REPORT OF THE EXPERT TEAM ON WEATHER MODIFICATION MEETING

Phitsanulok, Thailand, 17-19 March 2015

Prepared by

Roelof Bruintjes, Chair

In cooperation with Deon Terblanche, WMO Secretariat

Michael Manton, Masataka Murakami, Deon Terblanche (WMO) , Warawut Khantiyanan, Roelof Bruintjes (Chair), Yao Chen and Jivanprakash Kulkarni (absent: Zev Levin, Valery Stasenko and Alex Alusa)

Tuesday 17 March 2015

1. Opening and Welcome

Roelof Bruintjes, Chairperson of the Expert Team on Weather Modification (ETWM), open the meeting at 09:00 and officially welcomed the members present. He indicated that Zev Levin, Alex Alusa and Valerie Stansenko unfortunately could not attend but that he will consult with them throughout the meeting as necessary. He also thanked the Thai hosts and in particular Warawut Khantiyanan for the excellent arrangements and support that made the meeting possible.

Warawut, as both the local host and member of the Expert Team, officially welcomed the participants to Thailand. He also indicated that members of the scientific staff of the Department of Royal Rainmaking and Agricultural Aviation (DRRAA) in Thailand, were present as observers.

Deon Terblanche, Director for Atmospheric Research and Environment at WMO, expressed appreciation to the Thai hosts, Roelof and the rest of the Expert Team for their support to this activity of WMO. He also indicated that there is a growing need for WMO to have relevant and current advice in the field of weather modification as the desire to modify the weather is growing as environment pressure on the growing global population grows.

Nareeluck Wannasai, heading the local organizing committee, provided the participants with the local arrangements, transport logistics and schedule.

This was followed by the participants, including the Thai scientists, each giving a short introduction and background of themselves and their fields of expertise.

2. Update from WMO about the work and future of the Expert Team (Deon Terblanche)

Deon provided an overview of the WMO Commission for Atmospheric Sciences and the World Weather Research Programme under which the activities of the ETWM Modification resort.

He indicated that following CAS-15 in 2006, the decision was taken to support the activities of the ETWM from a dedicated trust fund. Unfortunately, contributions by WMO Members to this trust fund have been limited despite several attempts by both the WMO Secretariat and individual ETWM members. The trust fund is now all but exhausted and this is rather unfortunate as the requirement for WMO to maintain the assessment of weather modification remains valid as the number of countries with active programmes are increasing. Furthermore, the expertise within ETWM is relevant to the growing debate on climate engineering.

Deon mentioned the upcoming 17th session of WMO Congress, the main event that paves the way for the organization over the next four years. He indicated that this will be an opportunity for Members to consider the work of the ETWM.

3. Chairperson's report on activities since 2011

3.1 Current status of countries active in Weather modification activities.

During the past few years, the countries active in weather modification activities have grown in number, and individual programmes in several countries have also increased such as in the USA. While the total number of countries active in weather modification programmes in 2011 was 42, this has now increased to 52 countries. In addition, several new programmes were started in individual countries including the USA (new programmes in the States of Texas, Colorado and Wyoming amongst others to enhance winter snowpack). Many countries use the WMO Statement on weather modification and the guidelines to start their individual programmes. The Team members provided individual guidance to several countries for their programmes. More countries are also starting to use this technology as a long-term water resources management tool instead of just during drought periods.

Although the Expert Team meeting in mentioned in 2015 did not materialize because of lack of funds to support the travel of the Team members, several international meetings of importance did take place during the past year that have impact on the Team work. During the past year, Roelof Bruintjes gave lectures at the WMO International Training Course on Weather Modification in Beijing, China, sponsored by the Chinese Meteorological Administration (CMA) in August 2014. In addition, several Team members were invited to a meeting in Abu Dhabi to discuss a new grant programme for rainfall enhancement cloud seeding efforts in arid and semi-arid regions in the world. This programme is further described below. The last major meeting of interest is a meeting organized by the Bureau of Reclamation (BREC) in the USA in late November in Denver, Colorado. Until the early 1980's, the Bureau of Reclamation was the primary sponsor of weather modification research programmes in the USA with funding of more than US15million per year. Recently the Bureau of Reclamation has again started to provide funding to support research activities in the western United States.

