For analysis of extreme events, model output may be required at the daily time scale. Validation of variables (e.g. daily temperature) generally demonstrates inadequacies...
- Current models cannot generate sufficient spatial detail....
- There may be lack of consistency in model results...." (WGII FSM, section 17.4.2)

SEA LEVEL RISE

Land movement can be more serious than sea-level rise

"With respect to the coastal environment, it is relative sea-level that is most important--that is, the level of the sea in relation to that of the land. Regionally, and locally, vertical land movement can be quite large, even on the decadal time scale. For example, parts of Scandinavia experience uplift (and thus a relative sea-level decline) of about 1 meter per century....In contrast, the Mississippi delta is experiencing subsidence (a relative sea-level rise) of about 1 meter per century...." (WGII FSM, section 9.3.1.2).

IMPACTS ON FOOD SUPPLIES

"Given the wide range of microclimates already existing in mountain areas that have been exploited through cultivation of diverse crops, direct negative effects of climate change on crop yields may not be too great." (WGII FSM, section 5.2.4.1)

"The impact of climate change on human populations in terms of famine, chronic hunger, health, and nutrition will depend on how and whether currently poor areas develop over the next 20 to 50 years. The future path of development of currently vulnerable countries remains uncertain. Policy failures, wars, and political and civil unrest are identified causes, but correcting these problems has proved difficult (e.g., van Dijk, 1990/91; Anand and Ravallion, 1993). Lagging agricultural development has been identified as a consequence of significant policy distortions in many developing countries, conflicting with the industrial sector and limiting the ability of the broader economy to grow." (WGII FSM, section 13.8.1.5).

"While uncertainties continue to exist about the direction of change in global agricultural production resulting from climate change, changes in the aggregate level of production have been found to be small to moderate." (WGII FSM, section 13.8.2)

"More recent work considering global agriculture under climate change found far greater potential for global agriculture to adapt to changing climate than earlier studies." (WGII FSM, section 13.8.2)

"A number of studies indicate that adaptation and adjustment will be important to limit losses or to take advantage of improving climatic conditions....If climate change is gradual, it may be a small factor that goes unnoticed by most farmers as they adjust to other more profound changes in agriculture stemming from new technology, increasing demand for food, and other environmental concerns such as pesticide use, water quality, and land preservation." (WGII FSM, section 13.9)

INTENTIONALLY

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POLICY OPTIONS

Lessons that apply to all policies

"In addition, several lessons have been learned from past experience that apply to all policies:

- All policies should be evaluated frequently to determine their effectiveness.
- Many policies work in combination with others. Mutually reinforcing regulatory, information, incentive, and other programs offer the best hope....
- Finally, policy experimentation should be encouraged on a small scale. The process of experimenting, evaluating, improving, and expanding can result in policies that will successfully implement the wealth of technologies now available for reducing the emissions of gases contributing to climate change." (WGII FSM, section 22.5.1.8).

Impacts of policies must be considered in evaluating impacts of climate change

"A final factor to consider in projecting socio-economic trends under a changing climate is the effect that various policies designed to mitigate climate change might themselves have on the future state of the economy and society. For example, policies to reduce fossil fuel consumption through higher energy prices might alter the pattern of economic activity, thus modifying the possible impacts of any remaining (unmitigated) changes in climate that may occur)." (WGII FSM (Chapter 26, Technical Guidelines), section 6.7).

"Effective adaptation to climate change and sea-level rise therefore requires a flexible coastal management strategy at all time scales, that incorporates and integrates both short-term and long-term goals." (WGII FSM, section 9.6)

"The applicability of any option must be evaluated against (among other things) a background of a country's technology and human resources capability, financial resources, cultural and social acceptability, and the political and legal framework. This is not to suggest that these constraints are not insurmountable but that decision makers must be realistic when considering the range of options available to them." (WGII FSM, section 9.6.3)

"The technological capacity to adapt to climate change will be realized only if the necessary information is available and the institutional and financial capacity to manage change exists. Autonomous adaptation cannot be relied upon, and governments may have to set a suitable policy framework, disseminate information about climate change, and act directly in relation to vulnerable infrastructures. Many developing countries are dependent on single crops or on fishing and therefore are economically vulnerable to climate change through impacts on agroindustry. Diversifying economic activity could be an important precautionary response that would facilitate successful adaptation." (WGII FSM, section 11.0).

