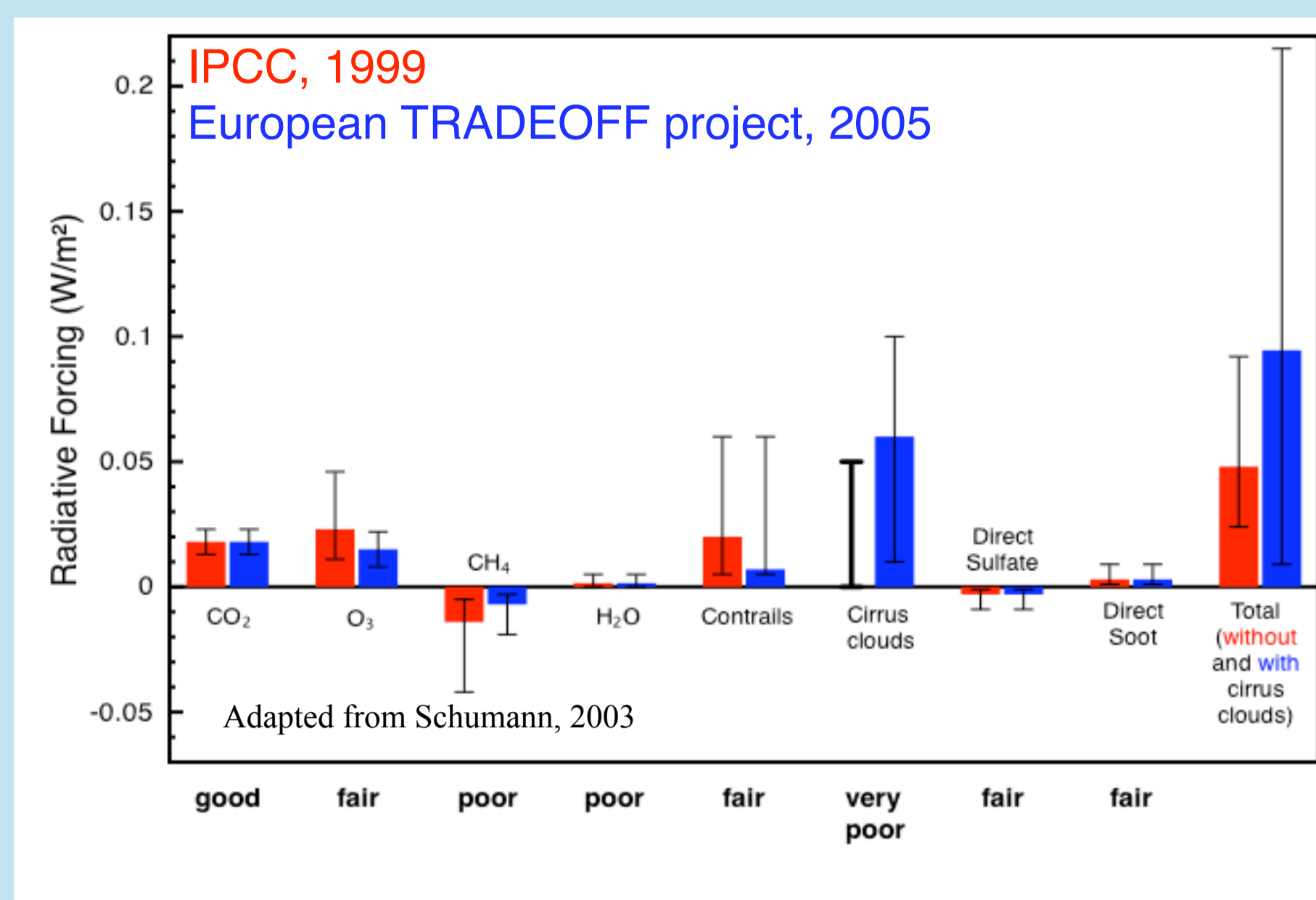


Is mitigation of aviation emissions and induced cloudiness needed to stabilise climate change < 2°C ?