Approximately 50 people attended the International Training Course on Weather Modification that was held in Beijing, China, from 18-29 August 2014. While most of the attendants were from provinces in China, about 14 persons representing 10 other countries also attended the course. I have attached the schedule of the course, the attendant's list and a short synopsis of the presentations that were given on behalf of the Expert Team to this document. Although the course was well organized and attended, it may be worthwhile in the future to enhance its international focus and to have some more thought put into the course content. The idea of the course is great but, especially with technologies rapidly developing and many countries not really familiar or inexperienced with the technologies, it is difficult to address and convey all the issues in such a short time. One idea would be to have the presenters provide a paper of their work that could be compiled into a report. The Expert Team in its last meeting also identified the need for comprehensive review report or book in this field. It was also clear in some of the presentations that although some countries have acquired new advanced instrumentation for their research, they often lack the experience on how to use these new tools in their research programmes.

The meeting in Abu Dhabi in the United Arab Emirates, in October 2014, was sponsored by the National Center for Meteorology and Seismology (NCMS). The workshop was organized to discuss a new UAE research programme for Rainfall Enhancement Science in Arid and Semi-Arid regions of the world. The higher authorities in the UAE have provided approximately $3mil per year for this future grant programme. The focus of the meeting was to identify critical research needs in this field that would have to be included in the Request for Proposals (RFP). The meeting was co-organized by ScienceWorks Inc. in the USA that is contracted to help develop the administrative structure of the grant programme for NCMS. The previous Chief Scientist of NASA in the USA was leading the ScienceWorks group and six members of the WMO Expert Team and representatives from WMO, South Africa, University of Belgrade and MASDAR University in Abu Dhabi attended the two-day meeting. The announcement for the request for proposals will go out early in 2015, and the idea at this stage is to award about two grants each year with approximately US$500,000 per year for three years to the successful applicants. The RFP will be widely distributed internationally and is not limited to only research in the United Arab Emirates. This is an exciting new opportunity to enhance the science in weather modification. The agenda for the meeting is attached.

The last meeting that was mentioned is the Bureau of Reclamation meeting in the USA on 25 November 2014 in Denver, Colorado. While the Western Governor's conference in the past few years have included again cloud seeding to enhance snowpack in their alternative sources for water resources document, the Bureau of reclamation has in the past few years again became involved in supporting research in this area. Currently the Bureau is evaluating how to become more involved again in this field of research and the purpose of the meeting in November is to evaluate the current status and how the Bureau should become involved. The agenda and associated documents for the meeting are attached.

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

1. China by far has the largest investment in both operational programmes and weather modification research programmes. Every province, except one, has an active weather modification programme in China.
2. After China, the USA, Thailand and India have the largest investment in operational and research weather modification programmes. There are currently 36 active operational weather modification programmes 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 programme 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 programmes around the world that have conducted cloud seeding annually for more than 50 years without interruption. In the USA and Australia these programmes are mostly supported by hydro-electric power companies.
4. Two major research programmes 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.
5. Over the past 60 years Israel conducted three rain enhancement experiments (Israel I, II and III) and an extended operational programme in the north of the country. These programs have generated extensive discussion in the scientific literature (e.g. Nirel and Rosenfeld, 1995; Levin et al, 2010; Kessler et al, 2006). Based on the extensive experience gained in the past, a new research experiment (Israel IV) of randomized orographic seeding that will start in the winter of 2013-14 will be conducted in the north of the country. Both airplanes and ground generators will be used, attempting to increase rainfall on the hills of the Golan Heights. Based on the recommendations of the WMO statement on weather modification, the experiment is designed and the results will be analyzed by independent prominent statisticians. Thus, a complete separation will be achieved between experimental design, operations, data collection and analysis.

Based on these meetings and the increase in activity in the field of weather modification globally over the past few years, and the prospects for substantial additional funding for research in this field in the future, it remains important to maintain the work of the Expert Team and provides also for a new dimension of the work of the Team.

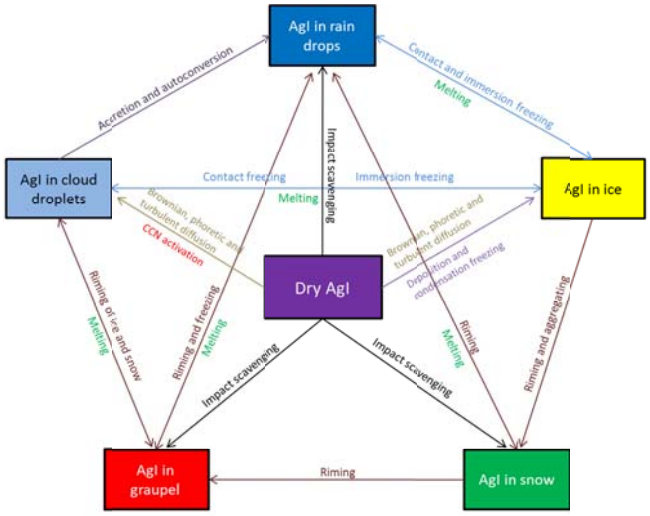
3.2 Recent scientific achievements

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 of Wyoming and the National Center for Atmospheric Research (NCAR). This programme 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 change 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.



