MEETING OF THE CAS EXPERT TEAM ON WEATHER MODIFICATION RESEARCH (ET-WMR)
REPORT

7 October 2011

Venue: Sanur Beach Hotel, Bali

Meeting participants::
ET-WMP Members: Roelof Bruntjes (Chair), Gabor Vali, Valery Stasenko, Jean-Pierre Chalon, Masataka Murakami, Yue Chen, Zev Levin
Invited experts: Warawut Khantiyanan (Thailand), Dan Breed (USA), Jivanprakash Kulkarni (India)
WMO Secretariat: Deon Terblanche, Slobodan Nickovic

Not present: Michael Manton

1. Adoption of the Agenda

The ET members adopted the agenda attached ANNEX

2. Weather Modification Research activities: past and for the 2010-2012 period

Report of the ET-WMR Chair;
Report of the WMO Secretariat, including Registry on WM activities (208-2010)

- After the last ET-WMR meeting (Abu Dhabi, United Arab Emirates (UAE), March 2010) ET made a proposal to the UAE National Center for Meteorology and Seismology (NCMS) to establish an International Center for WM Research. Furthermore, it was suggested to the UAE Government to provide 4-year financial support for the Center activities, including support for annual ET meetings and expert workshops as well as the Quadrennial Scientific Conference on WM Research. A Memorandum of Understanding between WMO and NCMS was drafted and assuming that UAE funding would be available to support to the 10th WMR Conference, planning for the conference was initiated. However, during the WMO Congress (May 2011), the Secretariat was informed that the UAE Government will

not be in position to sign the Memorandum, after which the Secretariat provided internal resources to partly cover the costs of the organization of the 10th WM Research Conference in Bali, Indonesia.

- ET recognized that future WMO activities in support of WMR are in the balance, and if these activities should continue, solutions to the funding support need to be found. Options for funding include: i) self-funding of the ET-members to attend ET meetings or video conference meetings; ii) contributions of Member countries to the established WMO WMR Trust Fund. It was stated that the Secretariat has already send several requests to WMO Members in this regard without success. ET recognized that if only a single country provides funding support it might bias the work by the ET-WMR. To avoid such a situation, a detailed workplan for activities and their budget implications has to be agreed to between WMO and a donor prior to entering into such MoU. Ideally, the ET-WMR should be supported by a number of Member countries, in which case the amount per country is relatively small.
- Possible contributions by countries such as China and Japan are complicated because support to WMR is focused on other activities (training workshops, e.g.) or due to budget restrictions, they are reluctant to contribute to the Trust Fund. The USA might contribute but only if several other countries decide to do the same. Another possible source of funding could be those commercial companies involved in WM.
- National met services could see a possible benefit in supporting WM activities since the required infrastructure (radars, rain gauge network, automated stations, and use of satellites) could also be of importance to other national activities such as nowcasting, mesoscale meteorology, and hydrology programs. When country PRs are contacted, it should be recalled that they represent the country, not only their met service. They have the obligation to contact all other role players in their countries that could be interested in supporting the activities of the ET-WMR.
- It should be noted that, with decreasing budgets the support of WMO activities through the trust funding mechanism has been increasing. Good examples are THORPEX and new programs for polar and sub-seasonal/seasonal predictions within ARE, where groups of Members agree to provide support on a non-budgetary basis.

- The Registry on WM activities of the WMO Members was collected for the period 2008-2010. Only 8 countries responded, reports include operational and research projects related to hail suppression or precipitation enhancement.
- Acton items:
    - Secretariat: to consider requesting registration fee to participants for the next Conference
    - ET members: to explore possibilities of contributions to TF from national organizations and commercial enterprises,
    - ET Chair: to summarize results of the survey from the previous point by the end of 2011
    - Secretariat: when submitting next circular letter to PRs requesting evidence on WM activities in their countries, Cc of the letter should be submitted as well to: participants of the Conference, and to ET members who should forward the letter to organizations that might contribute to the evidence.

