Global warming: Stop worrying, start panicking?

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In their excellent Perspectives article in this issue (1), Ramanathan and Feng (R&F) sound a harsh wake-up call for those concerned about anthropogenic climate change: the authors maintain that the greenhouse gas (GHG) emissions of the past have already loaded the Earth System sufficiently to bring about disastrous global warming. In other words, the ultimate goal of climate protection policy, as stipulated by the United Nations Framework Convention on Climate Change (UNFCCC) (2), appears to be a delusion. So should we stop worrying and rather start panicking now?

The scientific evidence about climate change comes in thousands of parcels, yet the monumental reports of the Intergovernmental Panel on Climate Change (IPCC) (3) are the guideposts for both experts and stakeholders. The IPCC format, perfected by the late Bert Bolin, is a painstaking self-interrogation process of the pertinent scientific community. In this process, virtually every stone in the cognitive landscape is turned and the findings, however mundane or ugly, are synthesized into encyclopedic accounts. Unfortunately, such an approach is inherently tuned for burying crucial insights under heaps of facts, figures, and error bars. Therefore, R&F must be commended for dredging up one of the most inconvenient truths hidden in the IPCC tangle, namely the aerosol masking of global warming (AMGW).

Also, by construction, the IPCC vessel tends to steer clear of value judgments that might be easily converted into "policy-prescriptive" statements. The downside of this well-meaning attitude is that the 2007 report does not, for instance, make a systematic attempt to characterize what dangerous anthropogenic interference (DAI) with the natural climate system is all about. Again, all of the relevant information is implicitly contained in the IPCC tomes, most notably in chapter 19 of the Working Group II report (3) (see also ref. 4). Yet even that chapter shies away from updating the "burning embers diagram" (5), which provides a direct scientific way to gauge the *political* target of limiting global mean temperature (GMT) rise to less than 2°C (6) against avoided climate impacts.

R&F (1) also dare to pull out this big issue from the IPCC ocean. They enrich their take on the two topics, i.e., DAI and AMGW, by recently published evidence and add the insights up in three disturbing conjectures.

(*i*) Our planet is already committed to anthropogenic warming in the range of 1.4–4.3°C, where 2.4°C is the most likely amount. The main reason why only roughly a quarter (actually 0.76°C since the latter half of the 1800s) of that equilibrium temperature response to the current atmospheric GHG concentrations has been observed is the (predominantly) cooling effect of various aerosols that often accompany GHG emissions. Large scientific uncertainties remain regarding the forcing potential of the various aerosol species. There is certainty, however, that GHG concentrations (in particular, CO_2 levels) will rise further in the medium-term future and that clean-air policies will remove that accidental antidote against global warming in the decades to come. Thus, the likelihood of global warming even beyond the 2.4°C margin in the 21st century is frustratingly high.

(*ii*) The resulting expectations for the planetary temperature clearly qualify for DAI, whether one refers to the emerging political consensus on a long-term climate stabilization goal as implicitly debated at the Conference of the Parties to the UNFCCC in Bali (COP13) or to the growing scientific evidence about critical thresholds for tipping vital Earth System components (e.g., the Greenland ice sheet) into different modes of operation.

(*iii*) No conceivable international CO_2-reduction strategy (including the one hoped to transpire from the COP15 negotiations in Copenhagen next year) could possibly avoid that the planet will enter the DAI zone, where largely unmanageable climate impacts (like sea-level rise in the multimeter range) lurk. All we can do is to limit the warming *in excess* of the 2.4°C.

The first point made by R&F (1) is substantial and hard to dismiss. The tale about our dubious friend (namely "ordinary" air pollution as manifesting itself in atmospheric brown clouds laden with sulfates and nitrates) who luckily counteracts global warming by "global dimming" has been around for a while. Yet the authors succinctly summarize the state of the art and provide a convincing estimate of the still-hidden component of anthropogenic planetary temperature rise.

One needs to appreciate, however, that R&F's assessment mainly results from clever composition of a limited number of syntheses done by other researchers [such as the paper by Roe and Baker (7)] and by masterly back-of-the-envelope reasoning. The paper performs a basically static thought experiment by pulling back the aerosol veil while keeping all other factors fixed. In the real world, some aerosol emissions will be harder to reduce than others: whereas sulfate aerosols might face a quick decline, ammonium or nitrogen oxides might not. The AMGW might vanish quickly, as R&F suggest, but could also stick around for a while. Also, there will be intricate dynamic adjustment and feedback processes (involving, for example, the terrestrial and the marine carbon cycles) that can be captured only by simulation runs of fully fledged climate-system models. I will return to this crucial argument below.

