

Safe Emissions Corridor

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The climate negotiations: climate goals and their emission corridors

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Abstract

This paper presents an evaluation of the consequences of long term climate goals, as proposed in current climate negotiations, on short term emission targets. An approach called "safe emission corridors" is used for this evaluation. Safe emission corridors are the allowable range of emissions over time that comply with constraints on cumulative temperature increase, decadal temperature increase, cumulative sea level rise, and maximum rate of emission reductions. The emission corridors are computed using IMAGE 2, a global integrated model of climate change. Using this approach, it was estimated that the European Union's proposed limitation of 2.0°C increase in temperature (above pre-industrial) can be achieved if anthropogenic global emissions of CO₂, CH₄, and N₂O in 2100 are between 7.6 and 12.4 Gt C/yr (using year 2100 as target year). In this case, emissions from Annex I (industrialized) countries should be between 1.3 and 6.1 Gt C/yr, or 25 to 111% of their 1990 level (5.3 Gt C/yr). To achieve the proposed AOSIS limitation of 20 cm sea level rise (from 1990 to 2100), global emissions in 2100 should be between 7.6 and 9.5 Gt C/yr. The sum of emissions from Annex I countries should be in the range of 1.3 to 3.2 Gt C/yr, or 25 to 61% of their 1990 level. Because of time lags in the climate system, sea level may increase after 2100 by a further factor of two to three before stabilizing, despite the stringent emission reductions needed to achieve the target of 20 cm in 2100.

Introduction

As a result of the Berlin Mandate (Conference of Parties, 1995) negotiations are underway to agree upon a possible protocol to the Framework Convention on Climate Change (hereafter referred to as the "Climate Convention"). The protocol, in principle, should help Signatories to achieve the stated objective of the Convention, namely to prevent "dangerous anthropogenic interference with the climate system". To prevent this "interference" some Signatories of the Convention have submitted protocol proposals that specify limits to the rise of sea level and the increase in surface temperature. It is not easy, however, to relate these climate goals to emission targets because the two have quite different time scales. The time scale of interest in setting climate goals are several decades or centuries because it can take this long for greenhouse gases, global temperature, and sea level rise to stabilize. By contrast, the time scale of interest in setting emission targets is much shorter (years 2005 and 2010 are commonly discussed in the climate negotiations) because policymakers find it unrealistic to plan emission reductions far into the future. The first objective of this paper is to present an approach for linking the long time scale of climate protection with the short time scale of

emission targets. This approach is called "Safe Emission Corridors". The second objective of the paper is to use this approach to compute emission corridors that correspond with the climate goals specified in two important protocol proposals - those of the European Union (EU) and the Alliance of Small Island States (AOSIS). These two proposals are receiving considerable attention in the current negotiations.

What are Safe Emission Corridors?

The concept of safe emission corridors was developed during a series of informal international workshops between 1995 and 1997, that aimed to promote a dialogue between global modelers and policy makers engaged in the climate protocol negotiations (Alcamo, *et al.* 1996a, van Daalen, *et al.* 1997). Safe emission corridors are the allowable range of emissions over time that comply with long and short term climate goals. The term emission corridors arose from an analogy with aviation: in order to land safely an aircraft needs to approach the airport in such a way that it neither hits the ground too early by going down too quickly, nor crashes behind it by going down too late. To land safely it should stay within a so-called safe corridor, guiding it to the landing strip. In the context of the climate issue, the future pathway of emissions of greenhouse gases should be such that it neither disrupts socio-economic development by reducing emissions too fast or too early, nor leads to serious climate impacts by reducing emissions too slow or too late. As a consequence, like the airplane, the short term emissions of greenhouse gases should stay within a corridor; the so-called "safe emission corridor".

The procedure for computing safe emission corridors requires results from a global climate model. Repeated runs are required with the model, so it is desirable to use a model with a fast turnaround time. The first corridors were computed using IMAGE 2, an integrated model of global change (see Appendix B and Alcamo, 1994). However, other global models are now also being used to compute emission corridors (see, for example, Matsuoka, *et al.* 1997) and results from different models are being standardized and compared (Alcamo, 1997). In this paper we use IMAGE 2 to compute emission corridors.

Results from a global model are employed in such a way that an analyst can select certain climate and other goals, and the emission corridors are automatically calculated. The procedure is described in Appendix C. Other applications of the approach are given in Alcamo and Kreileman (1996a and 1996b). The emission corridors approach has been automated in an interactive program, and in this paper we use Version 3 of this program (Kreileman and Berk, 1997).

