AVOID is a DECC/Defra funded research programme led by the Met Office in a consortium with the Walker Institute, Tyndall Centre and Grantham Institute.

AVOID – providing key advice to the UK Government on avoiding dangerous climate change

AVOID – Avoiding dangerous climate change

Are the emission pledges in the Copenhagen Accord compatible with a global aspiration to avoid more than 2°C of global warming?

A technical note from the AVOID programme

Lowe J.A.[1], Gohar L.K.[1], Huntingford C.[2], Good P.[1], Bernie D.[1], Pardaens A.[1],Warren R.[3] and Raper S.C.B.[4]

1: Met Office Hadley Centre, Exeter, U.K.
2: Centre for Ecology and Hydrology, Wallingford, Oxfordshire, U.K.
3: University of East Anglia, Norwich, U.K.
4: Centre for Air Transport and the Environment, Manchester Metropolitan University, Manchester, U.K.

What does the science tell us that the Copenhagen Accord will achieve?

Headlines

1. New work from the AVOID consortium looks at the implications of the Copenhagen Accord for global mean temperatures, ocean acidification and sea level rise.

2. The 2020 pledges alone and no further cuts after 2020 are very unlikely to limit the global temperature rises to 2°C in 2100 let alone beyond 2100.

3. The current 2020 target is a significant first step. It is still feasible to limit warming to 2°C, with a 50% probability, but it would be extremely challenging and depend on substantial cuts in global emissions after 2020.

4. When the emissions are reduced enough to limit 21st century warming to 2°C, the expected increase in 21st century ocean acidification can be reduced by almost two thirds, and the sea level rise by around one third (relative to a business as usual scenario, in this case the A1B SRES IPCC scenario).

What are the numbers that underline these headlines?

5. In the Copenhagen Accord nations have pledged reductions in greenhouse gas emissions for 2020 and in some cases 2050. Many countries have given low and high targets for 2020 and we have used both in our analysis.

6. We assess that the 2020 emissions pledges lead to global emissions of between 49.4 Gt CO_2e/yr (low pledge) and 48 Gt CO_2e/yr (high pledge).

7. To estimate temperatures to 2100 we also had to estimate emissions after 2020 - we have considered three different assumptions about the way long-term emissions will evolve.
    - Reference case: Lowest emission pledges followed by no further reductions in emissions after 2020. Temperature increases are very likely to be above 2°C and there is a 50% chance of temperature rises being limited to 3°C.
    - Continued reductions "_case1": Highest emissions pledges followed by substantial further emission reductions. Annex 1 nations would reduce emissions by 80% of 1990 levels by 2050 and non-annex 1 nations would reduce emissions to 57% below their business-as-usual emissions by 2050. Reductions would continue beyond 2050.
    - Continued reductions "_case2": By 2050 the annex 1 reductions are 95% below 1990 levels and non annex 1 reductions are 53% below business-as-usual.

    In both case 1 and case 2 there is a 50% chance of temperature rises being limited to 2°C during this century.

8. To limit temperature rises to 2°C beyond 2100 even greater emissions reductions would be required – as shown by earlier AVOID work.

How does this compare with other people's results?

9. Other researchers have estimated that the Copenhagen pledges will lead to 2020 emissions being between 46.7 Gt CO_2e/yr and 54.8 Gt CO_2e/yr, and our numbers are within this range, albeit toward the lower end of the range.

10. These emission reduction pledges are also not sufficient to reach the "climate responsible" target of 44 GtCO_2e in 2020 suggested by Lord Stern.

Background information

11. AVOID is a consortium led by the Met Office involving The Walker Institute, Tyndall Centre and Grantham Institute in a programme funded by DECC and Defra. The Manchester Metropolitan University and the Centre for Ecology and Hydrology have also contributed to this study.

12. These results are subject to uncertainty; assumptions have been made about the values of the emission pledges, the construction of the emission pathways and the range of scientifically possible outcomes. In particular, one alternative study concludes that the emission pledges may only lower emission to 54.8 Gt CO_2e/yr in 2020, which would make achieving 2°C more difficult. Furthermore, if lower sulphate aerosol forcing is used, this can raise the temperature prediction for 2100 by around 0.2°C or more.

1. Introduction

We consider here whether the emission pledges in the annex to the Copenhagen Accord are compatible with limiting global average warming to no more than 2ºC above pre-industrial levels. This is a complex task for several reasons. First, the pledges can be interpreted in a variety of ways leading to a range of emissions in 2020. Second, the accord focuses on emission reductions in the year 2020 but estimating the temperature throughout the 21st century also requires information on the emissions at later times. Our approach is to construct future scenarios that include ranges for year 2020 emissions and also test a set of alternative assumptions for emissions after 2020. We highlight that the conversion from emissions trajectories to climate change trajectories is subject to multiple scientific uncertainties[1].

