MEETING REPORT

Geoengineering and India*

The national roundtable discussion on geoengineering was held recently in Delhi. While research on geoengineering is fairly advanced in the international arena, very little R&D efforts have been undertaken in India. Hence, the Department of Science and Technology (DST) has recently launched a Major R&D project (MRDP) at Centre for Amospheric and Oceanic Sciences (CAOS), Indian Institute of Science (IISc) to undertake climate modelling experiments in order to generate strategic knowledge on stratospheric aerosol geoengineering. The primary objective of convening the roundtable discussion on geoengineering was to seek views of the experts and policy makers on the issue of whether and how geoengineering is likely to impact India.

What is geoengineering? It is the 'intentional planetary scale' manipulation of the climate system that helps reduce or reverse global warming. There are two categories of geoengineering proposals: (a) Solar radiation management (SRM), (b) carbon dioxide removal (CDR) methods.

SRM schemes propose to increase the amount of solar radiation reflected by our planet. Placement of mirrors in space or reflective aerosols in the stratosphere, and enhancement of the reflectivity of marine clouds are some examples. CDR methods propose to accelerate the removal of atmospheric carbon dioxide (CO_2) through either natural carbon cycle processes or industrial means. Afforestation/reforestation, ocean iron fertilization, accelerated weathering of silicate and carbonate rocks, and direct air capture of CO_2 are some of the proposed CDR methods. Since SRM can cool the climate system rapidly and is relatively cheap, most of the geoengineering discussion is now centred on SRM methods. Prominent among them is the proposal to inject aerosol particles such as sulphates into the stratosphere and deflect 1–2% of the incoming solar radiation. Hence, the scientific objectives of the MRDP and the round-table discussion were centred around the stratospheric aerosol geoengineering.

Geoengineering may have several consequences. Injection of aerosols into the stratosphere could alter the global rainfall pattern or cause stratospheric ozone depletion. Hence the question of whether we should take this unknown road to deal with climate change arises. In what way will geoengineering benefit or affect India? Is geoengineering immoral, unethical and illegal? What should be India's position on geoengineering? An inclusive and transparent approach for understanding the scientific, social, economic, ethical, legal, moral, political and technological concerns is needed, and India must participate in the global debate on geoengineering. In this context, the roundtable brought together and facilitated interaction among physical and social scientists and policy makers.

The meeting was attended by about 35 participants from 14 institutions. Representatives from DST, the Ministry of Environment, Forest and Climate Change (MoEF & CC) and the Ministry of Earth Sciences, Government of India (GoI) also attended the roundtable. The meeting was organized in four sessions: inaugural session, two technical sessions and a concluding session. In the inaugural session, R. R. Rashmi (MoEF&CC) stressed upon the importance of scientific research in geoengineering and the generation of strategic knowledge which would be useful to the Indian delegates at the COP (Conference of Parties) meetings when geoengineering comes up for discussion in the future. He contrasted this scenario with the situation two decades ago when scientific inputs on climate change from Indian researchers were not available to the Indian delegation participating in COP meetings.

In the first technical session, chaired by S. K. Dube (former Director, IIT Kharagpur), seven presentations were made. G. Bala (IISc) introduced the field of geoengineering and presented some key climate modelling results. He showed that geoengineering could markedly diminish regional and seasonal climate change as well as extreme events caused by anthropogenic climate change. He also showed that geoengineering involves undesirable side effects such as weakening of the global water cycle. SRM does not address 'ocean acidification' which could be detrimental to marine life. Further, SRM could commit us to maintain it (e.g. artificial aerosol layer in the stratosphere) for decades to centuries – until atmospheric CO_2 levels fall to sufficiently lower values. If SRM fails or is halted, the Earth could experience warming rates several times that of the current warming, subjecting human and natural systems to severe stress following an abrupt termination of SRM.

The multi-model assessment of geoengineering for Indian climate was presented by Saroj K. Mishra (IIT, Delhi), who showed that geoengineering could moderate the impacts of climate change in India. He had identified no remarkable side effects from the model simulations. However, a cautionary note on the ability of the current generation of climate models to accurately simulate regional climate was also made by Mishra. On the issue of geoengineering governance, Arunabha Ghosh (Centre for Energy, Environment and Water, Delhi) pointed out that there is presently no international governance framework for research, field study or implementation of geoengineering. He advocated the development of national and regional frameworks of governance on geoengineering before dealing with the international framework.