3. Report on selected national and/or regional WMR activities

3.1 Indian Institute of Tropical Meteorology, Pune (An autonomous institute under Ministry of Earth Sciences, Government of India)

Cloud Aerosol Interaction and Precipitation Enhancement Experiment (CAIPEEX)

Multi year multi organizational experiment to understand rain processes in the Indian clouds

J. R. Kulkarni

Program Manager

Indian agriculture being largely (two thirds of the cropped area) rain fed, any drought like condition leads to major loss of agricultural productivity and seriously affect livelihood of a large population. While major droughts affect the whole country, even during a ‘normal’ monsoon year there are regions within the country that may experience drought like conditions. Therefore, there is considerable demand on increasing rainfall in these regions by whatever possible means. Cloud seeding by hygroscopic aerosols has been considered by many as the panacea for the problem. However, considerable uncertainty exists on the success of such an endeavor at a given location. To unravel the pathways of aerosol-cloud interaction through which this would be achieved, a national experiment

"Cloud Aerosol Interaction and Precipitation Enhancement (CAIPEEX)" is being led by Indian Institute of Tropical Meteorology (IITM) Pune, under the Ministry of Earth Sciences (MOES) Government of India. IITM has a history of more than 40 years of the research in this field.

Objectives

(i) To make necessary simultaneous measurements of aerosols, cloud microphysics and large-scale meteorological conditions to document and understand the pathways through which aerosols interact with clouds and influence precipitation over continental Indian monsoon region.

(ii) To quantify the efficacy of seeding in precipitation enhancement over a suitable location in India.

To achieve these objectives, it has been planned to carry out CAIPEEX in three phases. As India is characterized by existence of diverse climate conditions across the country and the seasonal cycle is very large, the Phase-I of CAIPEEX aimed at collecting simultaneous aerosols and cloud microphysics data from a number of locations across the country.

Phase I

With this background, Phase I was conducted during May – September 2009 from six base locations, namely Pune, Pathankot, Hyderabad, Bareily, Bengaluru and Guwahati. A Piper Cheyenne model PA-31 T instrumented aircraft was utilized in the program. Total 219 hours of flying was done during the period.

Phase II

The objective of Phase-II is to quantify the efficacy of seeding in precipitation enhancement. It is proposed to use two instrumented aircraft, one for seeding and one for cloud microphysics measurements. Based on preliminary results of Phase-I, Hyderabad was considered as the base station for Phase-II experiment. Hyderabad is located in the rain shadow region during south-west monsoon on eastern side of the Western Ghat Mountains and the region around it is vulnerable to local droughts. In order to be able to delineate contribution of seeding from naturally occurring precipitation, sample size need to be sufficiently large. As a result, it was proposed to conduct the Phase-II experiment at least for two monsoon seasons.

First year of Phase-II was conducted in the year 2010. S-band radar from IMD, located at Hyderabad and a C-band radar located at Sholapur, were used to monitor the clouds. Simultaneous with the aircraft flights, balloon flights were conducted for measurement of large scale winds, humidity and temperatures. Total 13 seeding trial flights were conducted during the period. Phase-II Second year program is in operation in the monsoon and post monsoon seasons of 2011. It is planned to conduct 250 hours of flying during the experiment. To supplement aircraft observations, ground observations from variety of instruments are carried out from Integrated Ground Observational Campaign (IGOC) station located at Palamur (Mahabubnagar).

Many national organizations viz India Meteorological Department (IMD), National Center for Medium Range Weather Forecasting(NCMRWF), National Balloon Facility-Tata Institute of Fundamental Research (NBF TIFR), Vikram Sarabhai Space Center (VSSC), National Aerospace Laboratory (NAL), Indian Institute of Science (IISC) and Universities are participating in the experiment.

Phase III consists of detailed analysis of the data for preparation of guidelines for operational cloud seeding program and parameterization of cloud microphysical processes for numerical weather models for improvement of weather and climate forecasts.

3.2 Bureau of Royal Rainmaking and Agricultural Aviation (BRRAA) in Ministry of Agricultural Aviation and Cooperatives (MOAC).

New phase in weather modification research activities

Mr. Warwut Khantiyanan
Director, BRRAA.

Background

Climate is particularly critical to Thailand because surface water is the prevalent source of water used. Hence, rainfall is critical in terms of both timing and distribution. Thailand has a progressive agricultural system and the growing need for water appears most heavily related to the needs of an expanding population and Thai economy. Besides, drought condition occurs more frequently, possibly resulting from unsolved development

problems such as deforestation, changing of land uses, and increasing of atmospheric pollution.