For illustrative purposes we also provide projections of other key climate attributes. This includes estimates of the spatial patterns of warming, the time series of ocean acidification and the time series of sea-level rise.

2. Methodology

2.1 Converting the Copenhagen pledges into national 2020 emissions

The submissions to the UNFCCC of national pledges to reduce emissions by 2020 are available in the appendices to the Copenhagen Accord. We briefly describe here how we used the information from these pledges to calculate absolute emissions in 2020 for Annex 1 and non-Annex 1 nations.

The majority of Annex 1 countries pledged 2020 emissions reductions relative to 1990. Using the national inventories compiled by the UNFCCC for greenhouse gases excluding land use changes, this enables the 2020 emissions to be derived directly from the pledge and the 1990 emissions for each country. In the case of Annex 1 countries with emissions pledges relative to another baseline year, the pledges were converted to a 1990 baseline year using the historical UNFCCC emission data. In the case of Australia's emission pledge, emissions from land use changes were also included.

Most non-Annex 1 countries' 2020 pledges are expressed relative to a national business-as-usual (BAU) scenario. In a few cases actual BAU estimates for 2020 are provided by the countries. In other cases, where a percentage emission reduction on BAU is pledged, the BAU emissions we used were based on IEA projections, and include information from MNP, IIASA and DIMA. Some non-Annex 1 countries submitted pledges in the form of carbon intensity, in which case the projections of the GDP in 2020 were used to calculate the 2020 emissions cuts.

A further complexity is that some nations provide both "high" and "low" emission reduction pledges, with a condition to transition from the low to the high case. Our interpretation of the emission reduction pledges are summarised in Appendix 1 of this note and give a global total range for 2020 emissions of 48.1 to 49.5 $GtCO_2e$/yr. This is within the wider range derived from several other studies of 46.7 $GtCO_2e$/yr to 54.8 $GtCO_2e$/yr (UNEP, 2010).

2.2 Construction of the emission trajectories

Our interpretation of the Copenhagen Accord pledges provides the emissions in year 2020 for most countries. However, to estimate the climate response we need trajectories of emissions that cover the period from 1990 to at least 2100.

For our default global BAU we used a modified version of the SRES A1B scenario (Nakicenovic et al., 2000) to provide the time series of the emissions. The early part of the Annex 1 component comprises of the national emissions available from 1990 to 2007 from UNFCCC sources and for beyond 2007, the curve transitions to the SRES A1B Annex 1 emissions. The non-Annex 1 component consists of the remainder of the SRES A1B emissions but scaled so that the curve passes through our estimated non-Annex 1 BAU emissions in 2020 as derived in secton 2.1.

[1] One of the key scientific uncertainties is in climate sensitivity, which is a measure of the eventual warming for a doubling of atmospheric carbon dioxide concentrations. In this work we use an uncertainty estimate of for climate sensitivity based on Murphy et al. (2004).

Our default global BAU is shown alongside alternative choices in Figure 1. Individual greenhouse gases are supplied to the climate model in this study. However for presentation purposes these are aggregated into an equivalent carbon dioxide emission using 100 year global warming potentials as used by the UNFCCC (Houghton et al., 1995)

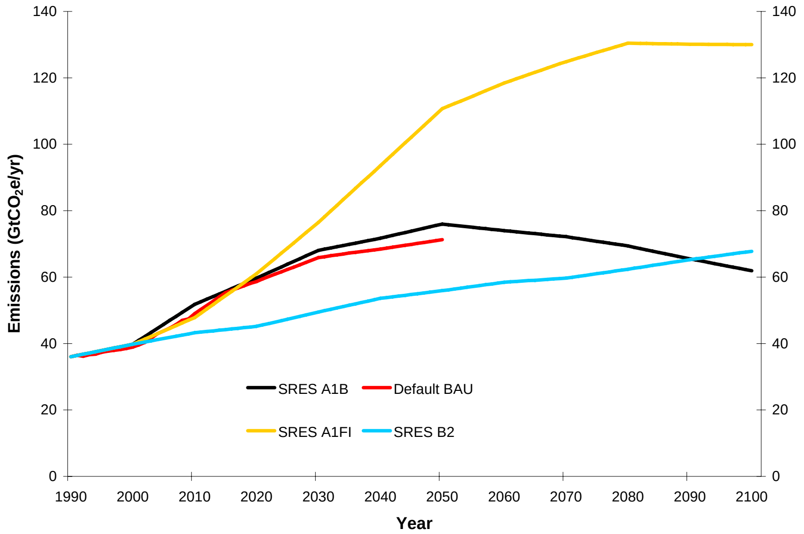

Figure 1 Global total BAU emissions for our default BAU and several SRES scenarios.