In the current version, the safe emission corridor is computed after setting constraints on four main indicators:

- Cumulative increase in global average surface temperature in °C (1990-2100)
- Rate of temperature increase in °C per decade (and the number of decades this rate may be violated)
- Cumulative increase in global average sea level in cm.(1990-2100)
- Rate of global emission reduction in % per year

These indicators can be related to the goals and conditions stated in the ultimate objective of the Framework Convention on Climate Change (FCCC), as defined in its Article 2. The first three reflect the goals "to allow ecosystems to adapt naturally to climate change" and "to ensure that food production is not threatened". The last indicator reflects the consideration that climate policies should "enable economic development to proceed in a sustainable manner" by taking into account technical and economic limitations of reducing emissions. Given the level of uncertainty about the future level of climate change and related impacts,

and the normative nature of evaluating these impacts, the safe emission corridor approach does not use any predefined values for the selected indicators. Instead, it offers decision makers a flexible framework to evaluate their own sets of climate goals. The fast accounting software enables this to be done in an interactive way.

For each set of indicator values, an emission corridor can be calculated for global greenhouse gas emissions (in CO₂-equivalent emissions) for the target year selected (e.g. 2010 or 2020). Between the target year and year 2100, there is at least one emission pathway emerging from the emission corridor that will comply with the specified set of indicator values. The top of the corridor indicates the maximum allowable emissions in the target year compatible with the selected climate goals. Near the top of the corridor, there are only few emission pathways that comply with these goals. Lower in the corridor there are many more pathways available after the target year that are compatible with the climate goals, and there is more room for a tightening of constraints if future scientific knowledge of climate change would make this desirable. The bottom of the corridor is defined by the constraint on maximum rate of emission reduction. To account for the present rate of climate change, resulting from historical emissions, the analysis also allows for specifying a number of decades after 2000 that the specified rate of temperature increase may be violated.

Evaluation of the European Union Protocol Proposal

In 1996 the EU Climate Council concluded that “global average temperature should not exceed 2°C above the pre-industrial level”, which means no more than about 1.5 degrees above the present level. In 1997 this temperature limitation was submitted as part of a protocol proposal to the climate negotiations (Ad Hoc Group, 1997). To determine the consequences of this proposal on the emissions corridor between 1990 and 2100, we must first make some additional assumptions. First of all, we assume that the target year for this temperature limitation is 2100. Next, we have to make additional assumptions about the decadal rate of temperature change, sea level rise and rates of global emission reductions over the period 1990 to 2100 (we use year 2010 here because it is a typical emissions target year being discussed in the climate negotiations.). In this example it is assumed (i) that the global rate of temperature increase may not exceed 0.15 degree °C/decade (being the average rate for a 1.5 degree °C increase over the next century) except for the first two decades, (ii) that sea level rise in 2100 should remain below 30 cm and (iii) that the maximum feasible rate of global emission reduction is 2% per year (with a maximum change in trend of 2% per decade). These are assumed to be intermediate values. Global sulfur emissions, which lead to sulfate particles in the atmosphere that somewhat compensate for global warming, are assumed to remain constant at their 1990 level.

What Are the Allowable Global Emissions?

The computed global emission corridor for these assumptions is shown in Figure 1a. In year 2010, emissions range from 7.6 to 12.4 Gt C/yr. These are the sum of the anthropogenic emissions of carbon dioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O) expressed in units of gigatons of equivalent CO₂ emissions per year (Gt C/yr). Since global emissions in 1990 are estimated to be approximately 9.8 Gt C/yr¹, the bottom and top of the corridor correspond to 78 to 127% of emissions in 1990.

It is important to note that the computed global corridors are, by definition, sensitive to the assumptions made for the constraints. For example, if we fix cumulative temperature increase, rate of temperature change, and sea level rise at their above values, but set the maximum rate of global emission reductions at 1% per year rather than 2% per year, we obtain global

