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Mission and Current Status of Weather Modification Research in Korea

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1. Introduction

- History of Weather Modification
- Comparison of Technological Level among Nations
- Structure of Weather Modification Research
- Experimental Region

History of Weather Modification

- 1946: First airborne cloud seeding experiments(USA GE Co., Vincent Schaefer)
- 1950: Establishment of USA Weather Modification Association (WMA)
- 1958: CMA artificial rainfall enhancement(Jilin, China)
- 1961: Establishment of commercial company (United States WMI Co.)
- 1963: KMA Artificial airborne rainfall enhancement (KMA)
- 1995~98: KMA ground-based cloud seeding experiment (Inje, 10 times)
- 2001~02: KMA artificial airborne snowfall enhancement (Air force plane, 3 times)
- 2006: Establishment of Cloud Physics Observation system (CPOS) in Daegwallyeong
- 2008: Verification of artificial snowfall enhancement effects by Airborne-Radar
- 2008~2016: Airborne cloud seeding experiments (Yongpyeong etc., 32 times)
- 2017: Introduction of first aircraft for atmospheric research and weather modification

The KMA first artificial rainfall enhancement exp.(1963)

Ground-based AgI seeding exp.(Inje, 1995)

Aircraft for Atmospheric Research and weather modification (2017. 11)

Comparison of Technological Level among Nations

section	Russia(CAO) (2015)	China(CAMS) (2013)	Japan(MRI) (2015)	Israel(NWC) (2016)	Korea(NIMS) (2017)
Operation	-	O	X	O	Case study
Hail Suppression / Fog Dispersion	Practical use	Practical use	-	-	Basic Research
Budget/year	-	80 M USD	6 M USD	2 M USD	1 M USD
Human Resources	-	37,000	50	30	10
Research Period (years)	60	60	30	60	10
Equipment	Aircraft 13	Aircraft 46	Aircraft 1	Aircraft 3	Aircraft 1
	-	Rocket 5,223 Artillery 7,016	-	Ground-based generator 10	Ground-based generator 1
	Cloud chamber	Cloud chamber	Cloud chamber	-	-

* National Technology Level Evaluation: 73.4% compared to advanced country(KISTEP, 2016)

Structure of Weather Modification Research

Experiments

- **Precipitation enhancement**
  (annually Dec.~Jun.)
  - Airborne/Ground-based Exp.
  - Verification by obs. network

Observation

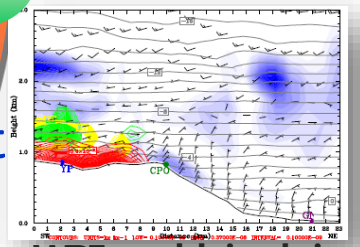
- **Cloud Physics Observatory**
  - Aerosol, Cloud, Precipitation
  - Microphysical measurement

<CPOS>

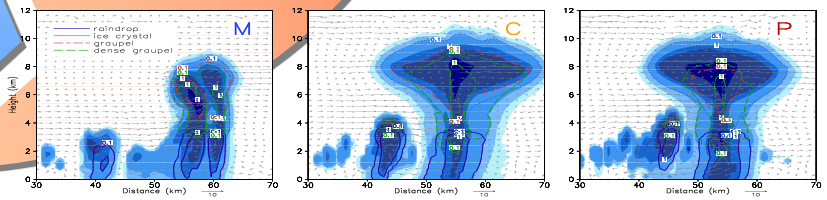

<Observatory site of experiment verification>

Modeling

- **Numerical Model for technology development**
  - Numerical verification
  - Simulation before seeding