We also constructed a set of policy scenarios. In these, our BAU emissions are assumed up to 2010. The trajectories then either transition to the 2020 emission pledge value described in section 2.1, if a nation has made a pledge, or remain on the BAU curve. Where the emission values imply a peak before 2020 then we have made the assumption that this occurs in 2014. Beyond, 2020 two families of trajectory were constructed:

- In the "reference" scenario set nations with no pledges continue to follow BAU throughout the 21st Century but those with pledges at 2020 keep emissions at the 2020 level through the remainder of the 21st Century. Our lowest estimates of 2020 pledges are used for this scenario.

- In the "continued reductions" scenarios we adjust both the percentage reduction that Annex 1 nations achieve in emissions at 2050, relative to 1990, and the percentage reduction of non-Annex 1 nations below their BAU scenario by 2050. The magnitude of reduction assumed for the Annex 1 nations are either 80% (twodegc_case1) or 95% (twodegc_case2). For each case the non-Annex 1 reduction is adjusted until the total global emission profile leading to 2°C with a 50/50 chance in our model framework is determined. Our highest estimate of emission reduction pledges are used for the continued reduction scenarios.

Our policy scenarios, which include the Copenhagen Accord pledges, are shown in Figure 2. The cumulative emissions between 2000 and 2100 for the three scenarios are 5231 $GtCO_2e$ (reference policy scenario) and 3013 $GtCO_2e$ (twodegc_case1) and 3031 $GtCO_2e$ (twodegc_case2). These can be compared with SRES A1B cumulative emissions of 6642 $GtCO_2e$.

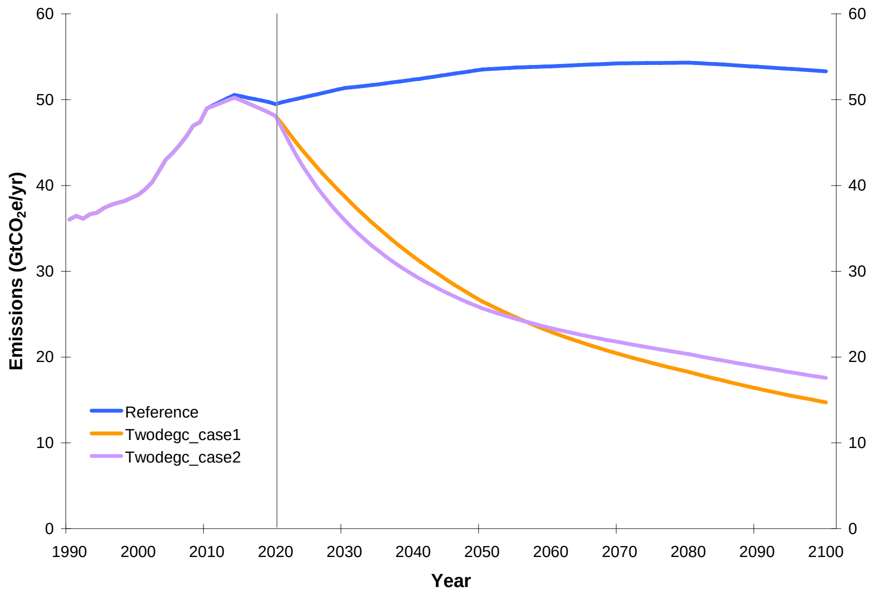

Figure 2 Emissions trajectories for the reference, twodegc_case1 and twodegc_case2 scenarios.

Sulphate aerosols are known to partially mask the warming effect from greenhouse gases. To investigate the sensitivity of our continued reduction trajectories to the choice of assumed sulphate aerosol emissions in our scenarios, an additional scenario is also considered (see section 3.2 for more details). In this alternative scenario much lower aerosol emissions after 2020 are used. This increases the magnitude of post 2020 emission reductions required to limit warming to 2°C, as shown in Table 2.

Table 2: Estimated percentage emissions reductions leading to a median projected warming of 2°C during the 21st Century. Numbers not in brackets are expressed relative to our BAU. The numbers in brackets show the reductions relative to alternative SRES BAUs.