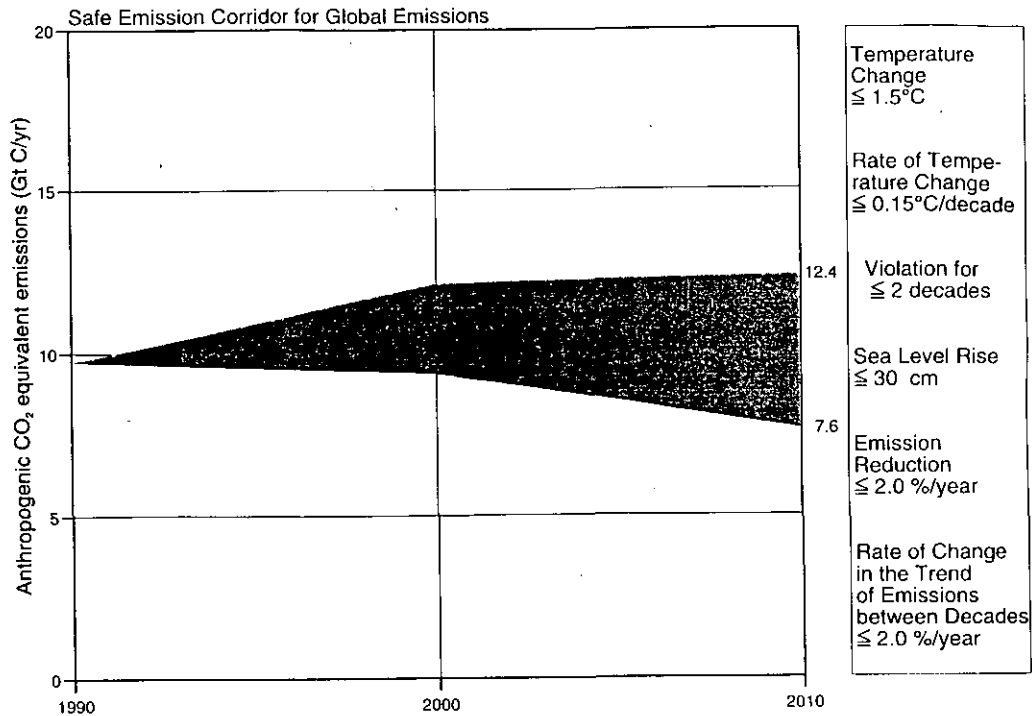
emissions in 2010 of 8.5 to 11.4 Gt C/yr. Relaxing this constraint to 3% per year, we obtain 7.3 to 12.5 Gt C/yr.

What Are the Allowable Annex I Emissions?

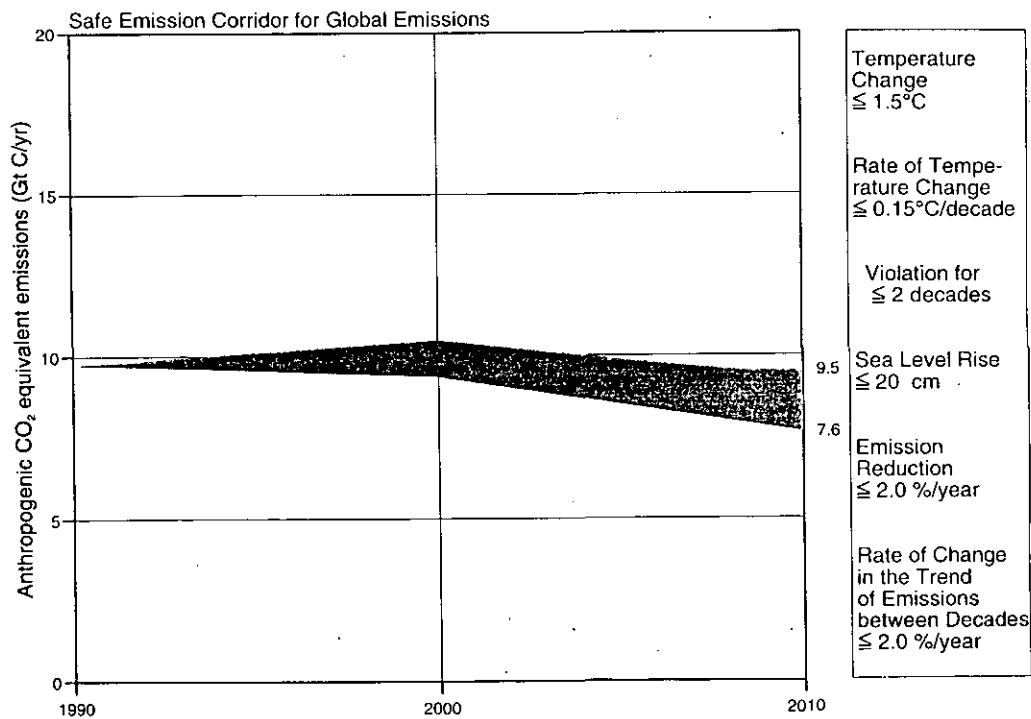
We now compute the allowable emissions in Annex I (industrialized) countries that will ensure that global emissions fall within the safe emission corridor. To do so we take into account that the Berlin Mandate (adopted at the First Conference of Parties meeting in March, 1995) stipulates that non-Annex I (developing) countries will not have to control emissions under the protocol being negotiated. Therefore, we can assume that any agreed-upon emission controls for the period 1990 to 2010 will only be applied to Annex I countries. Our procedure, then, is to estimate the uncontrolled emissions level of non-Annex I countries for year 2010, and subtract these emissions from the global emissions. What remains is an estimate of the allowable emissions from Annex I countries. For these calculations we use IPCC estimates of uncontrolled emissions from non-Annex I countries (Leggett, *et al.* 1992). These estimates range from 5.5 to 7.0 Gt C/yr in year 2010, with an intermediate estimate from the "IS92a" scenario of approximately 6.3 Gt C/yr (this is the sum of anthropogenic emissions of CO₂, CH₄, and N₂O in units of equivalent CO₂). In the following paragraphs we will only use the intermediate estimate of non-Annex I emissions, 6.3 Gt C/yr, to compute the Annex I emissions, but the reader should keep in mind that because of the range of non-Annex I scenarios for 2010, all of our estimates for Annex I also have a range of about ± 0.75 Gt C/yr.