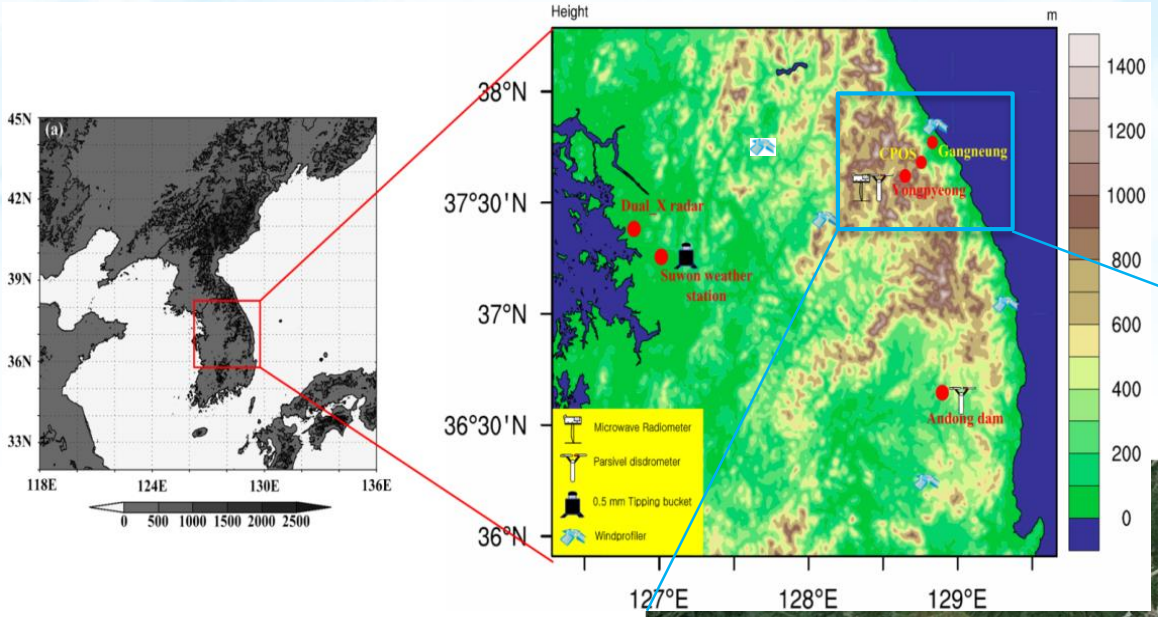


<WRF model simulation of ground-based experiment>



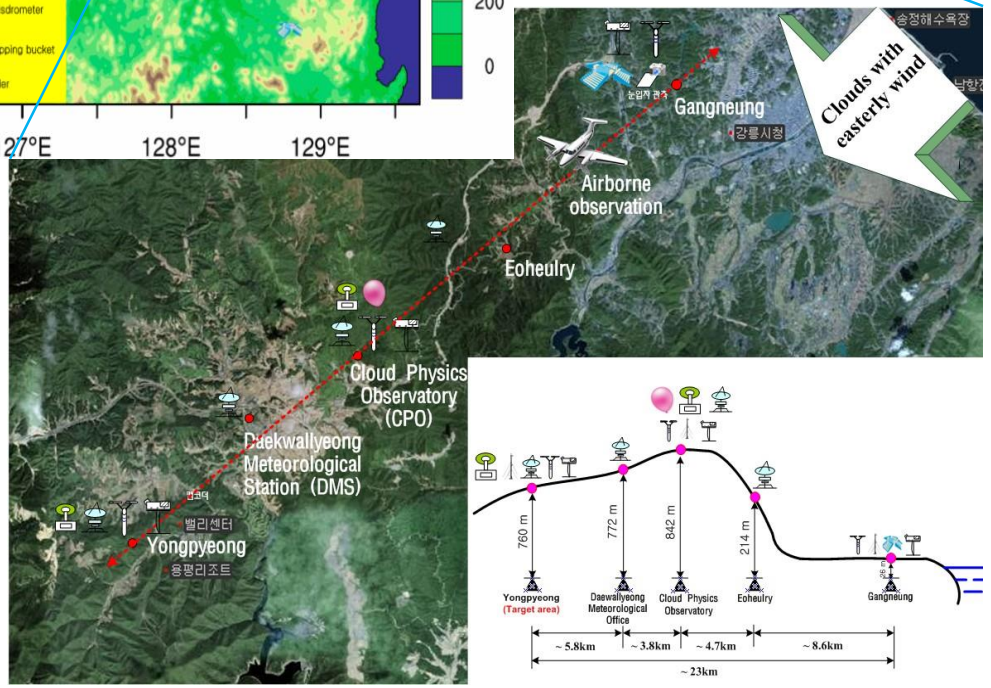
<Cloud-Precipitation simulation by aerosol type>