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1. Impacts of aviation on climate

Aviation transportation is one of the fastest growing activities influencing climate, so it is important to take it into account in analysis of mitigation required for climate stabilization (ABCI, 2008). The European Union recently decided to include carbon dioxide emissions from aircraft in its Emission Trading Scheme (EU-ETS), but this policy does not yet take into account the non-CO₂ impacts of aviation. In this context, the next step is expected to focus on NO_x emissions, which have both a warming effect through increasing tropospheric ozone concentration and a cooling effect by accelerating the destruction of methane. Despite limited quantitative knowledge, current estimates suggest that the impact of aircraft induced cloudiness (AIC), i.e. condensation trails and their evolution into cirrus clouds, is significantly greater than NO_x, and greater than aviation CO₂ on short-medium timescales.



2. Background: conditions for contrail formation

The engines of a jet airplane emit mainly water vapour and carbon dioxide at high temperatures. The exhaust gases mix up in a few seconds with the ambient air. If during this mixing process the air becomes saturated with respect to water a contrail will form (case 1). If the environmental air is ice-supersaturated, the contrails will persist (up to several hours) and spread out (case 2). It is important to note that for thermodynamical reasons, more efficient planes are more prone to form contrails.

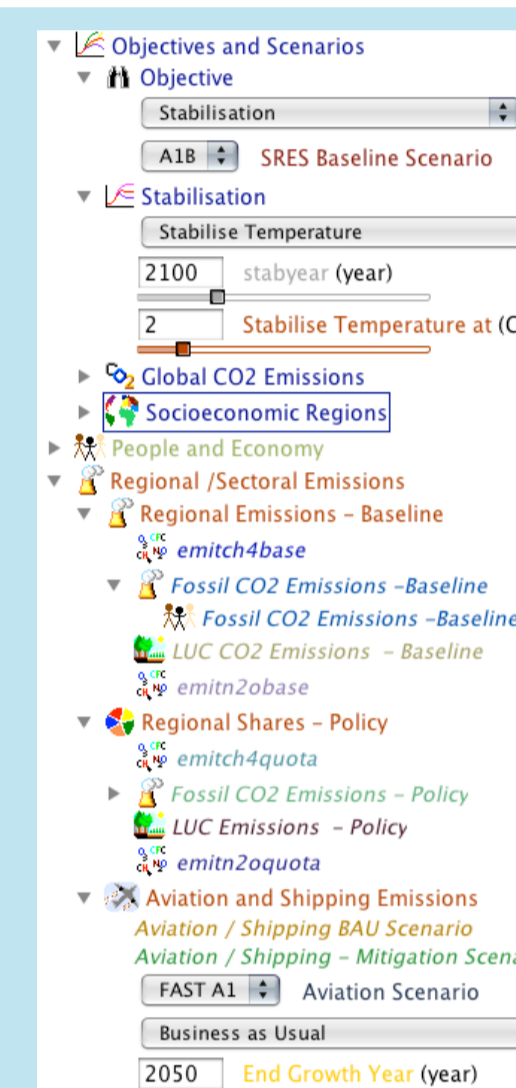


3. Model and 2°C stabilization

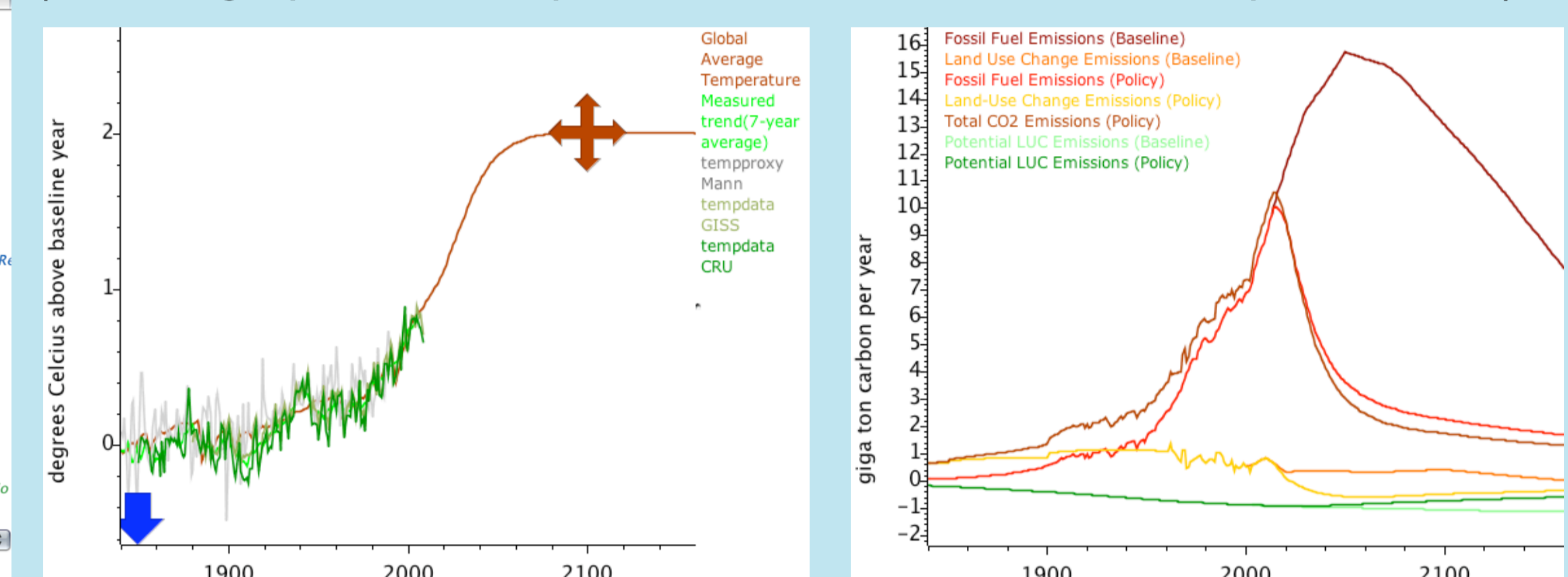
To investigate the implications of aviation on climate stabilisation, we use the Java Climate Model (JCM, available on www.climate.be/jcm), an "integrated assessment" model that was designed to facilitate the interactive exploration of scenarios, taking different stabilization objectives into account. The originality of JCM is that users can see an instant response to adjusting parameters, and thereby explore sensitivities of scenario projections to diverse

options and uncertainties. The climate and carbon cycle components consist in relatively simple (but non-linear) models with sets of parameters based on results from more complex models.

In this poster, the model is used in the "temperature stabilization" mode : it internally adjusts the future emissions mitigation for all sectors together by an iterative process so that temperatures reach stability from a given year, for example 2°C (above preindustrial level) starting in 2100.



Scenario providing the total emissions: 2°C temperature stabilization (the left graphic shows part of the model interface and parameters)