Addressing needs that will occur anyway can offset many adverse effects of climate change

"Adaptation is concerned with responses to both the adverse and positive effects of climate change It refers to any adjustment, wither passive, reactive or anticipatory, that can respond to anticipated or actual consequences associated with climate change. Many policies of adaptation make good sense in any case,

since present-day climatic variability (in the form of extreme climatic events such as droughts and floods) already causes significant damage in different parts of the world. Adaptation to these events can thus help to reduce damage in the short term, regardless of any longer-term changes in climate....the identification and evaluation of adaptation options is an essential component of impact assessment." (WGII FSM (Chapter 26, Technical Guidelines), section 8.1.)

"Many of these strategies will be beneficial regardless of how or whether climate changes." (WGII FSM, section 13.9.2.)

"However, if a rational management strategy is undertaken to deal with reasonably foreseeable needs of a region in the absence of climate change, according to the principles espoused in Agenda 21, that strategy will also serve to offset many of the range of possible adverse consequences of climate change." (WGII FSM, section 14.4.1)

"The list of nations with water supply problems will expand with the accelerated pace of urbanization. By the year 2030, urban populations will be twice the size of rural populations...Addressing these issues would make it easier to cope with the impacts of climate change when if they become significant.). (WGI FSM, section 14.4.2).

"The reality is that increasing water demands will intensify competition for scarce water and further concentrate water use in urban centers. During the next 30 years, these real and complex needs will preoccupy water managers. Water management planning will address these needs, which precede the climate change signal and thereby serve as a *de facto* adaptation mechanism. Climate change, in its many manifestations, is likely to be a perturbation on what are already difficult and complicated water management problems. Existing drainage systems, water control structures, and conveyance and distribution systems are typically designed on the basis of design floods or droughts of different return periods and/or annual exceedance probabilities, which are derived from past failures and associated perceived degrees of tolerable risk and economic costs. Because there is a significant turnover in water management infrastructure, with considerable maintenance and major rehabilitation occurring in most countries about every 30 years, it can be expected that the operating capacity of such structures can be made to conform to the evolving changes in climate." (WGII FSM, section 14.4.2).

The only tax that makes sense is a global tax

"Internalizing environmental costs in energy prices and tariffs through ecotaxes is particularly problematic for the industrial sector because of the consequences for national competitiveness on international markets. Taxes that are not levied on a global scale make provoke industry relocation, which may adversely affect emissions efficiency as well as international competitiveness. Most countries are hesitant to embark on policy ventures that might endanger their international market position and their attractiveness as industrial locations....It is difficult for a single nation to impose full environmental cost accounting and remain competitive unless other nations do the same." (WGII FSM, section 20.5.3.3).

Reducing emissions in the transportation sector will be challenging

"Experts may not agree on the best approach among options and sometimes give conflicting advice. Nevertheless, there is an emerging consensus that attempts to move traffic to less energy-intensive modes de-

pend on using well-integrated strategies designed specifically for local situations....In many circumstances, strategies may not be implemented if they might reduce the benefits provided by transport systems to individuals and firms. Greenhouse gas mitigation strategies will have to address this issue and find ways to meet or change the needs and desires currently met by energy-intensive transport. Preferences in travel behavior are driven by social and cultural factors, as well as by cost-effectiveness in meeting needs." (WGII FSM, section 21.0).

