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REPORT FROM EXPERT TEAM ON WEATHER MODIFICATION RESEARCH FOR 2012/2013

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1. Introduction

This report provides an overview of the work of the Team since the International Weather Modification Conference in Bali, Indonesia in 2011 and plans for the future. The current list of members of the Expert Team on Weather Modification (hereafter the Team) is attached as Appendix A.

Since 2010 the Expert Team has been dependent on a WMO Trust Fund to support its activities. A request was sent to the Permanent Representatives of the WMO countries to request them to contribute to the fund. The reaction to this request has been extremely limited. Considering that weather modification activities in most countries are conducted outside the auspices of the Meteorological Services in separate government departments it is not surprising that very little response was received form the Permanent Representatives of members of WMO. This may call for a different approach to obtain funding for the Trust Fund supporting the Team work by directly identifying the entities that are involved in weather modification activities and then approaching them through the PR's.

Many countries are still using the WMO statements on weather modification including the guidelines. The Team is planning its next meeting in Beijing, China in October 2013 coinciding with the Course on Weather Modification that is sponsored by WMO and the Chinese Meteorological Administration (CMA). CMA will also sponsor the committee meeting and cover some of the associated travel costs.

2. Current catalog of countries active in weather modification activities

The following list of countries with weather modification programs was assembled from several sources. The World Meteorological Organization maintained a *Register of National Weather Modification Programs.* The WMO published the proceedings of its 10th Scientific Conference on Weather Modification, with most of the papers report on weather modification in the author's home countries(World Meteorological Organization 2012). Finally, the membership of the Team provided information on activities that they were involved in. The list created in this fashion identifies 42 countries with active weather modification projects.

Nation	**Source**	**Notes**
Algeria	Register of National Weather Modification	Rainfall enhancement
Argentina	Register of National Weather Modification Register	Hail suppression and rainfall enhancement
Australia	Participation in the Team	Precipitation enhancement
Austria	Register of National Weather Modification Activities	Hail suppression
Bosnia and Herzegovina	Register of National Weather Modification Activities	Hail suppression
Bulgaria	Register of National Weather Modification Activities	Hail suppression
Burkina Faso	Register of National Weather Modification Activities	Precipitation enhancement
Canada	Register of National Weather Modification Activities	Hail suppression
Chad	Register of National Weather Modification Activities	Precipitation enhancement
Chile	Register of National Weather Modification Activities	Precipitation enhancement
China	Official statements, participation in WMO Expert Team on Weather Modification	Precipitation enhancement, hail suppression, fog dispersal
Cuba	Presented at 10th WMO Scientific Conference on Weather Modification (Bali, 2011)	Precipitation enhancement
France	Presented at 10th WMO Scientific Conference on Weather Modification (Bali, 2011)	Precipitation enhancement
Germany	Register of National Weather	Hail suppression

	Modification Activities	
Greece	Presented at 10th WMO Scientific Conference on Weather Modification (Bali, 2011)	Hail suppression
India	Participation in the Team	Precipitation enhancement
Indonesia	Presented at 10th WMO Scientific Conference on Weather Modification (Bali, 2011)	Precipitation enhancement
Iran	Presented at 10th WMO Scientific Conference on Weather Modification (Bali, 2011)	Precipitation enhancement
Israel	Participation in the Team	Precipitation enhancement
Japan	Participation in the Team	Precipitation enhancement
Jordan	Register of National Weather Modification Activities	Precipitation enhancement
Korea, Republic of	Register of National Weather Modification Activities	Precipitation enhancement, fog dispersal
Libya	Register of National Weather Modification Activities	Rainfall Enhancement
Macedonia	Register of National Weather Modification Activities	Hail suppression
Malaysia	Presented at 10th WMO Scientific Conference on Weather Modification (Bali, 2011)	Precipitation enhancement
Mali	Register of Weather Modification Activities	Precipitation enhancement
Mexico	Register of National Weather Modification Activities	Rainfall enhancement
Mongolia	Register of National Weather Presented at 10th WMO Scientific Conference on Weather Modification (Bali, 2011)	Precipitation enhancement
Morocco	Presented at 10th WMO Scientific Conference on Weather Modification (Bali, 2011)	Precipitation enhancement
Pakistan	Presented at 10th WMO Scientific Conference on Weather Modification (Bali, 2011)	Precipitation enhancement