	Default sulphate aerosols		Lower sulphate aerosols	
	Annex 1 relative to 1990	Non Annex 1 relative to BAU	Annex 1 relative to 1990	Non Annex 1 relative to BAU
Twodegc_case 1	80%	57% (47-73)	80%	67% (60-80)
Twodegc_case 2	95%	53% (42-71)	95%	64% (56-78)

2.3 Construction of the climate change trajectories

We aggregate national greenhouse gas emissions to give a global total emissions scenario and then use this as input to a simple earth system model. This model produces projections of global mean temperature and an estimate of the probability that the temperature will exceed 2°C above the pre-industrial level. The basis of our modelling system is the well-established MAGICC model. Following Lowe et al. (2009) probabilities are assigned to three key parameters, obtained from distributions of climate sensitivity (Murphy et al., 2004), oceanic heat diffusion (Wigley and Raper, 2001) and climate-carbon cycle feedback strength based on the C4MIP simulations (Friedlingstein et al., 2006). For each triplet of parameters used, a total probability is assigned. It is important to note that this is just one model framework and alternative models and methodologies for generating uncertainty estimates are available. However, this method has been previously shown to have skill at replicating the global average warming response of more complex models (Lowe et al., 2009).

3. Results

3.1 Global average warming projections

The simulated time series of median (50th percentile) global average temperature change relative to pre-industrial times (taken as year 1750) is shown in Figure 3. Warming to year 2100 in the SRES A1B and reference policy scenarios are 4°C, 2.9°C, respectively, and by design 2°C in twodegc_case1 and twodegc_case2. The slight increase above the SRES A1B scenario between years 2010 and 2030 by the policy scenarios is due to the rapid loss of aerosol cooling in the policy scenarios. In all of the scenarios we considered the temperature is still rising at year 2100.

The cumulative distribution functions of global average warming are shown in Figure 4, and confirm that all of the policy scenarios have a greater than 90% probability of avoiding 4°C of warming. However, both twodegc_case 1 and twodegc_case2 scenarios also have a greater than 90% chance of avoiding 3°C of warming.

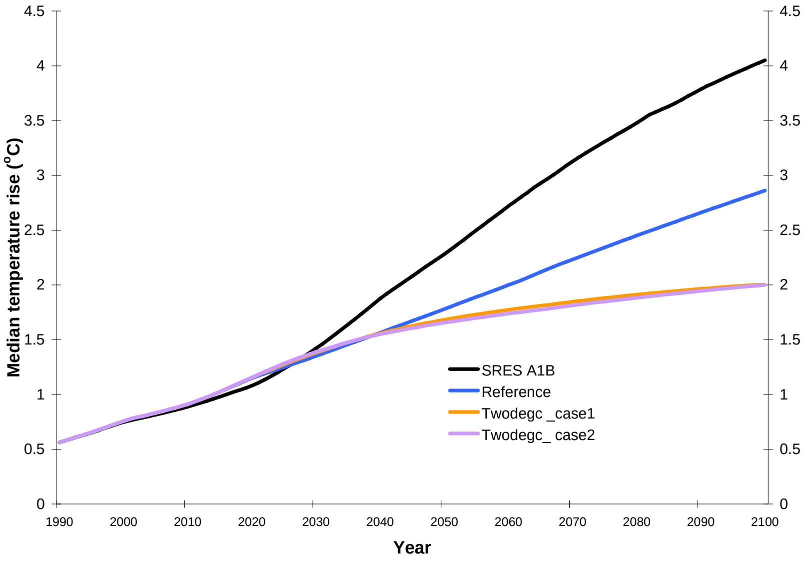

Figure 3. Projected median global average temperatures for the reference policy case, twodegc_case1 and twodegc_case2

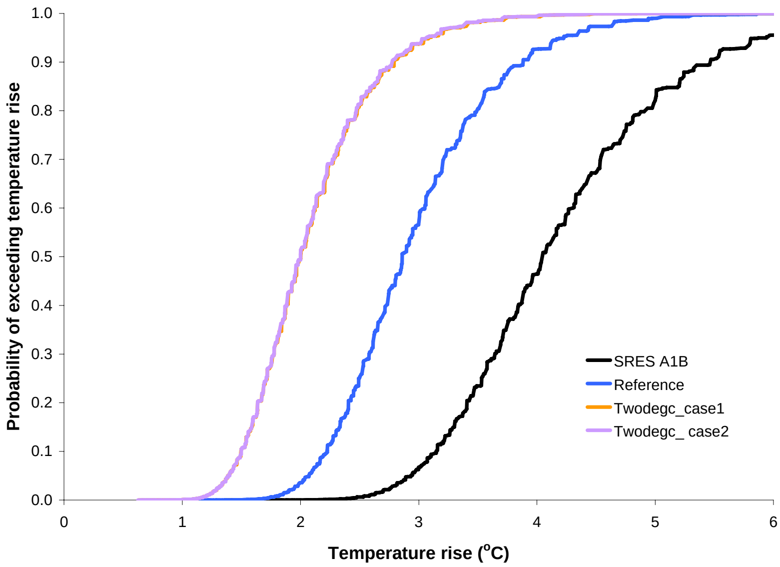

Figure 4. Cumulative distribution of 21st Century global average warming for the reference policy case, twodegc_case1 and twodegc_case2. Note that the two_degc_case2 overlays the two_degc_case1 cumulative distribution.