Xue et al., 2013: Implementation of a silver iodide cloud seeding parameterization in WRF. Part I: Model description and idealized 2D sensitivity tests. *JAMC*, revision submitted.

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 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 programmes. 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 programmes.

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.

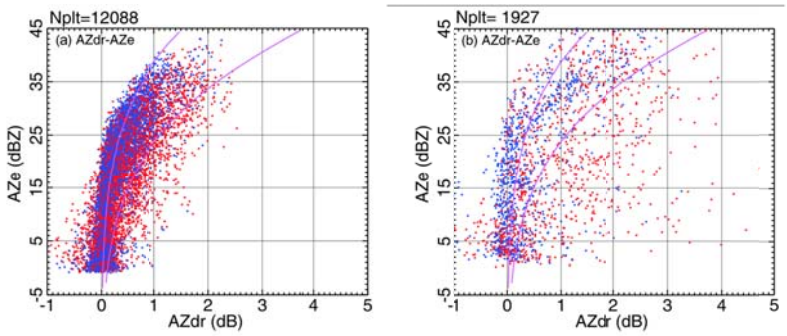


Figure 2: Comparison of a) RICO and b) Queensland plots of AZ_h versus AZ_{dr} . The data are for all radar elevation angles above 0.5 deg. The red points represent growing phase (AZ_h increasing) and the blue points represent AZ_h either constant or decreasing. The RICO data represent 190 clouds and 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.

3.3 Weather modification and geo-engineering

During the past year, WMO established an Ad-Hoc Team to help WMO to develop a statement for WMO on Geo-Engineering. The Team was co-chaired by the Chairperson of the Expert team. The statement closely follows the Statement of the American meteorological Society on this issue. In the past year again, there has been a large body of literature in this field.

3.4 Trust Fund activities

During the past year, several team members, in coordination with the PR's, have approached entities that are active in this field in different countries, with the result that several entities in countries such as China, USA, Russia and South Africa, have come forward with potential contributions to the trust fund. We anticipate that early in the New Year some of the contributions will reach the trust fund. These contributions will come from a variety of different entities including government agencies and the private sectors, all of which have an interest to

further the science in this field and to support the work of the Expert Team. We anticipate that once the initial contributions are received that other countries and entities will start to participate also. 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.

4 Updates from members of significant developments in the field.

4.1 Cloud Seeding Activities in Australia

Operational cloud seeding is carried out in Australia by Hydro Tasmania and by Snowy Hydro Ltd. Hydro Tasmania has been using aircraft to seed all suitable wintertime clouds since the 1970s. Snowy Hydro Ltd commenced operational seeding of wintertime cloud in 2014 using ground-based generators with a seeding ratio of 7:1.

Research in Tasmania has focused on the analysis of aircraft and satellite observations. The Queensland Cloud Seeding Research Program was carried out in 2008-09 and 2009-10 in collaboration with the USA National Center for Atmospheric Research. Experiments in warm-cloud seeding yielded results similar to those found in other hygroscopic seeding projects (Tessendorf et al. 2012). Results of the first phase of the Snowy Precipitation Enhancement Research Project (SPERP-1) have been published (Manton and Warren 2011). The second phase of SPERP was carried out in the winters of 2010-13, yielding similar results. The impact of seeding is best quantified using improved estimates of the natural precipitation in the target areas.

The Australian Research Council has provided an Industry Linkage Grant to support research in southeastern Australia on improved observation, understanding and prediction of orographic precipitation. The programme involves collaboration between Monash University, Bureau of Meteorology, CSIRO, Snowy Hydro Ltd, Hydro Tasmania and the Victorian Government Department of Environment. The southeast of Australia is found to have remarkably high frequencies of supercooled liquid water.

4.2 Significant Weather Modification Developments in China (Yao CHEN)

China weather modification activities have shown significant developments in recent years. The operations and the research continue to grow and the scale of efforts and funding is the largest in the world. Under government leadership, CMA improved weather modification activities remarkably. The CMA oversees all weather modification activities in China and is the only entity, which is designated to conduct these activities.

a. Strengthen the Top-level Design

(1) *Organization*

China National Coordination Committee of Weather Modification (NCCWM), established in 1994, is expanded and now includes all ministries and departments in the central government related to weather modification activities.