S. Ramachandran (Physical Research Laboratory) compared major volcanic eruptions to stratospheric aerosol geoengineering – sulphate aerosols injected into the stratosphere by major volcanic eruptions cause surface cooling, but they also result in large warming in the stratosphere and ozone loss. V. Vinoj (IIT, Bhubaneswar) reviewed the radiative properties of proposed geoengineering

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aerosols, and concluded that higher refractive index and smaller size are important for larger deflection of sunlight. However, S. N. Tripathi (IIT, Kanpur) in his review of the various aerosols for geoengineering (sulphates, tin oxide, alumina, diamond, calcium carbonate, etc.), showed that smaller-sized particles have larger surface area and hence could accelerate ozone loss. R. Ramesh (National Institute of Science Education and Research, Bhubaneswar) made a brief review of the CDR method of ocean iron fertilization for sequestering carbon in the ocean and its potential limitations.

The second technical session, chaired by Prodipto Ghosh (MoEF&CC) and moderated by Akhilesh Gupta (DST) discussed the following science and policy issues of geoengineering.

(1) Will geoengineering adversely impact India?

(2) Will it impact monsoon rainfall in India and cause severe droughts?

(3) Will there be benefits for India? If yes, what are they? For example, will it reduce the heat wave related deaths in India?

(4) Do we believe that our climate would be controlled and manipulated by other countries through geoengineering?

(5) Should India consider joining a 'coalition' of countries that support geoengineering?

(6) What are the international protocols and agreements that are relevant to geoengineering experiments and implementation?

(7) What should be the role of India in developing the global governance framework on geoengineering (for laboratory research, field experiments, and large-scale deployment)?

(8) Should India develop a national network of geoengineering research programmes?

(9) What mechanisms are needed to increase the capacity of a national programme?

(10) Should India develop international joint research programmes with other countries, taking into account research capacities, funding mechanisms, liability rules and intellectual property rights?

(11) What should be India's stand on geoengineering, nationally and internationally?

Valuable comments and suggestions on the above questions were provided by several participants. In the concluding session, the following recommendations that emerged from the discussion session were presented by Akhilesh Gupta.

(i) DST may encourage various research groups to undertake geoengineering research in the country through a network programme.

(ii) DST may foster research on unintended consequence of geoengineering on physical and biological systems (e.g. acid rain, coral, fisheries) by employing sophisticated earth system models.

(iii) Geoengineering research should be largely funded by GoI. However, international collaboration may be encouraged.

(iv) Circumstances need to be identified and defined for deployment of field experiments, if any, in the long run.

(v) Need for mapping of groups/researchers/institutions doing or willing to take up geoengineering research and policy in India and abroad.

(vi) Need to set up a Global Technology Watch Group on geoengineering.

(vii) Development of a national strategy on geoengineering research.

(viii) Organize a national conclave on climate change with a special session on climate modelling.

(ix) Bring out a detailed report on the theme of the roundtable at the earliest.

(x) MoEF&CC and DST may jointly develop a policy paper on 'Geoengineering and India'.

(xi) IISc may go ahead with the implementation of MRDP supported by DST and study the impact of geoengineering on monsoon circulation and rainfall, extreme events, cyclones, drought, floods, heat waves, etc.

(xii) IISc may organize the next roundtable in Bengaluru after a year to discuss the initial results from the project.

(xiii) Involve a few other relevant ministries such as the Ministry of External Affairs, Ministry of Agriculture, Ministry of Water, etc.

In his valedictory address, V. K. Gaur (CSIR 4th Paradigm Institute) characterized the roundtable discussion on geoengineering as a visionary step to safeguard India's independent initiatives by high reliability knowledge and capability against possible adventurist climate interventions. He remarked that geoengineering has thrown up a challenge to Indian scientists to empower the nation while forging constructive engagements with global partners and stakeholders.

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MEETING REPORT

Latest trends in quasicrystal research*

A publication in *Physical Review Letters* by Shechtman *et al.*[1] in 1984 announcing the discovery of a new and unusual quasiperiodic atomic order in solids led to excitement in the scientific community, especially among mathematicians, physicists, crystallographers and materials scientists. It resulted in a race to describe the structure of quasicrystals, development of higher dimensional crystallography, prediction of its properties and potential applications. It also resulted in a new series of conferences on quasicrystals. The 13th international conference on quasicrystals was held in 2016. It was attended by 134 participants from all over the world. The biggest challenge has been to describe the structure of quasicrystals. While challenges still remain, by now there is a good idea of how the

*A report on the 13th International Conference on Quasicrystals (ICQ13) held at Kathmandu, Nepal, during 18–23 September 2016.