Under the previous assumptions, we compute that the allowable CO₂ equivalent emissions of the industrialized countries in 2010 would range between 1.3 and 6.1 Gt C/yr, or 25 to 113% of their 1990 level (5.3 Gt C/yr¹), with a median value of 3.7 (69%). Put another way, depending on where emissions should fall within the corridor, Annex I emissions can be decreased by 75%, or can increase by 13% in 2010 (relative to 1990).

From an economics perspective, it is logical to allow emissions to rise to the very top of the emissions corridor because emissions here require the least amount of controls but can still meet the same climate goals as emissions lower in the corridor. However, as noted above, a drawback to this approach is that the higher the emissions in 2010, the faster they should be reduced afterwards, leaving less room for policy flexibility. In other words, if global emissions are high in the corridor then both Annex I and non-Annex countries will have to work harder after 2010 to reduce global emissions in order to reach the specified climate goals. Therefore, taking into account the precautionary principles stated in Article 3 of the Climate Convention, it seems sensible to both carry-out early reductions of Annex-I emissions and to simultaneously help developing countries to limit the growth of their future emissions, e.g. by technology transfer. With these several considerations in mind, it may be prudent to aim for an emissions level in 2010 that is somewhat below the top of the corridor. For example, a "precautionary policy" could be to require Annex I emissions to be between the middle of the corridor (3.7 Gt C/yr), and halfway between the middle and top (4.9 Gt C/yr). This would require reductions of about 9 to 31% of Annex I emissions by 2010 (relative to 1990).



(a) global emissions.



(b) Annex I emissions.

Figure 1: Safe emission corridors for EU protocol proposal.

Evaluation of the AOSIS Protocol Proposal

In the current climate negotiations, the Alliance of Small Island States (AOSIS) has proposed a limitation of 20 cm on global mean sea level rise and 2.0 °C on the increase in global surface temperature above its pre-industrial level (which means no more than about 1.5 degrees above the present level, as noted above in the EU example) (Ad Hoc Group, 1997). To compute the safe emission corridors corresponding to these targets, we must also make additional assumptions, as we did in the EU example. First, we assume that the target year for achieving the limitation on sea level rise and temperature increase is year 2100. Shortly we will see that the selection of this target year for sea level rise has important policy implications. We further assume that (i) the global rate of temperature increase may not exceed 0.15 degree °C/decade except for the first two decades, (ii) the maximum rate of global emission reduction is 2% per year, and (iii) global sulfur emissions remain constant at their 1990 level. These are the same assumptions made for the EU example, and hence the only difference in the AOSIS analysis is the stricter constraint on sea level rise (20 vs 30 cm).

What are the Computed Emission Corridors?

Under the above assumptions, global emissions in 2010 range from 7.6 to 9.5 Gt C/yr (78% to 98.5% of 1990 emissions), which is substantially narrower than in the EU example (Figure 2a vs 1a). The narrower corridor arises from the stricter constraint on sea level rise in the AOSIS proposal.