Along with the organizational structure, the weather modification center of CMA has been established as the national headquarters with six regional weather modification centers planned, and one of them, Northeast Regional Center, has been in operation since 2014.

(2) *Enhanced Infrastructure*

The Northeast Regional Center as an example for the other five planned centres, consists

of six parts:

- Two MA60 instrumented aircraftaircraft and one King Air 350 instrumented aircraft were acquired. This is the first time that CMA at the national level owns such airborne measurement facilities to assess weather modification activities. Another three instrumented aircraftaircraft are being acquired by individual provinces in China. Another three existing aircraftaircraft will be modified and the plan is to rent three more aircraftaircraft.
- Ground Services for the aircraftaircraft are currently being constructed ;
- Surface operation centres for the operational projects are also developed;
- A new Command and Control system is under development;
- Evaluation Field Experimental Tests are improved for randomization experiments;
- A new laboratory with advanced equipment is being built for testing and validation of seeding material.

(3) *Standardization*.

Several new CMA WM regulations are issued and additional regulations are underway.

(4) *National Planning*.

“Development Planning on National Weather Modification (2014-2020)” was approved by central government in 2014.

“National Guideline on Weather Modification” was approved by CMA in 2014.

b. Enhanced Modification of Equipment

(1) Enhance and expedite the construction of dedicated weather modification aircraft
(2) Promote operation of warm cloud seeding agents countrywide
(3) Put into use new types of rockets
(4) Apply advanced requirements for equipment such as Radars (8mm; 3cm; dual polarization), Profiling Radiometers, GPS/Met, Raindrop spectrometer, The Hydroscopic Flare Test Facility, etc.

c. Improve the Science and Technology Level of Weather Modification

(1) Improve the Evaluation Test Area for Randomized Experiments

- Extend the experimental area from 100x100km to 200x200km
- Increase weather stations (measuring six parameters) to 106 from 15
- Increase to 1350 weather stations (measuring 2 parameters) from 185
- Add 20 Raindrop spectrometers
- Build 1 GPS Sounding system
- Build 1 X band radar
- Build 3 wind profiles
- Build 3 Profiling Radiometers
- Develop the Analyze software system

(2) Additional research

There are several national research projects for:

- Stratus Clouds in North China
- Convective Clouds in South China
- Mixed-phase Clouds in the Two Rivers Area
- Orographic Clouds in the Tian San Mountain Region

d. Strengthen the Training of Personnel

In 2014, we had three national level tainting courses in weather modification.

(1) *International training courses*.

The Weather Modification Center and WMO Beijing Training Center, co-organized withWMO, a training course with students from 10 foreign countries in addition to 40 Chinese participants. Some well know experts from China and other foreign countries acted

as teachers.
(2)*DMT airborne instrument training course*.
About 50 students from the key provinces attend the course with teachers from the U.S.
(3) *Aircraft data analyses, instrument maintenance and management training course*.
About 40 students from key provinces attended the course. The teachers were experiencedChinese scientists.

4.3 Recent Activities of weather Modification in Japan (Masataka Murakami)

There had been nation-wide weather modification activities in Japan from 1950 through 1965 which were supported by Japanese government and/or electric companies. But then the activities declined due to the shift from hydroelectric power plant to thermal electric power plant. There is currently no operational weather modification activity except for temporal cloud seeding experiments performed by local governments (e.g. Tokyo Metropolitan Government) when they have a serious drought. However weather modification research has been carried out for the last twenty years to evaluate the effectiveness of cloud seeding for precipitation augmentation in case of serious drought.

The Meteorological Research Institute (MRI), in cooperation with 10 other research organizations, has carried out a nation-wide, five-year-term research project “Japanese Cloud Seeding Experiments for Precipitation Augmentation (JCSEPA)” from 2006 through 2011 in order to aim drought mitigation and water resources management. Based on the results from JCEPA project, meteorological research note (a kind of monograph) “Frontier of Weather Modification Research” (in Japanese) will be published by Japan Meteorological Society at the end of March this year. The monograph covers wide aspects of precipitation enhancement, including glaciogenic and hygroscopic seeding. (see the appendix below from the contents of the monograph).