Philippines	Register of Weather Modification Activities	Precipitation enhancement
Romania	Register of National Weather Modification Activities	Hail suppression
Russian Federation	Register of National Weather Modification Activities	Precipitation enhancement, hail suppression, fog dispersal, precipitation redistribution, protection from snow avalanches
Saudi Arabia	Presented at 10th WMO Scientific Conference on Weather Modification (Bali, 2011)	Precipitation enhancement
Senegal	Presented at 10th WMO Scientific Conference on Weather Modification (Bali, 2011)	Precipitation enhancement
Serbia	Presented at 10th WMO Scientific Conference on Weather Modification (Bali, 2011)	Hail suppression
South Africa	Presented at 10th WMO Scientific Conference on Weather Modification (Bali, 2011)	Precipitation enhancement
Syria	Register of National Weather Modification Activities	Precipitation enhancement
Spain	Register of National Weather Modification Activities	Hail suppression
Thailand	Participation in the Team	Precipitation enhancement
United Arab Emirates	Register of Weather Modification Activities	Precipitation enhancement
Uzbekistan	Register of National Weather Modification Activities	Precipitation enhancement, hail suppression
Zimbabwe	Register of National Weather Modification Activities	Rainfall enhancement

Since the International Weather Modification Conference in 2011 the WMO and the Team have been approached by two countries to provide advice on weather modification programs namely, Burkina Faso and Qatar. In addition, in December 2011, the Sultanate of Oman organized a workshop in Muscat to investigate the feasibility of a weather modification program in the

Sultanate. In addition, individual members of the Team received requests for advice from the following countries:

1. Equador
2. Chile
3. Mexico
4. Costa Rica
5. Jordan
6. Iraq
7. Brazil
8. Kenya

While the list of countries active in weather modification programs provide an overview of the countries that are active in this field the investments in operational weather modification program vary greatly. A few interesting numbers are as follows:

1. China by far has the largest investment in both operational programs and weather modification research programs. Every province except one has an active weather modification program in China.
2. After China the USA, Thailand and India have the largest investment in operational weather modification programs. There are currently active operational weather modification programs in at least nine states located in the western United States with often times multiple cloud seeding projects in the individual states (California, Nevada, Utah, Idaho, Wyoming, Colorado, North Dakota, Kansas and Texas). While funding for weather modification has increased over the past five years in the USA it is still well below the levels in the 1980's. India is currently one of the largest investors in weather modification research with a major multi-year program conducted by the Indian Institute of Tropical Meteorology in Pune, India. Thailand is also embarking on a major research effort in this area.
3. There are now several operational programs around the world that have conducted cloud seeding annually for more than 50 years without interruption. In the USA and Australia these programs are mostly supported by hydro-electric power companies.
4. Two major research programs in weather modification to enhance snowpack are currently ongoing in the U.S. namely in Wyoming (Including modeling and field work in part funded by the National Science Foundation) and Idaho (modeling funded by Idaho Power). A smaller research project has been started in the State of Texas.

3. Weather modification and geo-engineering

The Team in its last meeting in Bali also discussed upon request the interaction between current weather modification activities and needs and the advance of geo-engineering (GE) activities and needs. The Team decided it is desirable for WMO to state its position on GE. There are many aspects common to both GE and WM but at different spatial scales. It was also stated that if we still do not understand WM at small scales, understanding what the impacts of GE would be at large/global scale, should be seen as a major challenge. It was also decided that a statement on GE should not be a part of WMR statement and GE in its totality should not be considered as part of the mandate of the ET-WMR because there are several aspects that do not relate to clouds in GE that falls outside the scope of expertise of the committee. Recently, the International Commission on Cloud Physics (ICCP) of IAMAS released a draft statement on Radiation Management Climate Engineering (http://www.iccp-iamas.org/pdf/ICCP_RadiationManagement_Statement_Jan14_V4_2013.pdf). This draft statement (Appendix B) highlights some of the challenges related to GE. While GE studies to date have primarily focused on desktop and modeling studies and no field work have been conducted as opposed to weather modification activities to enhance precipitation and mitigate severe weather that have both modeling and field data support. Increasing our understanding of the effects of cloud seeding on local and regional scales will also contribute to the understanding of GE principles (NAS, 2003). Many of the National Academy of Sciences report in 2003 have still not been implemented to date.