To compute the allowable emissions from Annex I countries, we follow the same procedure as in the EU example and assume that emissions from non-Annex I countries in 2010 are 6.3 Gt C/yr. Because of the narrower global emissions corridor, we also compute a narrower corridor for Annex I emissions, spanning from 1.3 to 3.2 Gt C/yr in 2010. This is equivalent to 25 to 60% of 1990 emissions (5.3 Gt C/yr). Put another way, reductions of 40 to 75% of Annex I emissions are necessary in 2010 (relative to 1990) to comply with the targets for sea level rise and surface temperature in the AOSIS proposal. A "precautionary policy" (as explained above for the EU proposal) would aim to hold emissions below the top of the corridor. An example of this policy would be to require that emissions be between the middle of the corridor (2.3 Gt C/yr), and halfway between the middle and top (2.7 Gt C/yr). This would require reductions of about 49 to 57% of Annex I emissions by 2010 (relative to 1990).

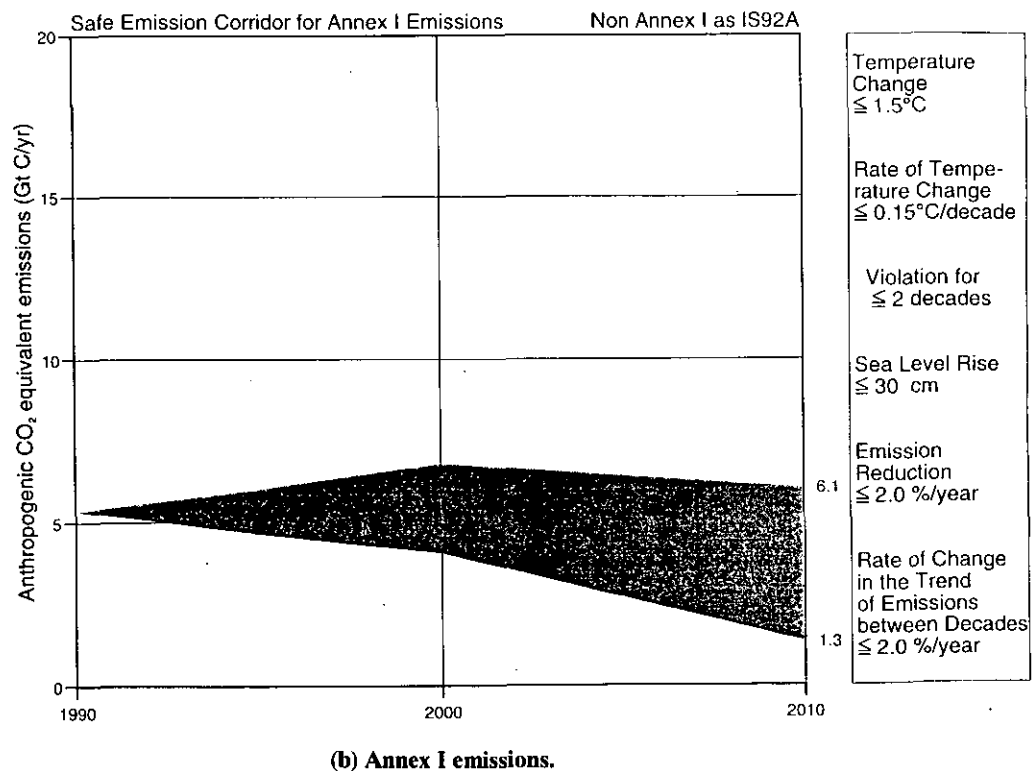
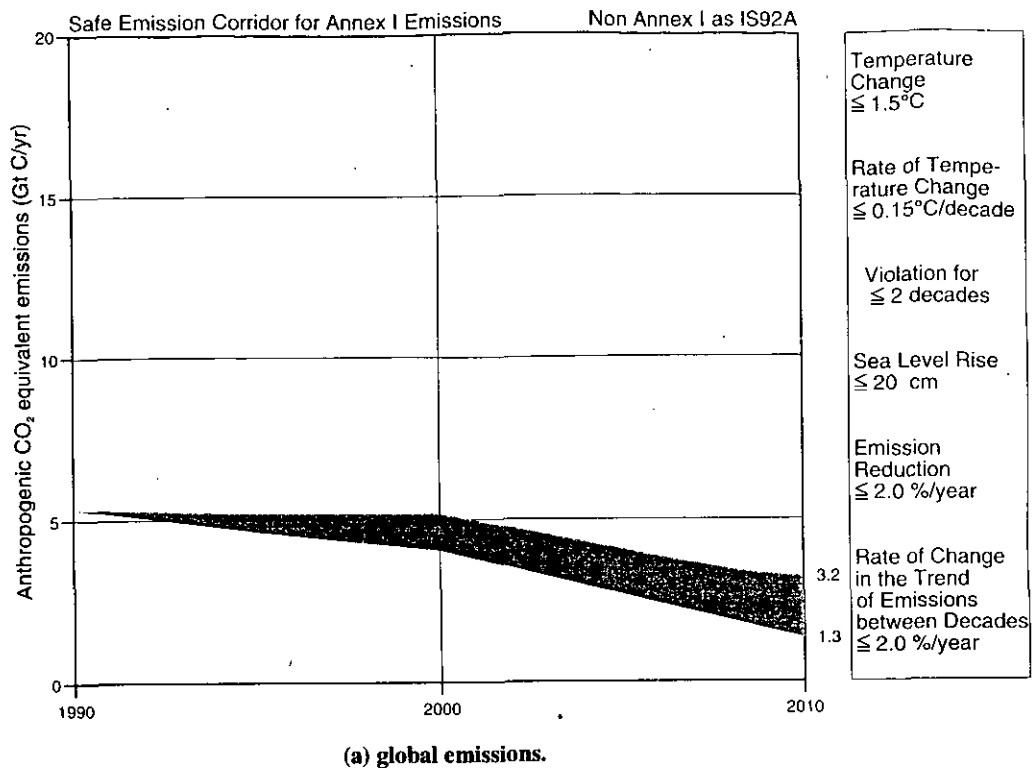