Experimental Region



〈Reason for selecting this region〉

1) Many orographic cloud cases (~140 foggy days/yr)
2) Upstream of the Han-River



Gangwon province

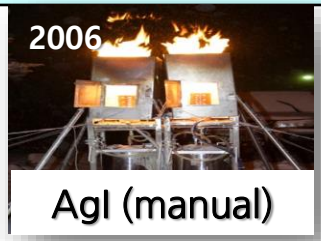
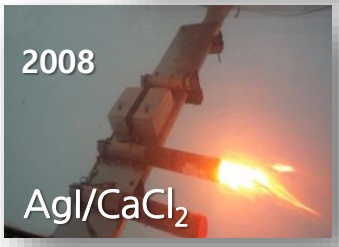
- Gangneung: Initial obs. point
- CPOS: main seeding place
- YP: main target
- DMS: verification point

2. Method and Previous EXP.

- Improvement of Experimental Method
- Previous Exp. of Snow Enhancement
- Experimental Optimum Condition

Improvement of Experimental Method

Contents		Before (~2014)	After (2015~)
Airborne experiment	Decision of seeding path	Based on observation	Based on model prediction
	Airborne instrument	-	OPC (Optical Particle Counter)
Ground-based experiment	Seeding Amount / Time	Not fixed	Optimum (38 g h^{-1})
	Target area	Seeding place only	Diffusion places(2 points)
	Burning method	Manual	Automatic

Criteria	Airborne experiment	Ground-based exp.(snowfall)	Ground-based exp. (rainfall)
Before			
After	 		

Previous Exp. of Snow Enhancement

❑ Airborne seeding

- Ave. snowfall enhancement: 0.7cm (250km^2)
- Validation rate : 43%
- Period/No.: 2008-2015/23 times

<Aircraft (Cessna 206)>


<AgI seeding>


<$CaCl_2$ seeding>

❑ Ground-based seeding

- Ave. snowfall enhancement: 0.6cm
- Validation rate : 30%
- Period/Number: 2006~2015/126 times


<AgI seeing>


<$CaCl_2$ seeding>


<AgI generator>

- Validation method: When the precipitation enhancement appears in the target region during 15min. - 3 hrs after the seeding without incoming nature precipitation

Experimental Optimum Condition

- Optimum seeding criteria

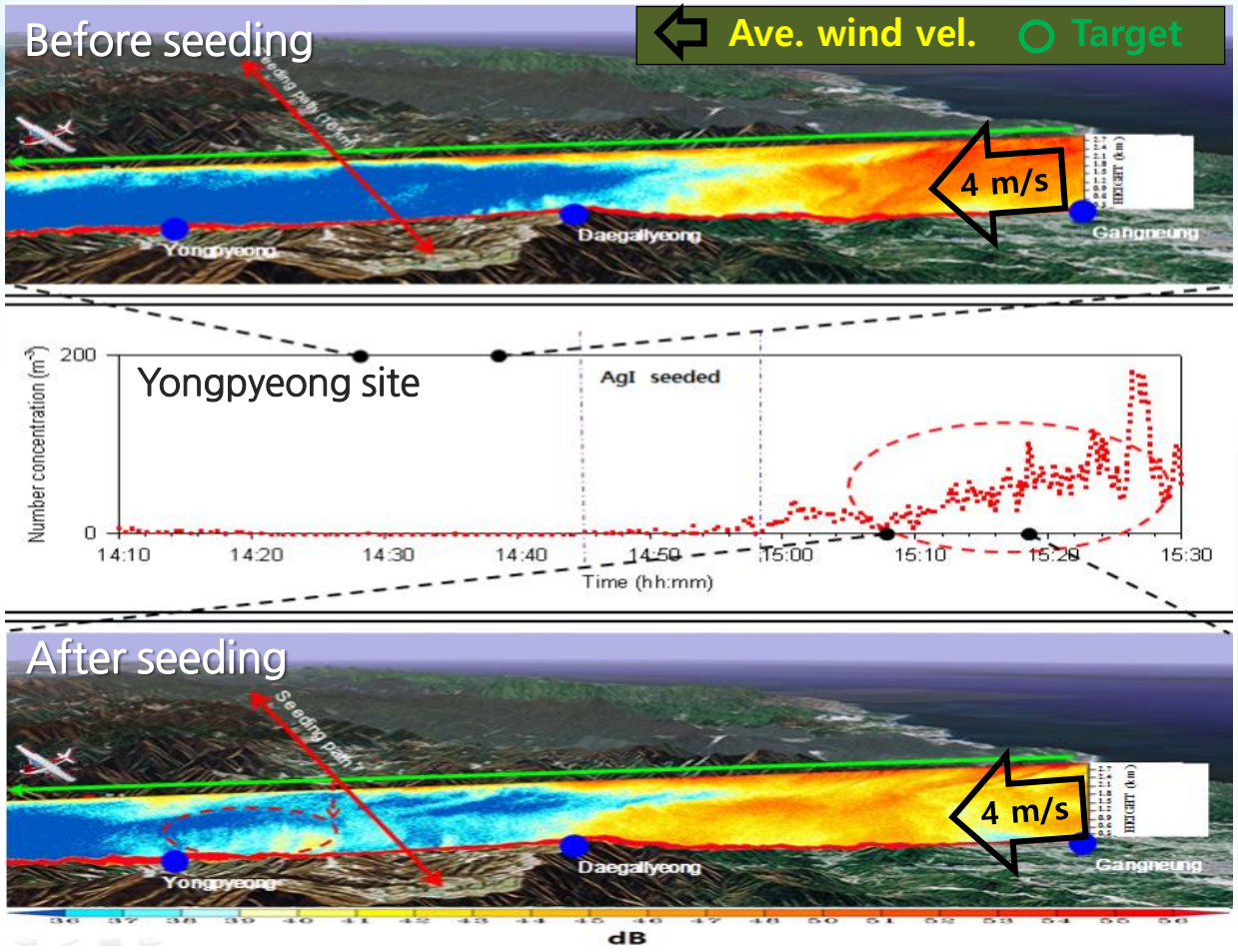
Criteria	Airborne experiment	Ground-based experiment
Synoptic condition	Northern High, Southern Low	
Temperature	≤ -5°C	
Wind speed	≤ 15 m s^{-1} (for safe)	≤ 5 m s^{-1}
Wind direction	Easterly wind(45~135°), maximum seeding height : ≥1400 m	
LWP in cloud	≥ 0.1 mm	
Cloud-type	Stratocumulus or Stratus	Winter orographic cloud
Restrictions	Heavy-snowfall warning for target region	
Seeding rate	~40 g min^{-1}	~37 g hr^{-1}

