WMO Expert Team on weather modification activities

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Available at
http://www.wmo.int/pages/prog/arep/wwrp/new/wwrp_new_en.html

Peer Review Report on Global Precipitation Enhancement Activities

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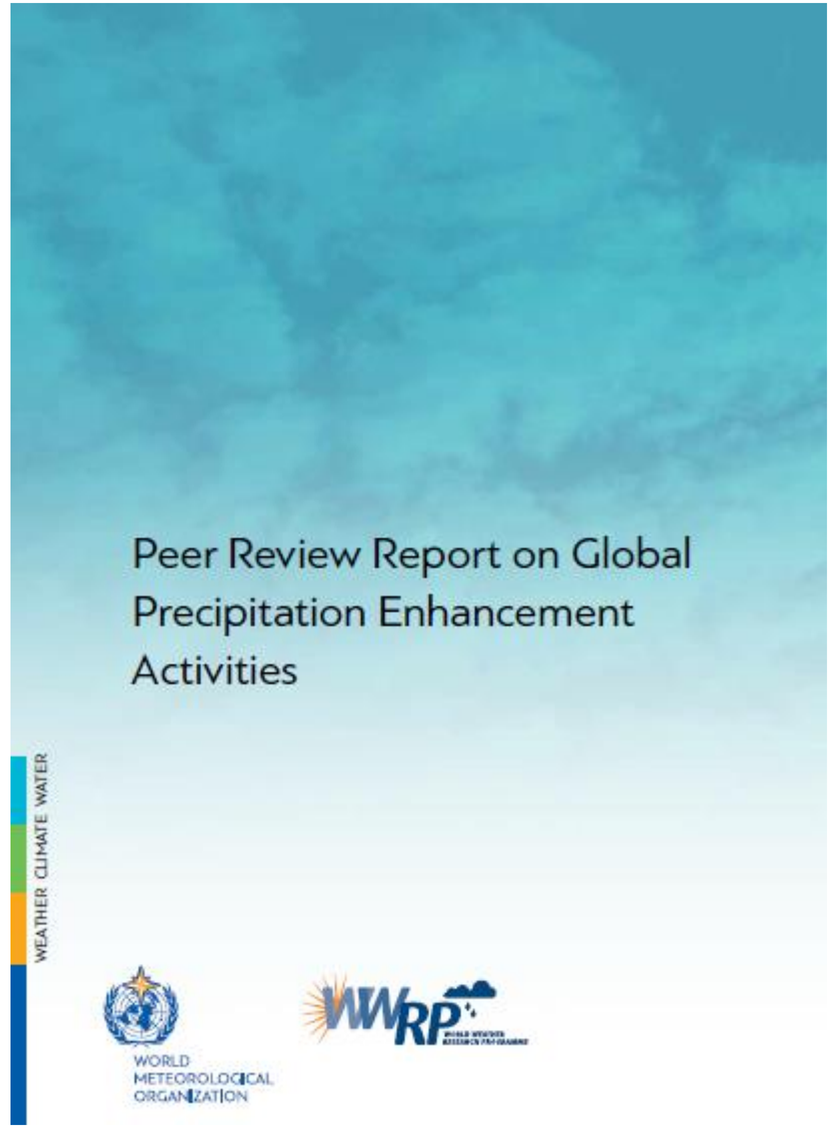
Reviewers: Zev Levin, Steven Siems and 2 anonymous reviewers

WORLD METEOROLOGICAL ORGANIZATION



http://www.wmo.int/pages/prog/arep/wwrp/new/documents/FINAL_WWRP_2018_1.pdf

Salient features of the report

- Exclusively on the scientific basis for precipitation enhancement
- Focus on two cloud types most seeded in the past

a) winter orographic cloud systems

b) convective cloud systems

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CONTENTS

Motivation

- No peer review report since WMO workshop report (WMO, 2000) and a USA National Research Council report (2003)
- More WMO Members are involved in precipitation enhancement activities
- High Power Computers and advanced instrumentation increased knowledge of cloud processes and their possible interactions

Topics

- Natural cloud systems and their variability
- Potential for precipitation enhancement
  - -Hygroscopic and Glaciogenic seeding
- Observations of aerosol, clouds and precipitation
- Modelling of natural clouds and seeded clouds
- Catchment scale research projects

Natural Cloud Systems and Variability

- Focus on dynamical features and the natural microphysical processes from aerosol particles to surface precipitation
- Major gaps
  - The formation and growth of solid hydrometeors.
  - Secondary ice multiplication processes
- Interactions between these processes as well as with the dynamics on all scales needs to be improved
- Orographic clouds have a well constraint dynamics and convective clouds have more variability