3.2 Sensitivity of the reference and continued reduction cases to assumptions

As part of this study we have estimated the sensitivity of the results to a range of alternative assumptions. The first sensitivities we consider relate to the emission scenario construction.

If we consider the interpretations of the Copenhagen Accord pledges from other researchers we find a range of 46.7 $GtCO_2e$/yr to 54.8 $GtCO_2e$/yr for 2020 emissions (UNEP, 2010). Our first sensitivity test involved modifying the emissions in the twodegc_case1 between present day and 2050 so that the 2020 emissions value becomes 54.8$GtCO_2e$/yr. The simulated median warming for this modified scenario at 2100 is 2.05°C, up from 2°C. This can be viewed as their being an increase in the risk of exceeding 2°C from 50% to 55%.

The next uncertainty considered is associated with aerosol forcing: we test an alternative (lower) sulphate aerosol forcing scenario. The default setting is to use an emissions ratio for estimating sulphur emissions from the SRES B1 scenario. However, since emissions of greenhouse gases are still quite significant in the later part of the century in both the reference and continued reduction cases, so is the sulphate aerosol emission and aerosol forcing. This implies little technological effort to improve this aspect of air quality. So in an improved air quality extension to the twodegc_case1 scenario we test a low aerosol emission scenario in which the ratio of sulphate aerosol to carbon emissions declines from the SRES B1 value in 2020 to zero a century later. Using lower sulphate aerosol emissions increases the median warming in 2100 from 2°C to 2.2°C, which can be viewed as their being an increase in the risk of exceeding 2°C from 50% to 66%. This implies that greater emission reductions would be needed to give a 50/50 chance of not exceeding 2°C than is implied with the default aerosol forcing.

Finally, we noted in previous work that using an alternative estimate of the uncertainty in the climate sensitivity, a key climate parameter, can alter the median temperature outcome for scenarios similar to the continued reduction scenario used here by up to around 0.5°C. In this work we used the climate sensitivity distribution of Murphy et al. (2004). Based on Meinshausen et al., (2009) most alternative choices of the climate sensitivity uncertainty distribution might be expected to give a greater probability of staying below a 2°C limit. It is also likely that the avoided temperature rise and avoided risk of exceeding 2°C by choosing one of the mitigation scenarios rather than the BAU will be more robust quantities than the absolute global average temperature change projections and accompanied risks of exceeding 2°C.

3.3 Limiting warming beyond the 21st Century

All previous estimates in this note have focused on limiting warming during the 21st Century. This is for consistency with similar tools by other researchers, and because the uncertainty resulting from assumptions on post 2050 emissions become much more important if we look at temperatures beyond 2100. However, the temperatures presented in Figure 3 were still increasing at year 2100, even in the continued reduction scenarios. Therefore we address here the question of what emissions would be required to keep warming below 2°C with a 50/50 chance up to 2500. This is a more stringent target than looking only to 2100 and so the emissions will need to be lower to achieve it.

To arrive at an estimate we use the simulation from twodegc_case2 above (Annex 1 emission reductions by 2050 are assumed to be 95% below 1990 levels) but this time examine the peak warming. We then extrapolate this to the emission reductions needed to limit peak warming (between 2000 and 2500) to no more than 2°C. We have done this for the lower aerosol forcing case to give an upper estimate on the non Annex 1 emissions, finding a reduction of 69% below our default BAU would be needed.

4. Discussion and Conclusions

Taking the lowest pledges and no further emission reductions after 2100 leads to a low probability (<10%) of limiting global average warming to 2°C, and in fact the median temperature prediction in our model framework[2] for year 2100 is expected to be 2.9°C.

The global total emissions trajectories that could limit warming to no more than 2°C by year 2100 can be divided between Annex 1 and non-Annex 1 nations in a range of different ways. If Annex 1 nations reduce emissions by 95% relative to 1990 by year 2050 this implies non-Annex 1 nations would need to make reductions below our default business-as-usual of between 53% and 64%, depending on aerosol forcing assumptions. A stricter target, of not exceeding 2°C between years 2000 and 2500, requires greater emission reductions.

Several other research groups have produced estimates of the warming associated with the emission pledges in the Copenhagen accord. At this time the “climateactiontracker” is projecting a warming of 3.5°C and the “climate interactive C-ROADS” tool is projecting 3.9°C. Another recent assessment was provided by Houser (2010). In common with our analysis this report also found that with no further emissions reductions after 2020 the global average temperature is likely to exceed 2°C, but further post 2020 reductions can constrain the warming to below this level with at least 50% probability. The different 21st Century warming values estimated by other studies are a result of differences in the interpretation of the 2020 pledges, the assumptions made for the business as usual emissions and the post 2020 emissions scenario. Additionally, differences in the climate modelling method will account for a further component. A thorough analysis of the differences would require a detailed intercomparison study.