The Tokyo Weather Modification Pilot Project is currently being carried out by MRI and Bureau of Waterworks of Tokyo Metropolitan Government, and is the major research activity in Japan at present. Target area is the catchment of Ogouchi Dam, which is located 65 km west of Tokyo. Its catchment is 263 km^2 and its storage capacity is 186 Megatons. Its role is the water supply to west part of Tokyo, which is about 20% of the total water consumed in Tokyo Metropolitan area.
In this project, ground-based multi-wavelength, active & passive remote sensors are used to investigate cloud & precipitation microphysics for evaluation of seedable cloud occurrence frequency and validation of NHM simulation results. MRI-NHM is used for multiple purposes; to study seedable clouds, seeding effects, seeding strategy (glaciogenic or hygroscopic seeding, ground-based or airborne seeding). MRI cloud simulation chamber is used to characterize seeding materials. Aerosol instruments, including CCN and IN counters, are used for the ground-based and airborne measurements to monitor background aerosols, CCN, IN and AgI particles. The in-situ aircraft measurements of aerosols, cloud and precipitation are also included, focusing on dispersion of AgI particles from ground-based generators.

Appendix

Contents of “Frontier of weather Modification Research” (in Japanese)

Part I: Review
1. Status of weather modification research before starting JCSEPA project
Part II: Results of JCSEPA project

2. Implementation system of JCSEPA
3. Climatology of droughts in Japan
4. Feasibility study of cloud seeding using operationally available data
5. Occurrence frequency of seedable clouds using ground-based remote sensing data
6. Laboratory and numerical studies on hygroscopic seeding
7. Physical evaluation of seeding effects
8. Effectiveness evaluation of glaciogenic seeding to secure water resources
9. Effectiveness evaluation of hygroscopic seeding to secure water resources
10. Statistical evaluation of seeding effect using physical predictor
11. Environmental effect of glaciogenic and hygroscopic seeding
12. Cost/Benefit ratio of dry-ice pellet seeding to secure water resources for Tokyo
Part III: Basic studies supporting weather modification research
13. Development of ground-based remote sensing technologies
14. Studies on aerosols acting as CCN and IN
15. Validation of numerical models used for weather modification research]

4.4 India (Jivanprakash Kulkarni)

A major experiment named the Cloud Aerosol Interaction and Precipitation Enhancement Experiment (CAIPEEX) is underway in India [conducted by the Indian Institute of Tropical Meteorology (IITM); seehttp://www.tropmet.res.in/~caipeex/] as an attempt to identify and understand the pathways through which aerosols may influence precipitation and what the effects of cloud seeding on rainfall would be. Observations of convective clouds, aerosol, and cloud condensation nuclei (CCN) at several locations were carried out during this experiment with instrumented aircraft and surface and satellite remote sensors. Several publications have resulted from this experiment (see Chairperson's report).

CAIPEEX has the following two major objectives:

1. To make necessary simultaneous measurements of microphysics of aerosols, CCN, cloud parameters (number concentration, liquid water, particle size, etc.), and large-scale meteorological conditions to document and understand the pathways through which aerosols interact with clouds and influence precipitation over the continental Indian monsoon region.
2. To quantify the efficacy of seeding in precipitation enhancement over a suitable location in India. A related objective is also to test the efficiency of different seeding materials in this process. (Also to formulate guidelines for cloud seeding based on direct observations.)

4.5 Thailand (Warawut Khantiyanan)

One of the research efforts under the BRRAA is known as the Applied Atmospheric Resources Research Program (AARRP). The programme involved the conduct and evaluation of the randomized warm-cloud and cold-cloud seeding experiments in the Bhumipol catchments area in northwestern Thailand. The AARRP Phase 1 focused on theoretical studies and randomized exploratory experiments to determine which of the physically plausible warm and cold cloud seeding concepts warrant further testing, and the design of a follow-on project to demonstrate their feasibility. The goal of AARRP Phase 2 is to quantify the water augmentation potential of promising rainmaking techniques identified under the AARRP (Phase 1) through proof of-concept experiments in a demonstration project.

The BRRAA is now reorganizing for upgrading to be the Royal Rainmaking and Agricultural Aviation Department (RRAAD). This establishment was completed within 2014. The RRAAD has been entrusted with the duty to take care of the national atmospheric water resources management. The main responsibilities are to enhance or reallocate or redistribute rainfall to provide additional water for agriculture, energy, domestic consumption, industry, and conservation and also to involve in the missions to prevent or suppress of damage causing by natural disasters such as hail storms, forest fires, and smoke from biomass burning.