Venturing into the 2+*x*°C-warming realm is risky, as the authors rightly emphasize in their second point, because large-scale nonlinear responses of the planetary machinery are likely to be triggered then (8, 9). These effects might even conspire to bring about—in the worst of all possible climate change science fictions—something like a runaway greenhouse effect. The present level of knowledge about the geobiosphere does not allow for rigorously ruling out such a cataclysmic accident, because we still do not possess genuine Earth models that could adequately simulate the hypercomplex dynamics involved. However, the research community keeps churning out relevant specific findings—for instance, about positive feedback processes such as methane release from Siberian thawing (10), teleconnections between tipping elements in the planetary system (11), or the volatility of the climate machinery as confirmed by empirical evidence about abrupt environmental transitions in the past (12). This topical information strengthens rather than weakens the R&F conjecture that we are heading toward DAI.

So the decisive question remains whether the authors' third point is correct: Are we really doomed to sail straightly into those stormy seas? My answer is a qualified "no."

The R&F projections make two pivotal assumptions, namely (*i*) that the atmo-

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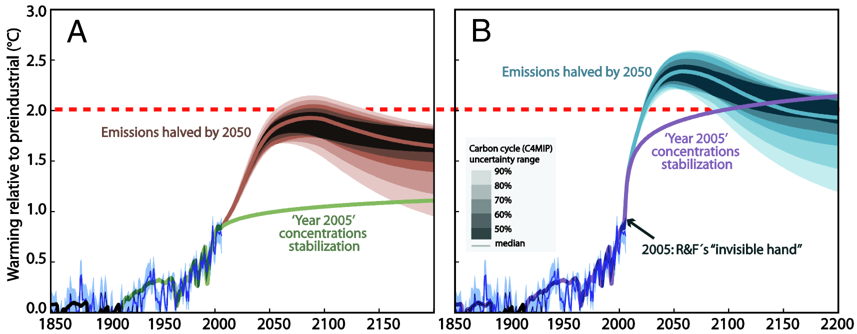

Fig. 1. Comparison of GMT development as resulting from fixing concentrations at 2005 levels [''concentrations stabilization scenario'' (CSS)] and halving global Kyoto-GHG emissions by 2050 relative to 2000 levels [''mitigation scenario'' (MS)], respectively. (*A*) Freezing of current air pollution and GHG levels in CSS, and concomitant gradual decrease of air pollution in MS. (*B*) The ''invisible hand'' of R&F (1) eliminates all forcings except those of long-lived GHGs and tropospheric ozone in 2005, i.e., aerosol cooling vanishes, in both CSS and MS. Climate sensitivity is chosen as 3°C throughout; other climate parameters (such as those affecting ocean inertia) are calibrated toward HadCM3; carbon cycle parameters are varied for representing the range of ten C4MIP models (14) by using MAGICC 6.0 (13). Historical observations of GMT are taken from HadCRUT3v (15).

spheric GHG concentrations are at least constant or increasing throughout the next hundred years, and (*ii*) that clean-air policy operates much faster than GHG-emissions-reduction policy. Both assumptions can be challenged, as I will demonstrate by a quick model-based comparison of GMT rise in the R&F thought experiment, on the one hand, and a realistic (yet ambitious) climate protection scenario rooted in IPCC ground, on the other hand. The latter scenario anticipates that COP15 will adopt the long-term climate-stabilization goal endorsed by the recent Group of Eight (G8) Summit in Japan, namely to halve global emissions of the Kyoto-GHGs (CO_2, methane, nitrous oxide, fluorinated gases) by 2050. 2000 is chosen as the reference year here, and a convergence to zero CO_2 emissions by 2100 is postulated. By way of contrast, the R&F assessment explores the effects of an artificial freezing of the Kyoto-GHG concentrations at their 2005 levels, tacitly assuming that climate policy could not possibly do any better.

The comparison is achieved by appropriate parameter choices in a well established climate-carbon cycle model (13) that emulates the ensemble dynamics of the most advanced full-complexity models, and are summarized in Fig. 1. In Fig. 1*A*, GMT results without the "invisible R&F hand" that instantaneously suppresses the aerosol effects (more precisely eliminating all forcings except those of long-lived GHGs and tropospheric ozone) are depicted. Note that the median trajectory in the G8-mitigation fan (as generated by state-of-the-art carbon-cycle uncertainties) avoids the 2°C line and even bends down again after peaking toward the end of this century. This favorable outcome is mainly due to the oceans' capacity to keep on taking up big quantities of certain GHGs for quite a while, so the concentrations of the latter will *fall* again—instead of just remaining constant—under the specified mitigation strategy. Also, in contrast to the R&F scenario, land-use changes (affecting surface albedo) and volcanic activities can be assumed to keep exerting some cooling effects. For the sake of validation and consistency, a control model run is done with concentrations of all global-warming-relevant atmospheric substances (including the ordinary pollutants) fixed at 2005 levels, which yields the slowly rising solitary curve below the G8 bundle.