We conclude from our analysis that current emission pledges are likely to be compatible with a long-term target of limiting warming to 2°C PROVIDED the emission reduction pledges are realised by year 2020 AND that further significant reductions continue beyond 2020.

[2] The numeric estimates of future climate within this report are based on a particular modelling framework and also assumptions on experimental set up made by the authors. Like all studies of this type the absolute projections of the future contain uncertainties.

5. References

Allen, M.R., Frame, D.J., Huntingford, C., Jones, C.D., Lowe, J.A., Meinshausen, M., Meinshausen, N.: 2009 Warming caused by cumulative carbon emissions towards the trillionth tonne. *Nature*, **458**, 1163-1166

Friedlingstein, P., et al.: 2006 Climate-carbon cycle feedback analysis: results from the C4MIP model intercomparison. *Journal of Climate*, **19**, 3337-3353.

Höhne N., Schaeffer M., Chen C., Hare B., Eisbrenner K., Hagemann M. and Ellermann C.: 2009 Briefing paper: Copenhagen climate deal – How to close the gap?, http://www.climateactiontracker.org/

Houghton, J.T., Meira Filho, L.G., Callander B.A., Harris, N., Kattenberg, A., and Maskell, K.:1995 Climate Change 1995: The Science of Climate Change. Contribution of Working Group 1 to the Second Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge Univ Press, Cambridge.

Hooijer, A., Silvius, M., Wösten, H. and Page, S.: 2006. PEAT-CO2, Assessment of CO2 emissions from drained peatlands in SE Asia. Delft Hydraulics report Q3943 (2006)

Houser, T.: 2010. Copenhagen, the Accord and the way forward. Paterson institute for international economics. Policy Brief 10-5.

Joosten, H., Couwenberg, C.: 2009 Are emission reductions from peatlands MRV-able? Report, 14 pp. Wetlands International, Ede.

Lowe, J.A., Huntingford, C., Gohar, L., Bowerman, N., Allen, M. and Raper, S.: 2010 The link between a global 2ºC warming limit and emissions in years 2020, 2050 and beyond. *Environmental Research Letters*, To be submitted.

Lowe, J.A., Huntingford, C., Raper, S.C.B., Jones, C.D., Liddicoat, S.K. and Gohar, L.K.: 2009 How difficult is it to recover from dangerous levels of global warming?, *Environmental Research Letters*, **4**, Art Number: 014012.

Meinshausen, M., Meinshausen, N., Hare, W., Raper, S.C.B., Frieler, K., Knutti, R., Frame D.J. and Allen, M.R.: 2009 Greenhouse gas emissions targets for limiting global warming to 2°C, *Nature,* **458**, 1158-1162

Murphy, J.M., Sexton, D.M.H., Barnett, D.N., Jones, G..S., Webb, M.J. and Collins, M.: 2004 Quantification of modelling uncertainties in a large ensemble of climate change simulations. *Nature*, **430**, 768-772.

Nakicenovic et al.: 2000 IPCC Special Report on Emissions Scenarios, Cambridge University Press, Cambridge, UK and New York, USA, 599pp

UNEP: 2010. How Close Are We to the Two Degree Limit? Information note to the UNEP Governing Council Meeting and Global Ministerial Environmental Forum. www.rona.unep.org/documents/news/20100223-temperature-briefing.pdf

Wigley, T.M.L. and Raper, S.C.B.: 2001 Interpretation of high projections for global-mean warming. *Science*, **293**, 451-454.

Appendix 1: Details of emission pledges in the Copenhagen Accord

A1.1 The 2020 emissions pledges for individual nations and country groups

The tables below detail the emissions pledges submitted by nations which were included in this analysis. The actual national 2020 pledges are available in the appendices to the Copenhagen accord and can be accessed from the UNFCCC website.

Table A1.1 The low end pledges. The "Other non-Annex 1" includes countries with pledges but with emissions contributions that are small compared to the nations detailed in the table. India's abatement in 2020 as submitted to the Copenhagen accord is estimated not to make an improvement on the BAU emissions (see also Houser, 2010). Australia's pledge includes contributions from land use, land use change and forestry (LULUCF) emissions. Peatland emissions are highly uncertain and here simple assumptions were made based on the works of Hooijer et al. (2006) and Joosten and Couwenberg (2009). The individual emissions may not add up to the total due to effects of rounding.