3. Main results

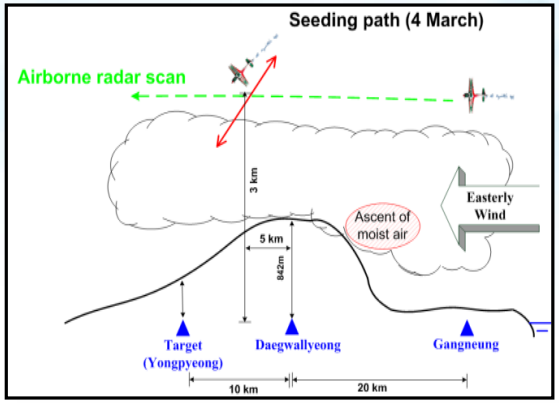
- Validation of Cloud Seeding by Airborne Radar
- Airborne Cloud Seeding in 2016
- Validation using Numerical Model
- Microphysical Validation of Ground-based Seeding
- Exp. for 2018 Winter Olympics

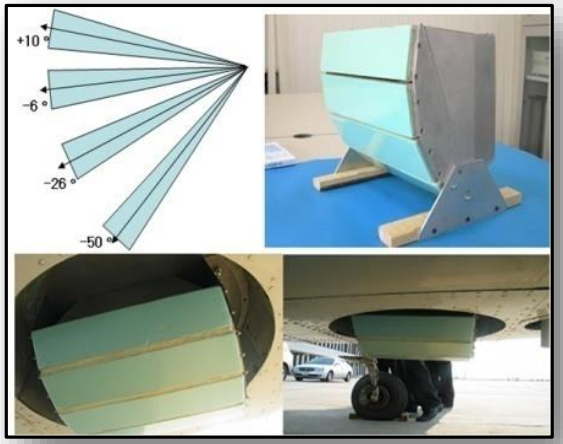
Validation of Cloud Seeding by Airborne Radar

- The enhanced radar reflectivity from seeding path is well appeared.