From 2011 to 2014, the BRRAA acquired a new King Air B-350 cloud-physics/seeder aircraft and upgraded another two King Air B-350, and also acquired a new S-band dual polarization Doppler weather radar. The instrumentation on the King Air included, among other things, Fast Forward Scattering Spectrometer (FFSS), Passive Cavity Aerosol Spectrometer (PCAS), High Volume Precipitation Spectrometer (HVPS), CCN counter, 2DS, CPI, AIMMS, Scanning Electrical Mobility System (SEMS), Nevzorov Sensor, Optical Particle Counter (OPC), Rosemount Icing Sensor (RIS) and so on. In addition, the aircraft was equipped with a forward-looking video camera and flare racks for both hygroscopic flares and AgI flares. The new S-band Doppler weather radar has dual polarization and TITAN software.

In accordance with the reorganization of BRRAA and in-service of the new and sophisticated instruments, the BRRAA plans to start a 5-year development programme namely, AARRP Phase 3. The goal of the programme is to increase manageable water resources in Thailand through the implementation of a scientifically-based weather modification project on an experimental basis. The project will lead to improvements in current cloud seeding operations that are conducted to provide limited relief to economic and social impacts of local droughts. The programme emphasis will be placed on evaluation of results to determine the feasibility of long-term weather modification application as a water resources management technique in Thailand. All equipment to carry out the AARRP Phase 3 will include the new cloud-physics aircraft, the dual-polarization Doppler weather radar with TITAN software, and various other cloud seeding aircraftaircraft and instruments.

The programme will promote research on the better understanding of cloud processes and their representation in numerical models. Cloud modelling workshops will be organized in collaboration with the scientific community. The programme will also offer an opportunity for international scientific and technical cooperation and collaboration in atmospheric and hydrological science.

4.6 USA (Roelof Bruintjes)

Operational cloud seeding projects have steadily increased over the past several years. Several new programmes were started in the USA (new programmes in the States of Texas, Colorado and Wyoming to enhance winter snowpack). In addition, research projects have also increased and more funding has become available for this purpose (See Chairperson's report). One of the major research programmes that came to a conclusion over the past year is the Wyoming snowpack enhancement programme. The results were summarized in a recent report and the highlights are presented here.

The Wyoming Weather Modification Pilot Program (WWMPP) was conducted to assess the feasibility of increasing Wyoming water supplies through winter orographic cloud seeding. Following a Level II feasibility study that found considerable potential for cloud seeding in the state (WMI 2005), the Wyoming Water Development Commission (WWDC) funded the WWMPP (2005-2014) as a research project to determine whether seeding in Wyoming is a

viable technology to augment existing water supplies, and if so, by how much, and at what cost. The WWMPP then established orographic cloud seeding research programmes in three Wyoming mountain ranges considered to have significant potential: the Medicine Bow, Sierra Madre, and Wind River Ranges.

The main purposes of the WWMPP are to establish an orographic cloud seeding programme in three target areas (the Medicine Bow Range, Sierra Madre Range and Wind River Range) and evaluate the feasibility and effectiveness of the cloud seeding. The logistics, infrastructure, and operations of the programme are covered under a contract with Weather Modification Inc. (WMI), while the evaluation activities fall under a separate contract with the Research Applications Laboratory (RAL) of the National Center for Atmospheric Research (NCAR).

The results of this programme are summarized in a document that can be accessed at: http://wwdc.state.wy.us/weathermod/WYWeatherModPilotProgramExecSummary.pdf

A major research programme following up on the Wyoming Program is planned for the State of Idaho in collaboration with Idaho Power.

5 Review of the WMO Statement on Weather

The Expert team systematically reviewed the WMO Status on Weather Modification document last updated in April 2010 and identified those sections where changes are required and additional issues that should be included. It was decided to first review the body of the document followed by an update of the executive summary and guidelines. The work was divided and groups were formed to deal with the various sections. It was decided that the groups should work overnight and provide their input to the Chairperson by midday on the second day of the meeting. The final draft would then be reviewed on the third day of the meeting.

Wednesday 18 March 2015

6 Weather Modification research programmes and potential for collaborations.

Roelof presented an overview of the latest UAE weather modification research funding that has been made available as well as the process established to date to manage the proposals and funds. He indicated that a total of $5 million is available for a number of research activities each through a 3-year grant of up to $1.5 million. This initiative focusses on arid and semi-arid regions and the emphasis is on rainfall enhancement. The successful proposals will be awarded after a scientific evaluation process involving international scientists. Roelof also indicated how ETWM members have been involved in the process to date through input in the criteria to be used focusing on fundamental science questions.

The ETWM felt that the opportunity provided by the UAE is an unique chance to advance several research aspects related to weather modification and in particular rainfall stimulation. Some members indicated that that they or their institutions have submitted initial concepts before the deadline in February 2015. Concepts have to be developed further into full proposals before the new deadline before the end of April 2015.