	Current Offer low	Emissions in 2020
Developed countries	**% on 1990**	**Gt CO_2e**
United States	-3%	5.9
Japan	-25%	1.0
EU-25	-20%	4.5
Australia	-24%	0.3
Russia	-25%	2.5
Canada	3%	0.6
Ukraine	-20%	0.7
Other Annex 1 excl. Turkey		0.3
Turkey		0.5
Annex 1 with pledges		15.7
Annex 1 no pledges		0.5
Total Annex 1	-13%	16.2
Developing countries	**% on BAU**	**Gt CO_2e**
China	-8.5%	11.4
Brazil	-20%	2.2
India	0%	3.8
Indonesia	-26%	1.8
South Africa	-17%	0.6
Mexico	-15%	0.7
South Korea	-30%	0.6
Non-Annex 1 with pledges		21.1
Other non-Annex 1	0	10.2
Total non-Annex 1	-8%	31.3
Other sectors		
Aviation and Maritime		1.3
Peatland emissions outside Indonesia		0.6
Annex I LULUCF		0.1
Total world		49.5

Table A1.2 The 2020 high end pledges.

	Current Offer High	Emissions in 2020
Developed countries	**% on 1990**	**Gt CO_2e**
United States	-3%	5.9
Japan	-25%	1.0
EU-25	-30%	3.9
Australia	-33%	0.3
Russia	-25%	2.5
Canada	3%	0.6
Ukraine	-20%	0.7
Other Annex 1 excl. Turkey		0.3
Turkey		0.6
Annex 1 with pledges		15.1
Annex 1 no pledges		0.5
Total Annex 1	-16%	15.6
Developing countries	**% on BAU**	**Gt CO_2e**
China	-8.5%	11.4
Brazil	-39%	1.6
India	0%	3.8
Indonesia	-26%	1.8
South Africa	-34%	0.5
Mexico	-30%	0.6
South Korea	-30%	0.6
Non-Annex 1 with pledges		20.4
Other non-Annex 1	0	10.2
Total non-Annex 1	-10%	30.6
Other sectors		
Aviation and Maritime		1.3
Peatland emissions outside Indonesia		0.6
Annex I LULUCF		0.1
Total world		48.1

Appendix 2: Regional climate change and impacts

A2.1 Introduction

Global average warming provides a summary indicator of the amount of global climate change. However, to understand the consequences of raised levels of atmospheric greenhouse gas concentrations it is necessary to examine regional climate change and alterations to quantities other than surface temperature. Here we present an initial estimate of the consequences of the Copenhagen Accord pledges and post-2020 emissions on regional warming, ocean acidification and sea level rise. These are presented as the median climate model outcomes. Future work will consider uncertainty ranges, and a much broader range of the impacts on society. The changes are reported for the default aerosol assumptions.

A2.2 Regional warming

We have produced spatial projections of warming by combining the global average warming estimates from the MAGICC model with the patterns of local warming per degree of global average warming from the QUMP (Quantifying Uncertainty in Model Predictions) ensemble of simulations, as generated at the Met Office Hadley Centre. Results are shown (Figure A2.1) for the twodegc_case1 scenario, i.e. with pledges being high followed by further significant emission reductions to give a global average warming to 2100 of 2°C, along with the reference scenario, i.e. with Copenhagen Accord pledges interpreted as being low for year 2020 and subsequently followed by no further emissions reductions.

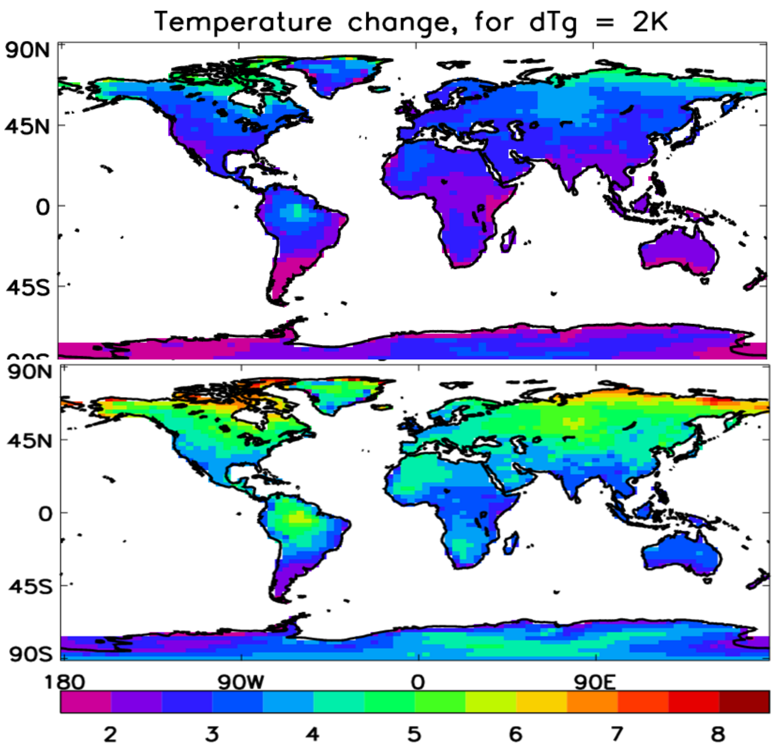

Figure A2.1: Yearly average patterns of temperature change (ºC) by year 2100 for the and twodegc_case1 continued reduction scenario (upper) and reference scenario (lower). Values are based on the median projection across the QUMP ensemble and median projections of global average warming.