Observations of Aerosols Clouds and Precipitation

- Success of a precipitation enhancement project is evaluated by the observation of increased precipitation on the ground, above the naturally expected level.
- Detection of increased precipitation is a major challenge
- Especially difficult for convective cloud systems, where both spatial and temporal variability are high
- Progress in remote sensing and *in situ* observations with aircraft probes

Seeding material typically used

Seed material	Type of seeding	Details
hygroscopic flares	hygroscopic seeding ; aircraft, rocket	Sodium chloride, potassium chloride, or calcium chloride particles ; size range 0.1-10 µm diameter
micro-powders	hygroscopic seeding, aircraft	Optimum suggested size of NaCl crystals is 7.5-10 mm
AgI, $AgIO_3$	Glaciogenic seeding, aircraft, ground burners ; pyrotechnic flares with 10 to 100 g of seeding agent per minute	mean size of 0.1mm; can also act as CCN in liquid clouds
Liquid CO_2	Glaciogenic seeding, aircraft	
Dry ice (solid CO_2)	Glaciogenic seeding, aircraft, rocket	pelletized (diameters of 0.6 to 1 cm and 0.6 to 2.5 cm) or small particles

Other approaches to cloud modification

- **Ionization and electrification** are not scientifically sound pathway for precipitation enhancement.
- **Laser technologies** might succeed in forming cloud droplets in subsatured regions, but these droplets could not grow to precipitation due to the overall lack of humidity.
- There is no convincing scientific basis for the **use of cannons.**

Glaciogenic seeding experiments

Snowy Precipitation Enhancement Research Project (SPERP-1 and SPERP-2)	Manton et al., 2011; Manton and Warren, 2011; Manton et al., 2017
Tasmanian experiments	Ryan and King, 1997; Morrison et al., 2009
Wyoming Weather Modification Pilot Project (WWMPP)	Breed et al. (2014)
SNOWIE: Seeded and Natural Orographic Wintertime clouds	Geerts et al. 2013, 2017; Pokharel and Geerts, 2016, 2017, French et al., 2017
Japanese Cloud Seeding Experiments for Precipitation Augmentation (JCSEPA)" from 2006 -2011 drought mitigation and water resources management	Hashimoto et al. 2008, Yoshida et al. 2009, Murakami et al. 2011, Ohtake et al. 2014, Hashimoto and Murakami 2016
The Tokyo Weather Modification Pilot Project by MRI and Bureau of Waterworks of Tokyo Metropolitan Government October 2011 to March	Araki et al. 2015, Tajiri et al. 2015
Randomized Experiments from Israel (Israel-1: 1961–67, Israel-2: 1969–75 and Israel-3: 1975–95; Israel 4)	Levin et al., 2010; Freud et al., 2015
Liupan Mountains in China (2018-2021) Chinese Academy of Meteorological Sciences and Ningxia Meteorological Bureau.	
Orographic cloud-seeding experiment at Taihang Mountains in China(2017-2019)	
2016 cloud seeding experiments Pyeongchang region of South Korea	Chae et al., (2018)

Hygroscopic seeding experiments

Japanese Cloud Seeding Experiments for Precipitation Augmentation (JCSEPA)”	Kuba and Murakami 2010, Yamashita et al. 2011, Kuba and Murakami 2012, Koshida and Murakami 2012, Murakami et al. 2011, Sakai et al. 2013, Yamashita et al. 2015
Indian experiments	Murty et al., 2000
The Queensland Cloud Seeding Research Programme 2008-09 and 2009-10	Tessendorf et al. 2012
United Arab Emirates Project for Rainfall Enhancement.	Semeniuk et al., 2013; NCAR Report 2005; UAE Report, 2007
Moldova and Ukraine (1970-1991)	Dinevich L. and Leskov B., 2008
Experiments on precipitation enhancement in Syria, Iran and Portugal	Dinevich L. and Leskov B., 2008
CAIPEEX (2009-continuing)	Prabha et al., 2011, Kulkarni et al., 2012
Chinese Randomized Precipitation Enhancement Experiment (CRPEEX) (2014-continuing	
Chinese Weather Modification Project (2006-2010),	Guo et al., 2013 Guo et al., 2015
Chinese Weather Modification Project (2001-2005),	Yao, 2006 Guo et al., 2015
Randomized Rain Enhancement Experiment in Gutian Area Fujian Province in China(1974-1986)	Yao, 2006
Stratiform Precipitation Enhancement Project in North China (1982-1990)	Yao, 2006

Catchment scale experiments

- to provide **evidence that the chain of physical processes can lead to enhanced precipitation** over catchment-scale areas and time scales of seasons
- carry out a range of **preliminary studies that demonstrate the suitability** of the meteorological environment of the proposed site for sustained precipitation enhancement.
- the conditions for effective cloud seeding are quite demanding, and so **suitable sites are limited geographically** and by season.