Figure 2: Safe emission corridors for AOSIS protocol proposal.

Table 1: Computation of long-term sea level rise (in cm relative to 1990) for several scenarios.

Year	Stabilization @350 ppm ^a		Stabilization @450 ppm ^a		Stabilization @550 ppm ^a		20 cm Sea Level Rise Profile ^b
	IMAGE 2	MAGICC ^c	IMAGE 2	MAGICC ^c	IMAGE 2	MAGICC ^c	IMAGE 2
2100	24	20	29	29	33	34	20
2200	41	25	56	48	66	64	30
2300	56	30	74	62	88	84	36
2400	68	34	90	74	106	101	38
2500	78	38	103	84	122	117	38

Notes to Table 1

a These refer to scenarios of stabilization of CO₂ in the atmosphere at the indicated concentration according to the time evolution prescribed in an IPCC model comparison exercise (Enting, *et al.* 1994). The calculations reported here for the MAGICC model (Raper, *et al.* 1996) assume that non-CO₂ emissions and sulfur emissions are constant at their 1990 level; whereas calculations from IMAGE 2 assume that sulfur emissions are constant but energy-related non-CO₂ emissions are proportional to the trend of back-calculated CO₂ emissions, and land use-related non-CO₂ emissions increase according to the Baseline A scenario in Alcamo, *et al.* (1996b).

b These are calculations of long term sea level rise that follow from limiting sea level rise to 20 cm in year 2100. Assumptions for emissions of this scenario are given in End Note 2.

c These data are from Raper, *et al.* 1996. These researchers compute sea level rise for a range of values for climate sensitivity and ice-melt parameters. Results presented in this table are only a small selection of their results, selected because they are comparable to IMAGE 2 calculations. For these results, a climate sensitivity of 2.5 and mid-range values of ice-melt parameters were used.

Will Sea Level Rise Beyond 2100?

An important factor to take into account when discussing limitations on future sea level rise is the long time lag in the climate system between emissions, the build-up or stabilization of greenhouse gases in the atmosphere, and global warming and sea level rise. These time lags arise from the long residence times of greenhouse gases in the atmosphere, from the slow circulation of heat in the ocean, and from other factors. Computer models which take into account these lags, compute that global sea level will continue to rise after 2100, even if emissions are sharply reduced and their atmospheric concentrations stabilized during the preceding century (Table 1). As an example, we select an emissions pathway that runs close to the emissions corridor computed for the AOSIS Protocol Proposal. This pathway was selected so that sea level rise is 20 cm in 2100 (relative to 1990), in accordance with preceding assumptions². Global emissions in this pathway decrease at a rate of 2% per year after 2010, reaching 2.0 Gt C/yr in 2100. Note in Figure 3 (line 4) that according to this pathway sea level rises from 20 cm in 2100 to 38 cm in 2500 (Figure 3, line 4). Hence, setting a target of 20 cm for 2100 does not guarantee that this will be maintained in the longer run, despite a sharp decrease in emissions. Limiting sea level rise to 20 cm in the very long run (up to 2500, for example) may require even sharper emission reductions.