In Fig. 1*B*, the corresponding results for switching off aerosol effects in 2005 are presented. The control curve generated by fixing the Kyoto-GHG concentrations nicely illustrates the R&F calculations by asymptotically approaching their equilibrium global warming estimate (≈2.4°C). The really interesting result, however, is the elevated transient temperature fan produced by G8 mitigation plus abrupt sky cleaning: the median trajectory overshoots the political 2°C guardrail by ≈0.4°C in 2070, and closely approaches it again some 70 years later. This can still be perceived as a dangerous climate excursion because it may be sufficient to trigger the collapse of the Greenland ice sheet, but the overall environmental dynamics differs fundamentally from the disturbing R&F scenario. And this is not the end of the story, because the assumption of instantaneous aerosol unmasking is certainly an unlikely one: relevant measures will be implemented rather inhomogeneously in geographical space and political time. On the other hand, the G8-mitigation scenario used here (16) already contains substantial removal of cooling air pollutants in phase with the substitution of fossil fuels and technological innovation. Therefore, the more realistic temperature developments under ambitious climate-policy conditions sit between the two fans depicted in Fig. 1 *A* and *B*, respectively.

My conclusion is that we are still left with a fair chance to hold the 2°C line, yet the race between climate dynamics and climate policy will be a close one. The odds for avoiding DAI may be improved by aerosol management as suggested by R&F (taking the warming components such as black carbon out first), and even techniques for extracting atmospheric CO_2 (like bio-sequestration) might eventually prove necessary. However, the quintessential challenges remain, namely bending down the global Kyoto-GHG output curve in the 2015–2020 window (further procrastination would render necessary reduction gradients too steep thereafter) and phasing out carbon dioxide emissions completely by 2100. This requires an industrial revolution for sustainability starting now.

1. Ramanathan V, Feng Y (2008) On avoiding dangerous anthropogenic interference with the climate system: Formidable challenges ahead. *Proc Natl Acad Sci USA* 105:14245–14250.
2. United Nations Framework Convention on Climate Change (1992) Available at http://unfccc.int/resource/docs/convkp/conveng.pdf. Accessed August 20, 2008.
3. IPCC (2007) *Climate Change 2007: Contribution of Working Group I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, eds (I) Solomon S, *et al.*, (II) Parry ML, *et al.*, (III) Metz B, *et al.* (Cambridge Univ Press, Cambridge, UK, and New York).
4. Parry M, Palutikof J, Hanson C, Lowe, J (2008) Squaring up to reality. *Nat Rep Clim Change* 2:68–70.
5. Smith JB, Schellnhuber HJ, Qader Mirza MM (2001) in *Climate Change 2001: Impacts, Adaptation and Vulnerability: Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change*, eds McCarthy JJ, Canziani OF, Leary NA, Dokken DJ, White KS (Cambridge Univ Press, Cambridge, UK, and New York).
6. Commission of the European Communities (2007) *Communication from the Commission. Limiting Global Climate Change to 2 degrees Celsius—The Way Ahead for 2020 and Beyond*. Available at http://eur-lex.europa.eu/lexuriserv/lexuriserv.do?uri=com:2007:0002:FIN:EN:PDF. Accessed August 20, 2008.
7. Roe GH, Baker MB (2007) Why is climate sensitivity so unpredictable? *Science* 318:629–632.
8. Lenton TM, *et al.* (2008) Tipping elements in the Earth's climate system. *Proc Natl Acad Sci USA* 105:1786–1793.
9. Lenton TM, Schellnhuber HJ (2007) Tipping the scales. *Nat Rep Clim Change* 1:97–98.
10. Khvorostyanov DV, Ciais P, Krinner G, Zimov SA (2008) Vulnerability of east Siberia's frozen carbon stores to future warming. *Geophys Res Lett* 35:L10703, 10.1029/2008GL033639.
11. Chang P, *et al.* (2008) Oceanic link between abrupt changes in the North Atlantic Ocean and the African monsoon. *Nat Geosci* 1:444–448.
12. Steffensen JP, *et al.* (2008) High-resolution Greenland ice core data show abrupt climate change happens in few years. *Science* 321:680–684.
13. Meinshausen M, Raper SCB, Wigley TML (2008) Emulating IPCC AR4 atmosphere-ocean and carbon cycle models for projecting global-mean, hemispheric and land/ocean temperatures: MAGICC 6.0. *Atm Chem Phys Disc* 8:6153–6272.
14. Friedlingstein P, *et al.* (2006) Climate-carbon cycle feedback analysis: Results from the (CMIP)-M-4 model intercomparison. *J Clim* 19:3337–3353.
15. Brohan P, Kennedy JJ, Harris I, Tett SFB, Jones PD (2006) Uncertainty estimates in regional and global observed temperature changes: A new data set from 1850. *J Geophys Res Atmos* 111:D12106, 10.1029/2005JD006548.
16. Meinshausen M, *et al.* (2006) Multi-gas emission pathways to meet climate targets. *Clim Change* 75:151–194.