7 Future of the Expert Team and Trust Fund

Deon provided background to the current arrangement which require that the activities of the Expert Team on Weather Modification (primarily the regular meetings to review the status of weather modification, the quadrennial conferences and related workshops and expert missions on request of WMO Members) should be funded through a dedicated trust fund. He also highlighted that apart from the contribution by the UAE about 5 years ago no other contributions has been forthcoming despite regular interactions with WMO Members on this matter. The members of the Expert Team agrees that this arrangement is not working and that a review is probably in order as it would be desirable to carry out the assessment independent from countries or entities directly involved in weather modification. Deon then described the procedure that could be followed using either the WMO Executive Council or Congress to consider alternative arrangements to support the work of the Expert Team – including support from the regular budget. He mentioned that it would be unacceptable if such support will come at the cost of other research activities of WMO.

The members of the Expert Team then discussed possible initiatives that they could undertake in cooperation with their respective PRs.

8 Excursion to DRRAA facilities

Members of the ETWM visited the research facilities and research aircraft of DRRAA at the airport in Phitsanulok. Two of the King Air research aircraftaircraft were presented. These aircraftaircraft are very well equipped with the latest aerosol and cloud microphysical sensors. Examples of the data extraction were also shown and in-depth discussion took place between ETWM members and the Thai scientists and technical staff. Also on display was a CASA aircraft use for seeding.

Roelof remained at the conference venue during this time to incorporate all the proposed changes to the WMO Statement, as received over the past day.

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9 Geo-engineering discussion and role of the Expert Team in these activities.

Deon mentioned that CAS, at its 16th session in November 2013, identified geoengineering as one of the future issues that deserve closer scientific attention. Roelof and Deon described the activities of the ad hoc team on geoengineering (or climate engineering as it is preferably calls within WMO) which provided WMO with advice before EC-66 in 2014, which resulted in CAS receiving the mandate to follow up on this matter. This matter will again be put before Congress in May 2015, with a specific resolution that calls on CAS to work with WCRP, IOC UNESCO, IMO, and others, towards an assessment of climate engineering. Deon also mentioned his involvement with the CAS President in an activity of the International Law Commission related to the protection of the atmosphere. The members of the Expert Team agreed that there are some experiences from weather modification (including the logistics of delivering seeding material, the complexities in proving cause and affect etc.) that could be valuable in the climate engineering discussions. The Expert Team is willing to work within CAS to contribute to the assessment.

10 Finalize the updated WMO statement on Weather modification

Roelof provided a summary of the changes / updates made to the WMO statement on Weather Modification. The Expert Team agreed that considering the process to approve the document (WWRP Scientific Steering Committee (SSC), CAS and WMO Executive Council), it would be realistic for the updated statement to be made available to WWRP SSC before their planned meeting in November, so CAS Management Group can review it early in 2016 to be presented to EC for approval in May/June 2016.

11 Expert Team membership and General Matters raised by the members

The Expert Team briefly discussed, assuming that the funding issues can be resolved, the possibility to replace the WMO Scientific Conference on Weather Modification by workshops on specific topics with possible broader support from WMO Education and Training Office. Capacity development is a major issue in the field of weather modification, especially considering the growing number of activities around the world and the increasing complexity of instruments, data analysis tools and models available. The possibility to link such workshops to existing events were also considered.

Deon mentioned that under current financial arrangements resources are simply not available to further pursue either the conference or provide support to workshops.

12 Closing and End of meeting

Roelof closed the meeting at 12:00 and indicated that there would still be informal consultations during the afternoon related to efforts to strengthen the scientific basis on future weather modification activities. He thanks all the ETWM members for their active participation, contributions and input and wished them a safe travel back home. He also expressed his appreciation to Warawut and his staff for their excellent hospitality during the meeting.

13 References

Bruintjes, R.T. Vidal Salazar, T. A. Semeniuk, P. Buseck, D. W. Breed and Jim Gunkelman, 2012: Design and performance of a hygroscopic flare cloud seeding test facility. *Journal of Weather Modification*, **44**, 69-94.

Breed, D., R. Rasmussen, B. Lawrence, B, Boe, T. Deshler, and C. Weeks, 2013: Evaluating winter orographic cloud seeding: Design of the Wyoming Weather Modification Pilot Project (WWMPP). Accepted for publication in *J. Appl. Meteor. Climatology.*

Geerts, B., Q. Miao, Y. Yang, R. Rasmussen, and D. Breed, 2010: The impact of glaciogenic cloud seeding on snowfall from winter orographic clouds, *J. Atmos. Sci.,* **67,** 3286 – 3302.