4. Recent scientific achievements

In this section we highlight a few recent achievements in the field of weather modification research. In an editorial column in Nature it was stated that "…weather modification is one of those areas in which science can have an immediate and obvious benefit for society" (Nature 2008). During the past ten years with the advent of a new set of remote sensors and more sophisticated airborne instrumentation in addition to more advanced numerical modeling capabilities new opportunities were provided to assess and quantify the results from cloud seeding experiments. Two major cloud seeding research projects have utilized some of these new capabilities recently.

The first was the Wyoming Weather Modification Pilot Project (WWMPP) sponsored by the State of Wyoming (Breed et al., 2013) with participation of the University Wyoming and the National Center for Atmospheric Research (NCAR). This program had a major observational component (Breed et al, 2013; Geerts et al., 2010), a numerical modeling component (Breed et al., 2013; Xue et al., 2013a and 2013b) and a randomized cloud seeding experiment that started in 2006 and will be completed in 2014. Although the statistical results from the randomized experiment is not yet available because the experiment is still ongoing, Geerts et al. (2010) provided for the first time experimental evidence using vertically pointing airborne radar data that ground-based silver iodide seeding can increase reflectivity in the PBL in orographic snow producing storms over complex terrain. Although the results have limitations based on the small sample size and natural variability they showed that the observed enhancement of high reflectivity values (>10 dBz)in the PBL has a 2.2% probability of being chance with a 97.8% certainty that the increased probability of higher snowfall rates during seeding is not by chance. These results provide strong observational support for the results from recent randomized statistical experiments in other parts of the world (Manton et al., 2011 and Manton and Warren, 2011). One of the major impediments in many previous statistical experiments in mountainous regions is the accurate targeting of appropriate supercooled cloud regions especially in ground-based cloud seeding experiments (Breed et al., 2013).

Another major achievement in the field of winter orographic cloud seeding is the use of numerical models such as the NCAR-WRF model to help design, guide and evaluate cloud seeding efforts to enhance snowpack in mountainous terrain. (Breed et al., 2013; Xue et al., 2013a and 2013b). In addition, a silver iodide cloud seeding parameterization has been recently implemented in the WRF model (Xue et al. 2013a and 2013b; Fig. 1). The seeding rates can be varied and two scenarios of seeding are possible (ground based and airborne). These studies provide a new opportunity to better design, guide and evaluate winter orographic cloud seeding experiments.

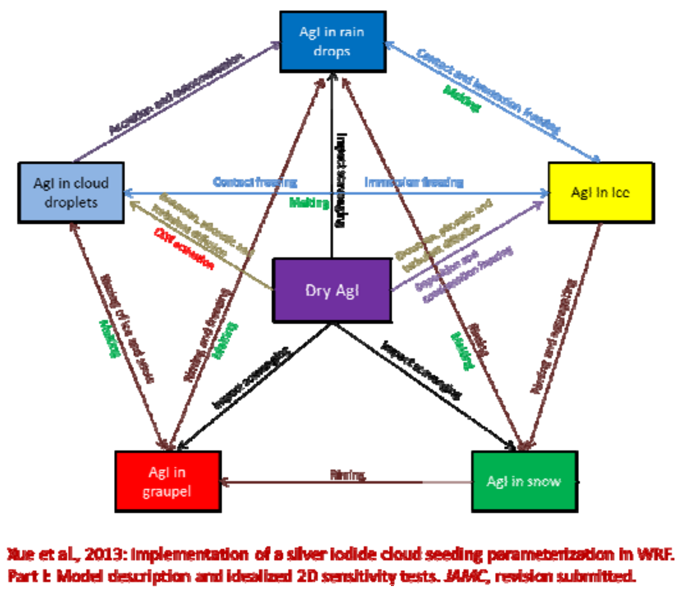

Figure 1: Implementation of a silver iodide cloud seeding module in the WRF Model.