〈 Airborne reflectivity before and after seedign in 4 Mar. 2008 〉





〈 Ka-band airborne radar 〉

Airborne Cloud Seeding in 2016

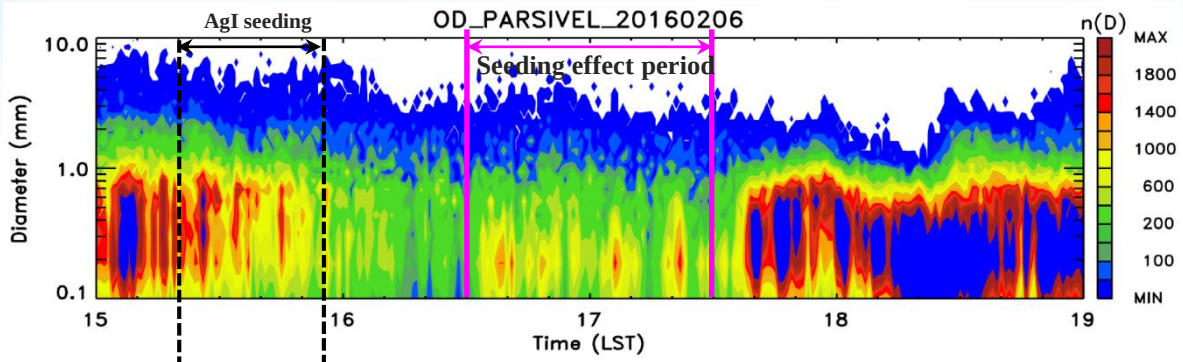
❑ Overview

No.	Date and time	Target	Seeding altitude/amounts	pictures
1	2016. 1. 29. 12:50~13:40	Gangneung	2.2km/AgI 1.35kg	
2	2016. 1. 29. 19:50~20:40	Pyeongchang (Not clear)	2.0km/AgI 1.5kg	
3	2016. 2. 6. 15:20 ~ 15:55	Mt. Odae (1.8 cm ↑) About 250km^2	1.8~2.5km/AgI 1.2kg	
4	2016. 2. 20. 13:55~14:25	Mt. Odae	2.5~2.9km/AgI 1.2kg	
5	2016. 3. 9. 13:16~14:00	Mt. Odae (0.3~0.4 cm ↑) About 250km^2	1.7~2.1km/AgI 1.5kg	
6	2016. 3. 9. 18:31~19:07	Yongpyong	1.7km/AgI 1.5kg	
7	2016. 6. 21 12:27~12:47	Yongpyong	1.8~1.9km/$CaCl_2$ 4kg	
8	2016. 6. 21 13:41~14:03	Yongpyong	1.8~1.9km/$CaCl_2$ 5kg	

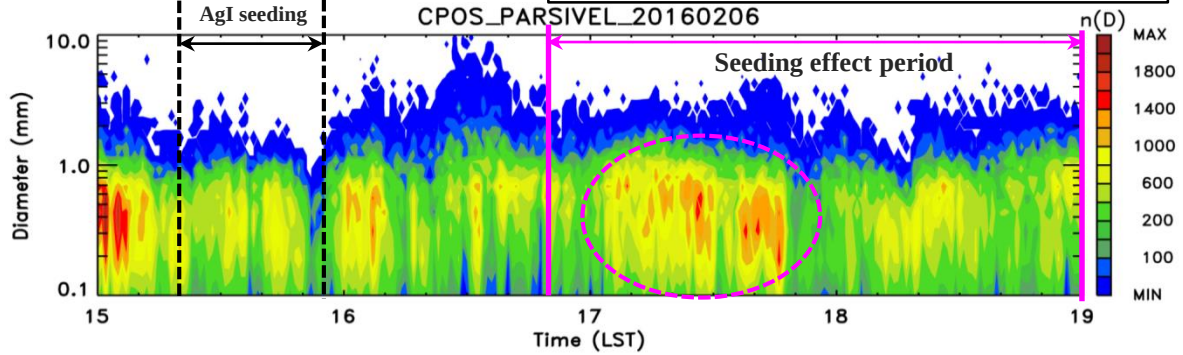
Airborne Cloud Seeding in 2016
– Microphysical Validation–

- Snow particles increase in target region by seeding
  - Airborne cloud seeding experiment at 6 Feb. 2016

OD: Upwind region (1000 m, AGL)