We can also compare sea level rise calculations based on the AOSIS Proposal with other policy scenarios being discussed in the climate negotiations. For example, Figure 3 shows results for scenarios of CO₂ stabilization in the atmosphere³. Note that stabilization at either 450 or 550 ppm leads to substantially higher sea level in 2100 than 20 cm (Figure 3, lines 2 and 3). However, the scenario of stabilization at 350 ppm (Figure 3, line 1) is close to the AOSIS target in year 2100 (their global emissions are also close in 2100). Nevertheless, because the 350 ppm scenario makes different assumptions for emissions *after* 2100, sea level in year 2500 is much higher than in AOSIS proposal, about 3.25 times its level in 2100.

We remind the reader that for an emissions pathway consistent with the AOSIS target we found a factor of 1.9 increase between 2500 and 2100. For comparison, Raper, *et al.* (1996) also computed sea level rise for the 350 ppm scenario, and found 20 cm in 2100 and a further increase of a factor of 1.9 between 2100 and 2500 (See Table 1).

To sum up, because of time lags in the climate system, sea level may increase after 2100 by a further factor of 2 to 3 before stabilizing, despite the stringent emission reductions needed to achieve the target of 20 cm in 2100. Moreover, limiting sea level rise to 20 cm in the very long run (up to 2500, for example) may require even sharper emission reductions.

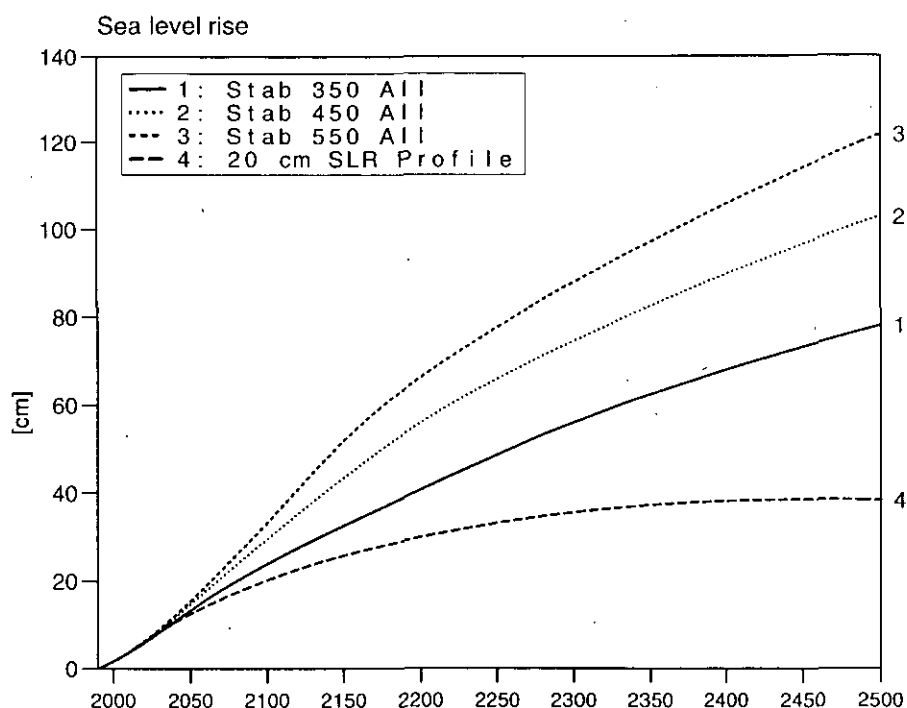


Figure 3: Sea level rise computed with the IMAGE 2 model for various scenarios.