Recognizing the potential in augmenting national water supplies, a concept of rainmaking or rain enhancement by means of cloud seeding was introduced by His Majesty King Bhumibol Adulyadej of Thailand on 14 November 1955. Since the late 1960's scientific and technical organizations in the Kingdom of Thailand have been involved with a series of experiments and operational programs to increase rainfall through weather modification. A national scale program of weather modification began in 1971 and was formalized in 1975 through establishment of the Bureau of Royal Rainmaking and Agricultural Aviation (BRRAA) under the Ministry of Agriculture and Cooperatives (MOAC).

BRRAA has a staff of about 500 persons including scientists, engineers, pilots, technicians, general administrators, and other staff. The BRRAA also has its own sizable facilities and extensive equipment such as 27 cloud seeding aircraft equipped with GPS and flight tracks, 3 cloud-physics instrumented/seeder aircraft, 5 Doppler weather radar for collecting and recording volume scan data at 5-minute intervals of the development of rain within convective clouds, 5 atmospheric sounding systems (Rawinsondes) to collect upper air data to be used as input to now-casting and seeding potential program modules, a network of tipping bucket recording rain gauges to assist with the evaluation of the seeding operation in conjunction with radars, and communication network and database systems to select weather maps, surface weather observations, radar observations, regional weather forecasts, and daily rainfall data obtained from the Thai Meteorological Department (TMD), to be used in daily operation planning, and as input to a subsequent evaluation that makes use of predictor and covariate variables.

At present, rain enhancement is successful and applied widely in Thailand. It provides considerable benefits to the nation's natural resources and economy. It becomes one of several ways to solve the water problems and benefits from its use are maximized as an integral part of a multi-solution approach to the national water resources management.

Weather Modification Activities

Operational Mission

The principal objective of the operational mission is to increase rainfall through the seeding of clouds over the important water basins and agricultural areas of Thailand,

where rainfall is less than optimal for crop production. The cloud seeding program is based on a seeding technique that is unique to Thailand: the seeding of warm clouds and cold clouds in a four-step process with exothermic, endothermic, Silver Iodide, and Dry-ice chemicals delivered in a specified time and space sequence in an attempt to produce a combination of dynamic and microphysical effects. The annual field operation missions normally start from the beginning of summer (March) to the end of rainy season (October).

Research Mission

One of the research efforts under the BRRAA is known as the Applied Atmospheric Resources Research Program (AARRP). The Program 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,

Warm Cloud Seeding Results

A warm-rain enhancement experiment under the AARRP was carried out during 1995–1998. The experiment was conducted in accordance with a randomized, floating single–target design. The seeding targets were semi-isolated, warm convective clouds, contained within a well-defined experimental unit, that, upon qualification, were selected for seeding or not seeding with calcium chloride particles in a random manner. The seeding was done by dispensing the calcium chloride particles at an average rate of 21 kg km^{-1} per seeding pass into the updrafts of growing warm convective clouds (about 1–2 km above cloud base) that have not yet developed or, at most, have just started to develop a precipitation radar echo. During the 4 yr of the experiment, a total of 67 experimental units (34 seeded and 33 nonseeded units) were qualified in accordance with the experimental design. Volume-scan data from a 10-cm Doppler radar at 5-min intervals were used to track each experimental unit, from which various radar-estimated

properties of the experimental units were obtained. The statistical evaluation of the experiment was based on a re-randomization analysis of the single ratio of seeded to unseeded experimental unit lifetime properties. The evaluation of the Thai warm-rain enhancement experiment has provided statistically significant evidence and supporting physical evidence that the seeding of warm convective clouds with calcium chloride particles produced more rain than was produced by their unseeded counterparts. An exploratory analysis of the time evolution of the seeding effects resulted in a significant revision to the seeding conceptual model (Silverman et al. 1999).

Cold Cloud Seeding

A randomized cold-cloud seeding experiment under the AARRP was carried out during portions of April, May and June in 1994-1998. The physical-statistical design was aimed at determining whether seeding with ejectable, free-fall; silver iodide flares near the tops (temperatures -6°C to -10°C) of vigorous suppercooled convective clouds growing within a floating-target area would enhance the rainfall over that area. The evaluation of the Thai cold-cloud enhancement experiment did not reach statistical significance in the time allotted to it. Thus, this experiment did not prove the efficacy of glaciogenic cloud seeding in this context. (Woodley et at. 2002).