"There are several factors that lead to inertia in the development of transport systems: Technologies and fuels now in the laboratory can require several decades for commercialization; transport infrastructure is developed slowly and has an influence that can last for centuries; stakeholders may be reluctant to change their practices; and transport user behavior and choice may also develop slowly in response to a changing environment. Once transport systems are developed to service the car, truck and airplane, it is very difficult to reverse the shift away from nonmotorized and public transport." (WGII FSM, section 21.0).

"The technical potential usually improves with time as new fuels, prime movers, materials, design techniques, and operating systems become available. The economic and policy potentials do not necessarily improve; they depend on the economic and other priorities of the providers and users of transport services. The extent to which these potentials are achieved depends on a complex interaction among technology, the economy, and choices made by consumers, producers, and policymakers. It is this interaction that most needs to be understood and addressed if policymakers wish to reduce greenhouse gas emissions from the transport sector. (WGII FSM, section 21.3.1).

Greenhouse gas emission reduction in the transport sector, more than in any other sector, depends on obtaining cooperation among the various stakeholders or interest groups who are able to take action or who might be affected by policies. " (WGII FSM, section 21.4.7).

"In addition to the importance of stakeholder consultation to obtain information about their needs and activities, measures in the transport sector are more likely to be effective if the people who will be influenced by the outcome are involved in the decision-making process....Consultation can be one of the most valuable steps in decision making more generally, as it may generate new ideas, can help to select the most satisfactory outcomes, and can help to give the eventual users of the system a sense of ownership." (WGII FSM, section 21.4.7).

HUMAN HEALTH

"A range of adaptive mechanisms for offsetting the potential human-health effects of global warming lie in improving certain aspects of health services and other public services that settlements provide in any case (World Bank, 1993). Improved sanitation and water treatment both reduce the spread of waterborne diseases and may provide a measure of safeguard against importing exotic enteric waterborne diseases such as cholera.....Finally, disease surveillance could be strengthened and integrated with other environmental monitoring to design early warning systems; develop early, environmentally sound public health interventions; and develop anticipatory societal policies to reduce the risk of outbreaks and subsequent spread of epidemics." (WGII FSM, section 12.5.6).

"Populations with different levels of natural, technical, and social resources would differ in their vulnerability to climate-induced health impacts. Such vulnerability, due to crowding, food insecurity, local environmental degradation, and perturbed ecosystems, already exists in many communities in developing

countries. Hence, because of both the geography of climate change and these variations in population vulnerability, climate change would impinge differently on different populations." (WGII FSM, section 18.0).

"Adaptive options to minimize health impacts include improved and extended medical care services; environmental management; disaster preparedness; protective technology (house, air condition, water purification, vaccination, etc.); public education directed at personal behaviors; and appropriate professional and research training. It will also be important to assess in advance any risks to health from proposed technological adaptations (e.g., exposures that could result from using certain alternative energy sources and replacement chemicals for chlorofluorocarbons; effects of pesticide use on resistance of vector organisms and their predator populations." (WGII FSM, section 18.0)

"In already endemic areas, especially in the subtropics, malaria may increase (although in some hot climates, further temperature increases may shorten the life span of mosquitoes, and local malaria transmission would then decrease)." (WGII FSM, section 18.3).

"At the population level, environmental management of ecosystems. (e.g., freshwater resources, wetlands, and agricultural areas sensitive to invasion by vectors, etc.) public health surveillance and control programs (especially for infectious diseases), and introduction of protective technologies (e.g., insulated buildings, air conditioning, strengthened sea defenses, disaster warning systems) would be important. Improved primary health care for vulnerable populations could play a significant role in reducing a range of health impacts, including some vector-borne and other communicable diseases, and the effects of extreme events....." (WGII FSM, section 18.5).

"Of course, it is not possible to attribute particular, isolated, events to a change in climate or weather pattern; other plausible explanations exist for each of them, and a number of different factors may combine to produce each event." (WGII FSM, section 18.7).

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