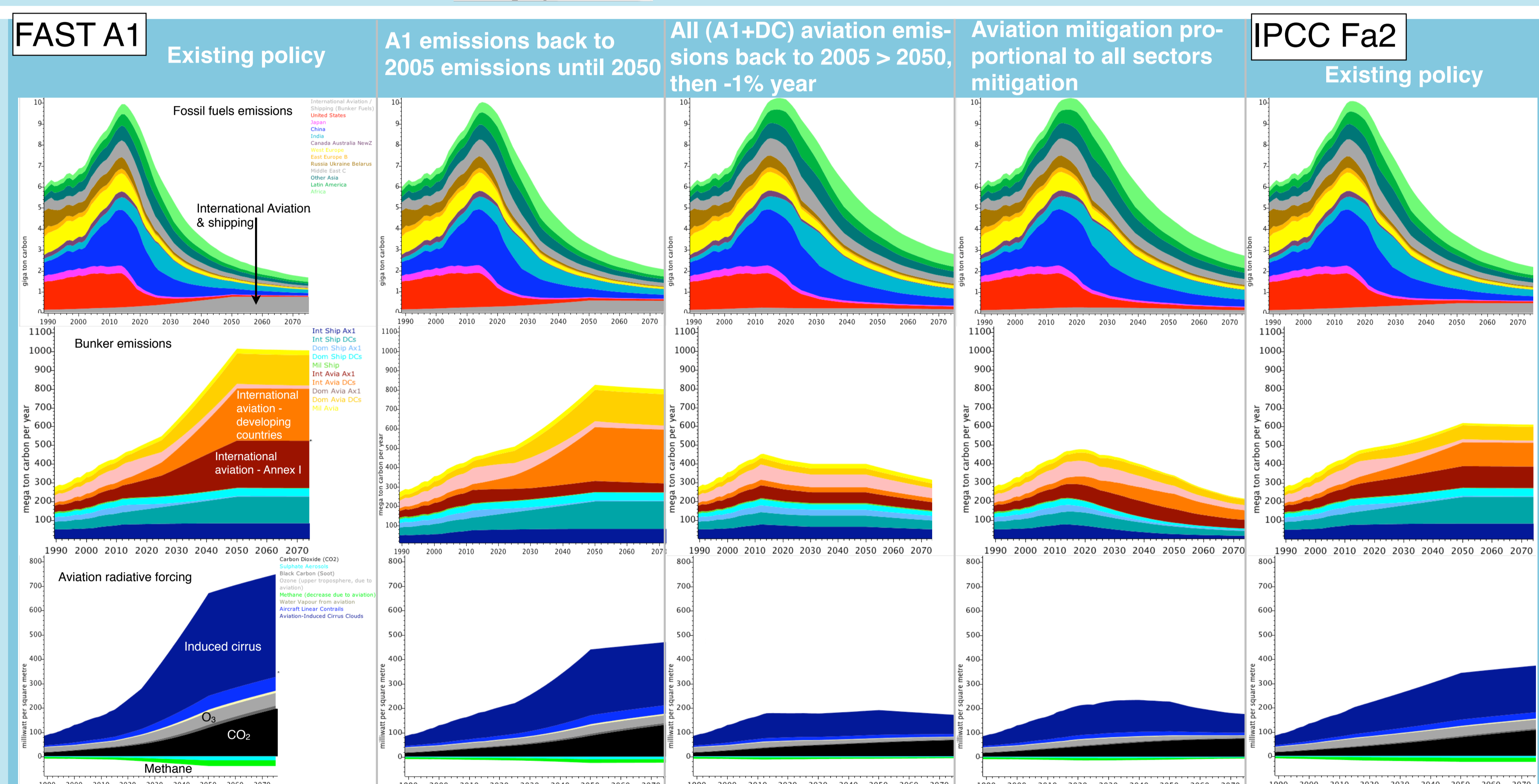
4. Example aviation scenarios

Baseline aviation emissions scenarios are taken from IPCC (1999), the CONSAVE project (Berghof et. al 2005), and the FAST scenarios (Owen and Lee, 2006), see also IPCC AR4. The radiative forcing changes due to aviation are calculated on the basis of IPCC (1999) adjusted to the more recent TRADE-OFF data (Sausen et.al, 2005) for CO₂, O₃, CH₄, sulphate and carbon aerosols, water vapour, linear contrails and cirrus.

An example of results is shown on the right figures for the FAST A1 scenario. The first column relates to the "continuation of existing policy" : in the aviation sector, mitigation is required only for domestic flights within Annex I countries. For aviation in these countries, the ratio of actual emissions to baseline aviation emissions is made equal to the ratio of CO₂ emissions for all sectors (constrained by the 2°C stabilisation) divided by its baseline (IPCC SRES A1B). As most aviation scenario where not defined after 2050, we use constant emissions thereafter. In this scenario without mitigation of international aviation, emissions are growing a lot. As the stabilisation temperature objective (2°C limit) is maintained, the emission budget available to other sectors is very small, and even the total "permitted" CO₂ emissions becomes small, due to the fact that there are very significant non-CO₂ emissions, in particular due to the aircraft induced cloudiness.

The 3 following columns present mitigation scenarios applied on the aviation sector. They are based on simple hypotheses aiming at exploring the consequences of mitigation in the aviation sector (or lack of it) on the remaining emission space for the other sectors, within de selected global change limit.

In the second column, only emissions from Annex I countries are reduced. The rule is that these emissions comes back to the 2005 level⁽¹⁾ in a few years after 2013, remain at that level



until 2050, then decrease at a rate of 1%/year. As shown by the second line of graphics, total aviation emissions are significantly reduced. As baseline aviation emissions were large, resulting in a tight constraint on emissions from other sectors, the limited aviation mitigation has a large impacts on these other sectors.

