1. Hansen’s *Pipeline* claims that 70% of the surface warming impact from CO2 forcing comes from feedbacks and only 30% from its direct greenhouse effect (Formula 1).
   1. Does this also apply to non-CO2 GHGs?
   2. Does it apply equally irrespective of the sign of the forcing i.e. if CO2 is increasing 70% of the warming is from feedbacks, and if it’s decreasing, 70% of the cooling is from feedbacks?
   3. What are the corresponding direct/feedback surface temperature impacts from changes in albedo? Do we know how these might vary between different SRM technologies and different deployment strategies for individual technologies?
2. In an earlier exchange of emails, my suggestion that a 1 W/m2 reduction in forcing from increased albedo would cool the surface faster than the same reduction from reduced atmospheric GHGs, was comprehensively rejected. The counterclaim was that a given change in forcing would be climatically the same irrespective of its source. Is this counterclaim valid for both the direct GHG effect and feedback effects on surface temperature?
3. Hansen’s *Pipeline* paper has a detailed examination of climate response time – the e-folding time over which changes in GHG forcing emerge as changes in surface temperature. He claims that for changes to CO2 this is of the order of 100 years in contrast to the IPCC’s established position of 10 to 20 years.
   1. Is the climate response time the same for all GHGs?
   2. Does this notion of climate response time also encompass albedo-driven changes in forcing?
   3. If not, what do we know about the time lag between changes in albedo and the corresponding changes in surface temperature? Note that Pinatubo is estimated to have caused a 0.5oC reduction in global mean surface temperature in the following year.
   4. How is climate response time (for both light and heat radiation) affected by feedbacks?
   5. How does the concept of climate response time affect the claim (2 *supra*) that changes to surface temperature are the same irrespective of the source of the forcing change that generates them? For the counterclaim to be valid, the climate response time for changes to both light and heat radiation must include all feedback effects and for it to be the same for both light and heat radiation. What is the evidence for this?
4. AR6 WGI 4.6.3.3 (in which you are cited several times) claims that an increase in albedo from 0.31 to 0.32 (corresponding to a 2% reduction in irradiance) would be sufficient to offset warming from 2xCO2. It also cites Matthews and Caldeira 2007 that includes the following result:

For all geoengineering runs, global temperature responded quickly to changes in incoming solar radiation; temperature decreased toward preindustrial temperatures in all cases with an *e*-folding time scale of ≈5 years. This is consistent with evidence from Pinatubo.

This is a substantially shorter e-folding time than the 100 years claimed by Hansen for changes in atmospheric CO2. If these two values are robust, it suggests that SRM would reduce surface temperature much faster than reducing atmospheric GHGs. However, it is unclear (to me) whether this difference is due to differences in the climate physics and chemistry of the two approaches, or differences in their scale and timing of deployment.

After a lengthy discussion of the potential problems from SAI, AR6 WGI 4.6.3.3.1 adds that:

By appropriately adjusting the amount, latitude, altitude, and timing of the aerosol injection, modelling studies suggest that SAI is conceptually able to achieve some desired combination of radiative forcing and climate response (medium confidence) (MacMartin et al., 2017; Dai et al., 2018; Lee et al., 2020; Visioni et al., 2020b).

Taken together with the evidence that SRM reduces surface temperature faster than GGR, does this imply that if time isof the essence in responding to global warming, SRM is a necessary additional tool precisely because it can reduce surface temperature so much more quickly than GGR?

1. Does Table 1 in *Pipeline* accurately represent the relationship between changes in GHG mass and the forcing?
   1. Does Table 1 refer to the direct radiative forcing to which must be added the feedback effects to generate the total warming (see d below)?
   2. Do these formulae operate equally for both increases and decreases in GHG ppm?
   3. Using the formula for CO2, a reduction of 1 W/m2 from a starting position of 425 ppm would require the net removal of 140GtC or 520 GtCO2.  This implies gross CO2 removal of ~900 GtCO2 after accounting for ocean and terrestrial outgassing.
   4. Using the NOAA formula [here](https://gml.noaa.gov/aggi/aggi.html), would increase the required net removal to 160 GtC or 1,250 GtCO2 gross. NOAA declare that their formula includes the direct forcing only and excludes feedback effects. They also exclude ‘spatially heterogeneous, short-lived, climate forcing agents, such as aerosols, clouds and tropospheric ozone’. If Hansen is correct that feedbacks account for 70% of the surface temperature change, does this imply that 1 W/m2 of negative forcing could be achieved by reducing atmospheric CO2 by only 30% of the above figures, i.e. ~50 GtC net or~350 GtCO2 gross and letting feedbacks deliver the other 70%?
   5. The corresponding figures using the Hansen formula for a 1 W/m2 negative forcing from reducing atmospheric methane imply a net removal of almost two thirds of current total atmospheric methane (1930 ppb).
   6. Note that Hansen assesses ECS to be 1.2oC ±0.3oC per W/m2. This suggests that a negative forcing of 1 W/m2 would deliver an equilibrium temperature change of ~1.2oC. However, since they also assess the EEI to be 4 W/m2 this implies a requirement for substantially more negative emissions than currently contemplated and supports the contention (qv. 6d below) that GGR on that scale is implausible.
2. The logistical scale implied by the removal of both CO2 and methane to deliver negative forcing of just 1 W/m2 is considerable and could realistically only be achieved over several decades.
   1. Do we have any insight into the logistical implications of a 1 W/m2 negative forcing from changing albedo?
   2. Is there a case to be made that the engineering and cost implications per W/m2 of scaling GHG interventions to deliver reduced forcing are so much greater than from increasing albedo to deliver the same negative forcing, that for practical purposes, if not for climate physics and chemistry reasons, albedo enhancement would reduce surface temperature faster than reducing current and removing past emissions?
   3. AR6 WGI 4.6.3.1 states that:

Emergence of the GSAT response to mitigation of individual short-lived climate forcers (SLCFs) would likewise not occur until several decades after emissions trajectories diverge, owing to the relatively small influence of individual SLCFs on the total ERF.

This would seem to imply that the response time for methane would be slower than for reduced CO2, which would mean that the response time was not the same for all GHGs (see 3a above). However, the paragraph following the above extract suggest that more recent studies give different results, although it remains unclear (to me) whether the response times would be the same for different GHGs.

* 1. AR6 WGI 4.6.3.2 summarises various papers to conclude that to avoid significant overshoot of 1.5oC, some 730 GtCO2 would have to be removed by 2100. It also refers to other studies that conclude that ‘it is implausible that any CDR technique can be implemented at the scale needed by 2050.’ It also notes that in high emissions scenarios ‘the potential role that CDR will play in lowering the temperature in high-emissions scenarios is limited (medium confidence)’.

1. Is W/m2 a suitable metric for policy purposes? It defines the forcing power but gives no indication of its sustainability or cost. A powerful cooling process in terms of W/m2 that can only be deployed at certain times of the day or year in a limited range of geographies or weather conditions, may be less effective than a less powerful one that can be kept delivering 24/7. Could alternative metrics that capture the efficacy and cost efficiency be of value? For example, Jm-2y-1 and $J-1m2y.