New Phase of the Development Program (AARRP Phase 3)

The BRRAA is now reorganizing for upgrading to be the Royal Rainmaking and Agricultural Aviation Department (RRAAD). This establishment will be completed within 2011. The AARRD 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.

In 2011, the BRRAA acquired a new King Air B-350 cloud-physics/seeder aircraft and new S-band 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 in the year 2012 a 5-year development program namely, AARRP Phase 3. The goal of the program 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 program 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 aircraft and instruments.

The Program 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 Program will also offer an opportunity for international scientific and technical cooperation and collaboration in atmospheric and hydrological science.

3.3 Wyoming Weather Modification Pilot Program (WWMPP) is funded by the State of Wyoming in the USA

Mr. Dan Breed (NCAR)

The Wyoming Weather Modification Pilot Program (WWMPP) is funded by the State of Wyoming in the USA, and is unique among state-sponsored programs in that it includes a substantial evaluation component.

The cost of the program is about $1M USD a year, and the program is scheduled to end after one more season of operations. The main purposes of the WWMPP are to establish an winter orographic cloud seeding program in three mountain ranges (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 program 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 evaluation of the WWMPP pursues two main approaches: a) a randomized experiment (a "cross-over" design) that builds distributions of seeded and control (unseeded) cases, and b) exploratory studies and observations to investigate the different responses or steps in cloud seeding to show that the seeding hypothesis is physically-based. Collaborations with other researchers, particularly those at the University of Wyoming, have led to “piggy-back” studies applicable to the assessment of seeding impacts on precipitation formation and eventually on streamflows.

The design of the randomized seeding experiment included estimates of the number of samples needed to realize a quantifiable (significant) result, based on several assumptions regarding precipitation characteristics and a range of possible seeding effects. As the experiment has progressed, a more accurate measure of the precipitation characteristics that are needed for estimating sample size has evolved. Given the updated parameters using gauge data from the experiment, sample size estimates were re-calculated, indicating that roughly 165 cases are needed to reach statistical significance (i.e., confidence in the results) if a seeding effect as small as 10% is to be detected. Currently, about 30-35 cases per year are realized and ~90 cases have been sampled to date. At least two additional seasons of operations will be needed to achieve the required number of cases, which will require additional funding beyond that already approved.

The Weather Research and Forecasting (WRF) model and the Real Time Four Dimensional Data Assimilation (RT-FDDA) system is used in operations to guide forecasters on expected conditions specific to seeding criteria, particularly when super-cooled liquid water might be expected and for estimating plume trajectories from individual seeding generators into the target regions. Comparisons with radiometer data, precipitation amounts, aircraft measurements, and other observations have shown remarkable fidelity of the model, which will enhance its application as an evaluation tool.

In summary, the Wyoming program is one of the few if not only weather modification programs in the US to incorporate a research effort. The randomized seeding experiment, while not novel, is based on sound statistical techniques and requires a manageable number of samples for reaching statistical significance. The numerical modeling work, initially limited to a forecast tool, has shown great potential for further utilization in the evaluation of the program. Physical studies, largely through collaborations and auxiliary measurement efforts, have provided some focused results into the physics of the precipitation systems affecting the Wyoming mountains, and have led to a major NSF-funded program to expand the measurements into a more comprehensive study of seeding effects on winter orographic storms.

4. Links to the IAMAS International Commission on Clouds and Precipitation (ICCP) Activities (Report of the Commission President Z. Levin)

- In 2009, the monograph "Aerosol Pollution Impacts on Precipitation" edited by Levin and Cotton was published by Springer, sponsored also by WMO.
- In 2008, ICCP had their last meeting, simultaneously with the Workshop on cloud modelling with several hundred participants. The intention of the workshop was to bring together modelling and observational scientists
- The next ICCP conference will be in Leipzig Germany from July 28 to August 3, 2012 (not 2013). The modeling workshop will be held the week before in Warsaw, Poland.. Both these events will be co-sponsored by WMO. The WMO support should be channeled mainly to young participating scientists originating from developing countries. Information about the workshop is disseminated to the WMO nowcasting and mesoscale meteorology research community. The ICCP and workshop web pages will be linked at the WMO ARE web site.