In the third column, the same mitigation rule is applied to all aviation emissions : back to 2005 level short after 2013, stable until 2050, then -1%/year (shipping emissions follow the same rule, but only for CO₂), resulting in further emission increases in the other sectors. In the fourth column, mitigation applies to all

bunkers again, but with a different rule : aviation emissions are reduced in the same proportion from their baseline as global (all sectors) emissions are reduced from their baseline.

Finally, the last column shows emissions and radiative forcing for an alternate baseline, the IPCC (1999) Fa2 scenario, with significantly less aviation emissions, so that the reduction in other sectors is less dramatic than in the FAST A1 case (column 1).

5. Results and conclusion

The table on the right summarize the main results, showing 2050 emissions for all sectors except aviation in % of 1990 emissions. All scenarios (in columns) except the last one are non-mitigation scenarios (no climate policy for aviation). We add mitigation hypotheses (shown in rows) as explained above. There is one additional intermediate scenario, in which this mitigation is again applied on international flights involving Annex I countries only until 2050, but in addition, both A1 and non-A1 reduces their emissions by 1%/year after 2050.

The main result is that the "continuation of existing policy", involving mitigation only for domestic Annex I flights, implies very large emission reduction in other sectors : from -55 to -82 % of 1990 emissions, in order to have roughly 1/2 chances that global warming remains below 2°C from pre-industrial (we used a medium climate sensitivity of 3.2°C and other mean parameters).

When mitigation is applied on aviation, the burden on other sectors becomes more bearable : for example, in

the high emission baseline FAST A1, the other sectors can only emit 18% of their 1990 emissions, but when reducing emissions from A1 countries then progressively all emissions (3rd case), the other sectors can still emit 37% of their 1990 emissions. The CONSAVE-DtE ("Down to Earth") scenario is another example of mitigation, also showing smaller mitigation efforts in non-aviation sectors than in the "existing policy" cases.

The model includes the feedback of increased surface temperature on the carbon cycle (via ocean chemistry and soil respiration) and the consequent increase of carbon dioxide concentrations in the atmosphere induced by aviation warming. The additional CO₂ released by this feedback has been provisionally estimated to be of the order of 30% of the direct emissions of CO₂ from aviation. It transforms short-lived radiative forcings (not only from aviation) into long term impacts on climate from CO₂.

Avoiding large increases in the aviation emissions is thus an important component of mitigation to achieve climate stabilization at a low level.

Table : reduction of CO₂ emissions from all sectors except aviation in 2050 in % of the corresponding 1990 emissions (including land-use change)

	IPCC		FAST		CONSAVE	
	Fa2	Fe1	A1	B2	ULS	DtE
Continuation of existing policy	55	70	82	68	73	-
A1 emissions back to 2005 emissions until 2050	50	60	69	59	63	53
Same as above + all aviation -1%/year after 2050	47	56	63	54	58	
All (A1+DC) aviation emissions back to 2005 until 2050, then -1% year			42			
Aviation mitigation proportional to all sectors mitigation	35	39	43	38	40	

These results represent a work in progress, as several questions regarding scenarios should still be addressed. More cases than those shown here can be interactively explored with the model (we encourage readers to download it from www.climate.be/jcm and/or contact the authors for further information, including possibilities for joint development of the model, that can be applied on several other issues outside aviation)

Sources and links

ABCI 2008: W. Hecq, et. al., Aviation and the Belgian Climate Policy: Integration Options and Impacts: Final report, phase I, Belgian Public Planning Service Science Policy, Brussels 87p. available on www.climate.be/abci

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IPCC 1999, Joyce E. Penner, et. al., editors. Aviation and the Global Atmosphere. Cambridge University Press, 1999.

Schumann, U., Aviation, Atmosphere and Climate - What has been learned, Proceedings of the AAC-Conference, June - July, 2003, Friedrichshafen, Germany, 2003

Note (1) : A similar example is proposed in a recently announced study by the UK Committee on Climate Change.