Geerts, B., B. Pokharel, K. Friedrich, D. Breed, R. Rasmussen, Y. Yang, Q. Miao, S. Haimov , B. Boe, E. Kalina, and B. Lawrence, 2013: The AgI Seeding Cloud Impact Investigation (ASCII) campaign 2012: overview and preliminary results**.** *J. Wea. Modif.,* **45**, (accepted for publication).

Kessler, A., Cohen, A., Sharon, D., 2006. Analysis of the Cloud Seeding Effectiveness in Northern Israel. Report to the Israeli Water Authority, Environmental & Water Resources Eng. Haifa. 117 pp. (in Hebrew—Abstract in English).

Konwar M., Maheskumar R.S., Kulkarni J.R., Freud E., Goswami B.N., Rosenfeld D., Aerosol control on depth of warm rain in convective clouds, *Journal of Geophysical Research***,** , **117**, July 2012, D13204, DOI:10.1029/2012JD01785, 1-10.

Kulkarni J.R., Maheshkumar R.S., Morwal S.B., Padma kumari B., Konwar M., Deshpande C.G., Joshi R.R., Bhalwankar R.V., Pandithurai G., Safai P.D., Narkhedkar S.G., Dani K.K., Nath A., Nair Sathy, Sapre V.V., Puranik P.V., Kandalgaonkar S.S., Mujumdar V.R., Khaladkar R.M., Vijaykumar R., Prabha T.V., Goswami B.N., The Cloud Aerosol Interaction and Precipitation Enhancement Experiment (CAIPEEX): overview and preliminary results (2012), *Curr. Sci.*, Vol.**102**, 2012, 413-425

Levin Z., Halfon N. and Alpert P., 2010: Reassessment of rain enhancement experiments and operations in Israel including synoptic considerations. Atmospheric Research 97, 513–525.

Manton, M. J., Warren, L., Kenyon, S. L., Peace, A. D., Bilish, S. P., and Kemsley, K., 2011: A confirmatory snowfall enhancement project in the Snowy Mountains of Australia. Part I: Project design and response variables. *Jour. of Appl. Meteor. and Climat*., **50**, 1432-1447.

Manton, M. J., Warren, L., 2011: A confirmatory snowfall enhancement project in the Snowy Mountains of Australia. Part II: Primary and associated analyses. *Jour. of Appl. Meteor. and Climat*., **50**, 1448-1458.

Nature, 2008: Change in the weather. *Nature*, **453**, 957958.

Nirel, R., Rosenfeld, D., 1995. Estimation of the effect of operational seeding on rain amounts in Israel. J. Appl. Meteorol. 34, 2220–2229.

Prabha T.V., Khain A., Maheshkumar R.S., Pandithurai G., Kulkarni J.R., Goswami B.N. (2011),Microphysics of Premonsoon and Monsoon Clouds as Seen from In Situ Measurements during the Cloud Aerosol Interaction and Precipitation Enhancement Experiment (CAIPEEX), *J. Atm. Sc***.**, Vol.**68** , 2011, DOI: 10.1175/2011JAS3707.1, 1882-1901

Tessendorf, S.A. and coauthors, 2012: The Queensland Cloud Seeding Research Program. *Bull. Amer. Meteor. Soc*iety, **93**, 1, 75-90.

Tessendorf, S.A., C.E. Weeks, D. Axisa, and R.T. Bruintjes, 2013: Aerosol characteristics observed in southeast Queensland and implications for cloud microphysics. *J. Geophys. Res*., **118,** 1-14, doi:10.1002/jgrd.50274.

Wilson, J. W., C. A. Knight, S. A. Tessendorf, C. Weeks, 2011: Polarimetric radar analysis of rain drop size variability in maritime and continental clouds, *JCAM,* **50**, 1970-1980.

Xue, L., A. Hashimoto, M. Murakami, R. Rasmussen, S. Tessendorf, D. Breed, S. Parkinson, P. Holbrook, and D. Blestrud, 2013a: Implementation of a silver iodide cloud seeding parameterization in WRF. Part I: Model description and idealized 2D sensitivity tests. *J. Appl. Meteor. Climatol.*, **52**, 1433-1457.

Xue, L., S. Tessendorf, E. Nelson, R. Rasmussen, D. Breed, S. Parkinson, P. Holbrook, and D. Blestrud, 2013b: Implementation of a silver iodide cloud seeding parameterization in WRF. Part II: 3D simulations of actual seeding events and sensitivity tests. *J. Appl. Meteor. Climatol*., **52**, 1458- 1476.

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