The second major cloud seeding research projects concerning summertime convective clouds were recently conducted in Queensland, Australia (Tessendorf et al., 2012 and Tessendorf et al., 2013) and in in India by the Indian Institute of Tropical Meteorology (IITM) (Kulkarni et al., 2012; Konwar et al., 2012; and Prabha et al., 2011). Both these projects highlighted the importance of natural variability that can mask the results form randomized cloud seeding programs. One of the major challenges still remains the large natural variability that can occur in both time and space even in one region. Both projects have shown that with new remote sensing tools this variability should be taken into account when conducting cloud seeding research programs.

In addition, in the Queensland project the use of dual polarization radar data provided new insights into the evolution of precipitation in clean (maritime) and more polluted (continental) environments. The initial evolutions of the rain drop size distributions were found to be different in maritime and continental clouds (Fig. 2). This has impacts on cloud seeding experiments because differences in rain drop size distributions if affected by seeding may influence the reflectivity especially when radar is used to assess cloud seeding effects.

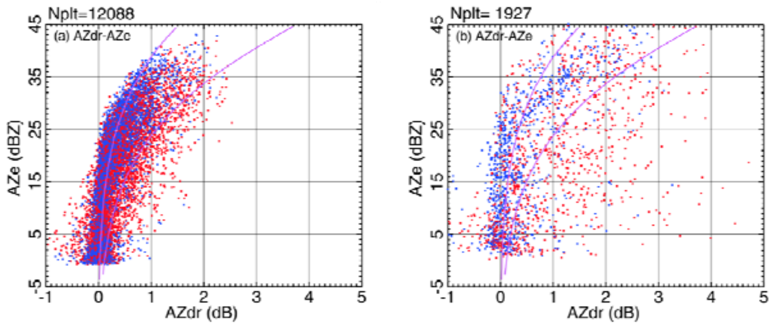

Figure 2: Comparison of a) RICO and b) Queensland plots of AZ_h versus AZ_{dr} . The data are for all radar elevation angles above 0.5 deg. The red points represent growing phase (AZ_h increasing) and the blue points represent AZ_h either constant or decreasing. The RICO data represent 190 clouds and the Queensland data 30 clouds. Each plot shows two reference curves the left represents the standard Marshall-Palmer rain drop size distribution and the right represents one drop per cubic centimeter of the size that produces the corresponding Z_h value.

Finally, many summertime convective cloud seeding experiments now use hygroscopic flares to enhance the condensation-coalescence process. Bruintjes et al. (2012) conducted a study to better characterize the particle spectra from these flares in order to be able to better assess the impacts of this seeding method.

5. *Conclusions and future work*

Based on the previous paragraphs it is clear that weather modification activities are still abounding around the world and several major research programs in this field have been initiated in the past few years which in my view emphasize the legitimacy and need for the Team. Although the contributions to the WMO trust fund for this activity have been very limited this is to some extent to be expected for reasons mentioned earlier. In the meantime the Team has been working with the CMA and their course on weather modification and hope to convene its next meeting to coincide with the course so that members can also give presentations at the course. The meeting will be sponsored by the CMA.

The immediate plans for the work of the Team are as follows:

a. Convene the next meeting of the Team in conjunction with the CMA course on Weather Modification in Beijing, China in October 2013.

b. Adapt the approach to solicit contributions for the work of the Team by including the agencies and private industry in countries that are active in the field of weather modification.
c. Draft a recommendation on how to address geo-engineering aspects