These results show that even in the scenario in which global average warming by 2100 is 2ºC, the average warming over the land is greater. Some regions warm by as much as 5ºC.

A2.2 Ocean Acidification and sea level rise

A consequence of increasing atmospheric carbon dioxide concentrations is that it makes the ocean more acidic. There is evidence that this acidification may lead to a range of ocean ecosystem impacts, including damage to coral and negative effects on some fish species. Here we have calculated (Figure A2.2) the change in ocean pH using a simple climate model.

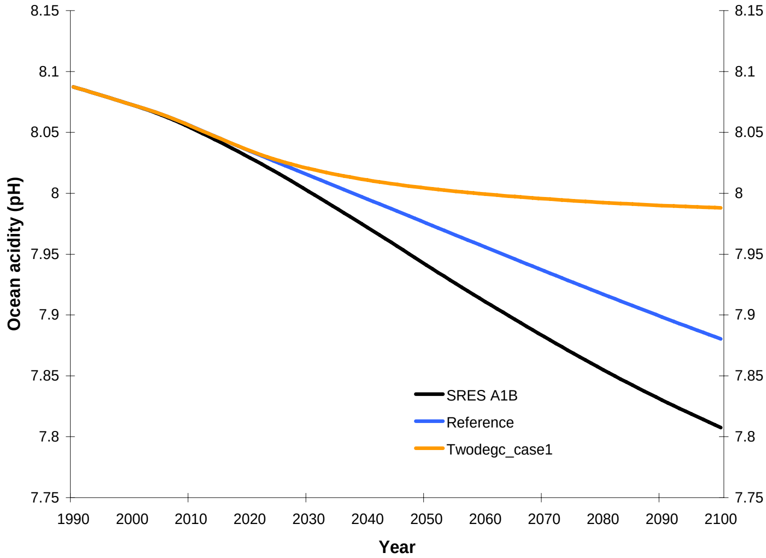

Figure A2.2: The median estimate of the ocean acidity time series for the baseline (black), "reference" (blue) and "twodegc_case1" (orange) scenarios.

Sea level rise can cause increased coastal flooding, loss of wetlands and, in some regions, salt water intrusion into freshwater supplies. Here we have estimated sea level rise (Figure A2.3) using the methodology described in the Appendix to Chapter 10 of the IPCC WG1 AR4 report for ice melt terms, and thermal expansion from the simple climate model. This does not account for any increases in flow rates of Greenland outlet glaciers or Antarctic ice streams.

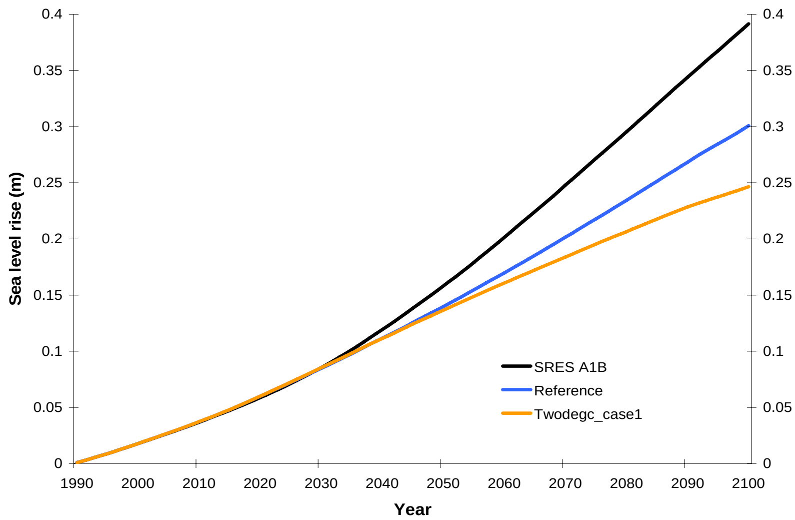

Figure A2.3: The median estimate of the ocean sea level rise time series for the baseline (black), "reference" (blue) and "twodegc_case1" (orange) scenarios.

In summary, our median projections indicate that in the continued reduction scenario we can avoid around two thirds of the 21st Century BAU change in pH and a third of the increase in global mean sea level rise.