Preliminary study needed

- the use of **historical data** to document the **variability of precipitation**
- to **estimate the time required to detect a statistically significant enhancement of the natural precipitation** across the target area on a seasonal time scale
- natural variability of cloud processes, including precipitation on the ground, is very large, **careful design and management are needed to optimize the probability of detecting and confirming the physical basis** of enhanced precipitation from cloud seeding
- Numerical modelling study of clouds

Need for randomized experiments

- Small “signal” of enhanced precipitation against the large “noise” of natural variability on large time and space scales
- Properties of specified seeded events to be compared with those of similar but unseeded events.
- A detailed protocol is to be prepared for the selection of events as seedable and for the seeding of randomized events.
- Protocols to be followed precisely and consistently throughout the experiment
- The accurate and consistent measurement of key variables such as the precipitation across the region of interest.
- Involve well calibrated radars throughout the experiment

Recommendations

- The comparisons are required **not only on the amount of precipitation in seeded and unseeded events**, but also on a range of **properties that identify the sequence of physical processes that lead to any enhanced precipitation**.
- The capabilities of observing systems at all scales from microphysical to synoptic are now very substantial, so that it is feasible to **employ ground-based, aircraft-based and satellite-based instruments to systematically observe these physical (and chemical) properties**.
- One aspect of the protocols is the **accurate and consistent measurement of key variables such as the precipitation across the region of interest**. Particularly for convective cloud, these measurements will involve radars, which must be routinely and consistently calibrated throughout the experiment.
- Supporting modelling studies for the seeded clouds

Evaluation of experiments

“The evaluation of a cloud seeding experiment needs to be based on **a scientific understanding of the chain of dynamical and microphysical processes leading to enhanced precipitation on the ground**. While the **chain of processes for wintertime orographic cloud is now reasonably well understood**, there remain **substantial uncertainties in the processes associated with the enhancement of precipitation in mixed-phase convective cloud**. “

Environmental effects

- Seeding agents such as **silver iodide are toxic**
- **External chemicals used in cloud seeding are generally too low** to cause the levels of these chemicals in the environment to approach ‘trigger’ levels for health concerns.
- It is important for any large-scale experiment to include **careful monitoring and assessment of environmental risks**.
- The **redistribution of precipitation at the ground** in both space and time. While some cloud seeding activities are specifically aimed at redistributing precipitation (in particular, at reducing precipitation in some urban areas),
- **Extra area effect**: There is little evidence that precipitation enhancement activities at a specific site lead to discernible changes in precipitation at downwind sites at the time of seeding or at later times.

Modelling requirements

- Model intercomparison projects
- Modern approaches like the “piggybacking” method
- To take ambient background aerosol population for the simulation of drop and ice particle nucleation. (competition between the two populations needs to be simulated)
- Seeding/natural aerosol particles acting as CCN and INP as prognostic variables
- parameterize ice nucleation capabilities of various atmospheric aerosol particles
- ice multiplication processes.
- Model skill in synoptic scale could not be translated to cloud scale dynamics, microphysics and thermodynamics and to precipitation production.

Glaciogeneic seeding

- Documented seeding effect in observations with radars
- Recent experimental results promising with AgI
- To consider AgI also as a CCN
- CCN and INP capabilities of particles from the combustion agent
- Spatial resolution of models are too coarse

Hygroscopic seeding

- type of clouds
- type of seeding materials
- Execution of seeding (aircraft, ground based, etc.)
- Results are not consistent
- There is little research on hygroscopic seeding using three-dimensional models
- Seeding schemes used in models need to be improved.

Catchment-scale experiments

- Requires a strict protocol
- Demonstrating an economic benefit of cloud seeding is difficult
- Large variability of natural precipitation
- Scaling up of seeding in mixed phase clouds is a challenge
- Need to investigate environmental risks through careful planning/monitoring
- Historical data analysis to determine duration

Convective clouds: outstanding challenges

- scaling-up of the effects of seeding mixed-phase convective clouds
- the uncertainties in the physical basis of the methodology
- the extreme variability of convective clouds in space and time
- Orographic clouds have encouraging results in experimental campaigns (enhancements < 20% seems feasible)

Outlook

The resolution of the substantial uncertainties that currently limit the scientific framework for cloud seeding, especially for mixed-phase convective clouds

Thank you

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