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Appendix A

Expert Team on Weather Modification Research

Family Name	Given Name	Affiliation	Country	Starting Date	Status	email
BRUINTJES	Roelof	NCAR	USA	Oct-11		roelof@ucar.edu
ALUSA	Alex	Gevernment	Kenya	Oct-11		alexalusa@gmail.com
CHEN	Yao	CMA	China	2005		chenyao@cams.cma.gov.cn
LEVIN	Zev	Tel Aviv University	Israel	2003		zevlev@post.tau.ac.il
MANTON	Michael	U o Monash	Australia	2007		michael.manton@sci.monash.edu.au
MURAKAMI	Masataka	JMA	Japan	2005		mamuraka@mri-jma.go.jp
STASENKO	Valery	Hydromet Service	Russia	2007		stasenko@mcc.mecom.ru
KHANTIYANAN	Warawut	BRRAA	Thailand	Oct-11		warawutku@yahoo.com
KULKARNI	Jivanprakash	Indian InstTrop Meteorology	India	Oct-11		jrksup@tropmet.res.in

Appendix B

International Commission on Clouds and Precipitation (ICCP)

Statement on Radiation Management Climate Engineering

Draft, January 2013

Global average temperatures are rising due to human emissions of greenhouse gases (GHGs). This is helping to drive widespread melting of snow and sea ice and will result in significant changes in precipitation patterns that will be detrimental to humanity and to Earth's biodiversity.

Different strategies have been proposed to reduce climate change risks. Emissions reductions are a possible long-term solution, but it has been difficult to make progress in achieving such reductions. Adaptation is a second possible course of action, but is likely to be one that sees large reductions in biodiversity and would not be a suitable strategy in the event of catastrophic climate change such as rapid melting and disintegration of the Greenland or West Antarctic ice sheets. A third possible course of action, and the most radical, involves *climate engineering* (or *geoengineering*). This is the deliberate manipulation of the Earth's physical, chemical or biological processes to counteract deleterious effects of climate change.

This ICCP policy statement focuses upon a subset of climate engineering strategies called *Radiation Management* (RM) that attempt to reduce the amount of solar or infrared radiation reaching the Earth's surface. Proposed RM techniques include: 1) those designed to reflect more sunlight back to space, examples of which include space-based mirrors, introducing sulfate aerosols into the stratosphere and increasing the droplet concentration in marine low clouds; 2) reducing thin cirrus optical depth and cloud cover that prevents longwave radiation escaping to space.

Given the current state of understanding, RM could only be considered as a strategy of last resort should catastrophic climate change become unavoidable in the future. ICCP recognizes that current scientific research on RM techniques is in its infancy and that the current level of scientific knowledge about the feasibility of RM techniques is an inadequate basis for shaping policy decisions. Little is known about the potential risks of deliberate attempts to change the Earth's radiation budget. For example, it is becoming widely accepted that anthropogenic GHGs, ozone and absorbing aerosols may all be playing important roles in changing the latitude of storm tracks and the intertropical convergence zone. Further regional to global-scale adjustments caused by climate engineering would induce regional precipitation changes that would not necessarily cancel those caused by GHGs and therefore may not uniformly benefit all nations, peoples and ecosystems. This has major sociopolitical and ethical implications that have to be considered.

In addition to the potential risks of climate engineering applications, there are also major concerns that the development of RM strategies might be seen as an equivalent to emissions reduction strategies. Radiation management cannot substitute for GHG emissions reduction strategies for the following reasons: 1) the areal patterns of radiative forcing associated with GHGs is fundamentally different from those expected from RM, 2) RM management does not prevent other deleterious impacts of GHGs such as ocean acidification, and 3) the lifetimes of GHGs are much longer than the species of gases and particles that have been proposed as potential geoengineering agents.

The International Commission on Clouds and Precipitation recommends:

- That further research is pursued to better understand the fundamental science and possible efficacy of radiation management climate engineering schemes.
- That climate engineering research be conducted in an open and independent manner that engages public participation, and is used to properly assess the potential risks involved.
- That research activities must include studies of the human impacts, ethics, legal and political impacts of climate engineering

Given the poor state of the current knowledge on clouds, aerosols, precipitation and their interactions, the ICCP does not support the implementation of climate engineering and does not expect that climate engineering can solve the global warming problem. Climate engineering cannot substitute for aggressive emissions reduction. However, ICCP supports conducting research to improve our basic understanding of the processes needed to explore the possibility that climate engineering might contribute to a broad risk management strategy to temporarily reduce some of the dangerous effects of climate change.