Discussion and Conclusions

It is important to note that results presented here for the EU and AOSIS protocol proposals have many sources of uncertainty. These include the uncertainties inherent in using the IMAGE 2 model or any global model for calculating emission corridors and sea level rise. Another important source of uncertainty is the effect of sulfur emissions on global cooling, and the effect of this cooling on calculations of emission corridors. In this paper, sulfur emissions are fixed in all regions at their 1990 level. However, Alcamo and Kreileman (1996a) have pointed out that calculated emission corridors could be significantly wider if sulfur emissions are assumed to substantially increase in developing countries. On the other hand, there is little agreement at this time about the future trend of these emissions in developing countries.

Pitcher (1997) has also pointed out that the computation of emission corridors depends on the value of climate sensitivity of the global model used for the computations. It was also noted earlier in the text, that the corridor for Annex I countries is sensitive to the trend of uncontrolled emissions from non-Annex I countries.

Keeping in mind these and other uncertainties, the main conclusions of this paper are:

European Union Protocol Proposal

The European Union's proposed limitation of 2.0°C increase in temperature (above pre-industrial) can be achieved if the sum of anthropogenic global emissions of CO₂, CH₄, and N₂O in 2100 are between 7.6 and 12.4 Gt C/yr (using year 2100 as target year). This implies that emissions from Annex I countries should be between 1.3 and 6.1 Gt C/yr, or 25 to 111% of their 1990 level (5.3 Gt C/yr).

It was also pointed out that the higher the emissions in 2100, the faster they should be reduced afterwards, leaving less room for policy flexibility. Moreover, both Annex I and non-Annex countries would have to work harder after 2100 to reduce global emissions in order to reach the climate goals proposed by the EU. Hence it may be prudent to aim for an emissions level in 2100 that is somewhat below the top of the corridor. Such a "precautionary policy" would require reductions of about 9 to 31% of Annex I emissions by 2100 (relative to 1990).

AOSIS Protocol Proposal

To achieve the proposed AOSIS limitation of 20 cm sea level rise (from 1990 to 2100), global emissions in 2100 should be between 7.6 and 9.5 Gt C/yr. The sum of emissions from Annex I countries should be in the range of 1.3 to 3.2 Gt C/yr, or 25 to 61% of their 1990 level, i.e. a reduction of 39 to 75% by 2100 (relative to 1990). Following the same reasoning as in the EU example, a "precautionary policy" to keep emissions below the top of the corridor could require reductions of about 49 to 57% of Annex I emissions by 2100 (relative to 1990).

With regards to the AOSIS proposal to limit sea level rise to 20 cm, it was found that stabilizing CO₂ in the atmosphere at 450 or 550 ppm may lead to a sea level rise that is substantially greater than 20 cm in 2100. By contrast, stabilizing CO₂ at 350 ppm will lead to a sea level rise only slightly above the AOSIS limit in 2100. However, because of time lags in the climate system, sea level may increase after 2100 by a further factor of 2 to 3 before stabilizing, despite the stringent emission reductions needed to achieve this target. Moreover, limiting sea level rise to 20 cm in the very long run (up to 2500, for example) may require even sharper emission reductions.

Acknowledgements

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End Notes

¹ This is an estimate from the IMAGE 2 model.

² The emission pathway that results in a 20 cm sea level rise is called "20 cm Sea Level Rise Profile". For this pathway, global greenhouse emissions from anthropogenic sources are somewhat above the top of the emission corridor in 2100 that was computed for the AOSIS Protocol Proposal. After 2100 we assume that all global anthropogenic emissions decrease by 2% per year. Natural emissions remain nearly constant except for certain climate feedbacks. Fluxes of CO₂ between the atmosphere and biosphere are computed automatically by the IMAGE 2 model in the course of the simulation. Sulfur emissions are assumed constant after year 1990.

³ For the stabilization scenarios, CO₂ concentrations in the atmosphere are not computed, but are assigned time pathways according to IPCC (Enting, et al. 1994). Fluxes of CO₂ between the atmosphere and biosphere are computed automatically by the IMAGE 2 model in the course of the simulation. We then back-calculate the emissions of CO₂ from the global energy-industry system, with the aim to achieve the prescribed atmospheric concentrations of CO₂. Emissions of non-CO₂ greenhouse gases from the global energy-industry system are set proportional to CO₂ from the energy-industry system. Natural and land use emissions are computed automatically by the IMAGE 2 model and change according to changing land use up to year 2100. After 2100, land use changes are set to zero. Hence, natural and land use emissions (non-CO₂) are also nearly constant after 2100, except for feedback caused by changing surface temperature. Sulfur emissions are assumed constant after year 1990.

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