5. Review of the WMO Statement on WM and WMO Guidelines on WM

There are no new developments since the Abu Dhabi meeting that warrants updates the Statement and Guidelines discussed in Abu Dhabi. It was also decided not to draft a separate statement on Geo-Engineering but to update the statement with any future

research done on cloud physics as a part of Geo-Engineering. Until this is done the committee feels that the current statement also addresses those issues related to cloud modification in Geo-Engineering.

6. Geoengineering (GE): Lessons learned from WM

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.

In conclusion:

- 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
- For those GE suggestions that relate to cloud processes, a reference could be made to the Statement on WMR that refer to such processes
- Deon Terblanche, Jean-Pierre Chalon and Roelof Bruntjes will write a paragraph expressing the position of ET-WMR on GE

7. Review of 10th WMO Scientific Conference and Forum on Weather Modification

In the discussion, more scientific papers and involvement of more young scientists would be useful in the next conference. Having more invited talks could attract more scientific contributions. Between the two conferences, organization of workshops and training courses of WMO managers would help. One of the proposal was that special sessions during the Conference could be useful (e.g. on how to design the WM program). For many participants coming from China and Russia, there is a language problem. Furthermore, it could be useful to invite experts from other science disciplines (economy, social science, etc.)

8. Re-structuring and membership of CAS Expert Team on Weather Modification Research (ET-WMR)

In order to follow a rotating membership schedule, ET agreed that two members with longer membership will not be re-appointed (Jean-Pierre Chalon and Gabor Vali), and two new members will be appointed (Jivanprakash Kulkarni and Warwut Khantiyanan) following decision to establish a rule limiting the nominations in ET to 2 mandates. It was also decided to approach Dr Alex Alusa from Kenya to ask him if he would be willing to be a member of the committee. Weather Modification research is currently high on the agenda of the Kenyan government and Dr. Alusa is directly involved in these activities. With the proposed changes, better geographical representation is provided, and also representation of new WMR long-term projects. .

9. Closing

The ET meeting was closed at 16:30, 7 October 2011

ANNEX

MEETING OF THE CAS EXPERT TEAM ON WEATHER MODIFICATION RESEARCH (ET-WMR)

7 October 2011

Venue: Sanur Beach Hotel, Bali

DRAFT AGENDA

10. Official welcome; introduction of participants

Attached material:
ET Members (ET-WMR.1.doc)

11. Adoption of the Agenda
Attached material:
Agenda (ET-WMR.2.doc)

12.

13. Weather Modification Research activities: past and for the 2010-2012 period

a. Report of the ET-WMR Chair (Related Activities since 2010 meeting)

The ET-WMR Chair will give an overview of activities and issues of relevance for WMR since the last ET meeting 2010.

b. Report of the WMO Secretariat (including trust fund, WM registry)

The Secretariat will briefly inform the ET-WMR on activities in the period 2010-2012.

Attached materials:
- TERMS OF REFERENCE FOR WMO WM RESEARCH TRUST FUND (ET-WMR.3b.1.doc)

c. Report on selected national and/or regional WMR activities

The overview talks: India (Kulkarni), Thailand (Wathana), USA winter (Breed), others; ~ 10 min each, invited by the ET Chair to present recent research in WM

14. Links to the IAMAS International Commission on Clouds and Precipitation Activities

Report of the Commission President Z. Levin

15. Review of the WMO Statement on WM and WMO Guidelines on WM

Discussion on updating WMR basic documents

Attached materials:
- WMO DOCUMENTS ON WEATHER MODIFICATION (ET-WMR.5.1.doc)

16. Geo-engineering: Lessons learned from WM

Discussion chaired by Roelof Bruintjes on preparation of a paper “Lessons Learned In Weather Modification Relevant to the Climate Change Geo-Engineering Debate”

17. Review of 10th WMO Scientific Conference and Forum on Weather Modification

Attached materials:
- Conference Program (ET-WMR.7.1.pdf)

18. Re-structuring and membership of CAS Expert Team on Weather Modification Research (ET-WMR)

19. Future activities in WM research and funding issues

20. Any other business

21. Closing