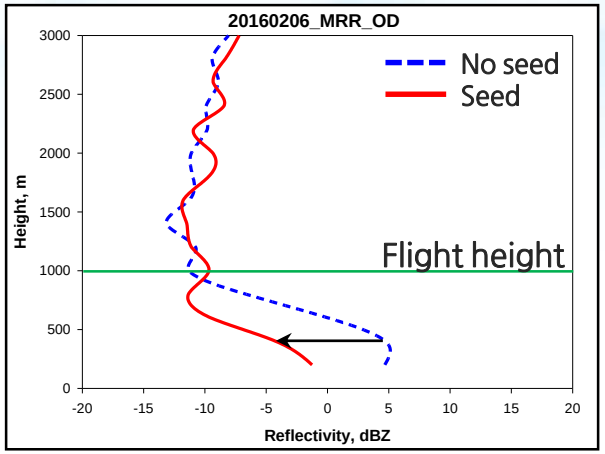


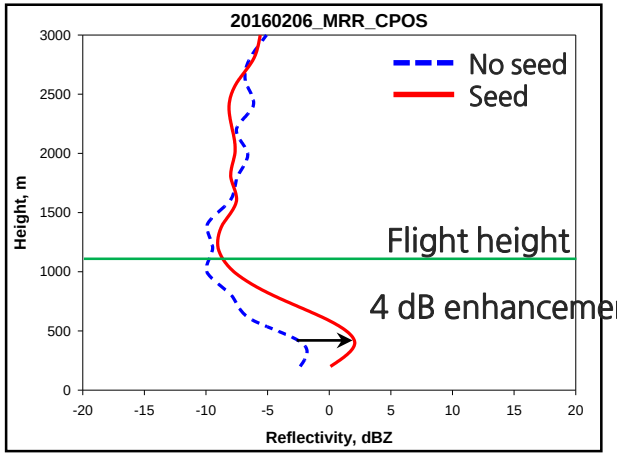
CPOS: Downwind region(843m, AGL)



↔ Seeding effect period: estimated by the diffusion model

- **Vertical reflectivity after seeding**

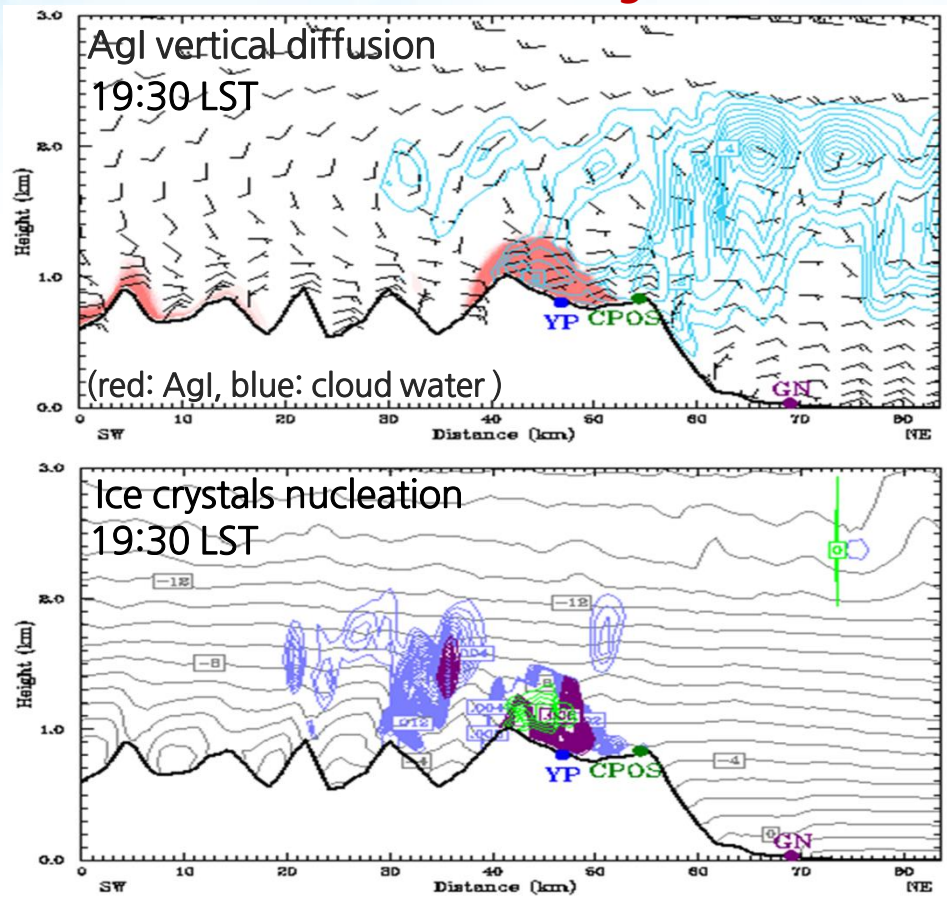




Validation using Numerical Model

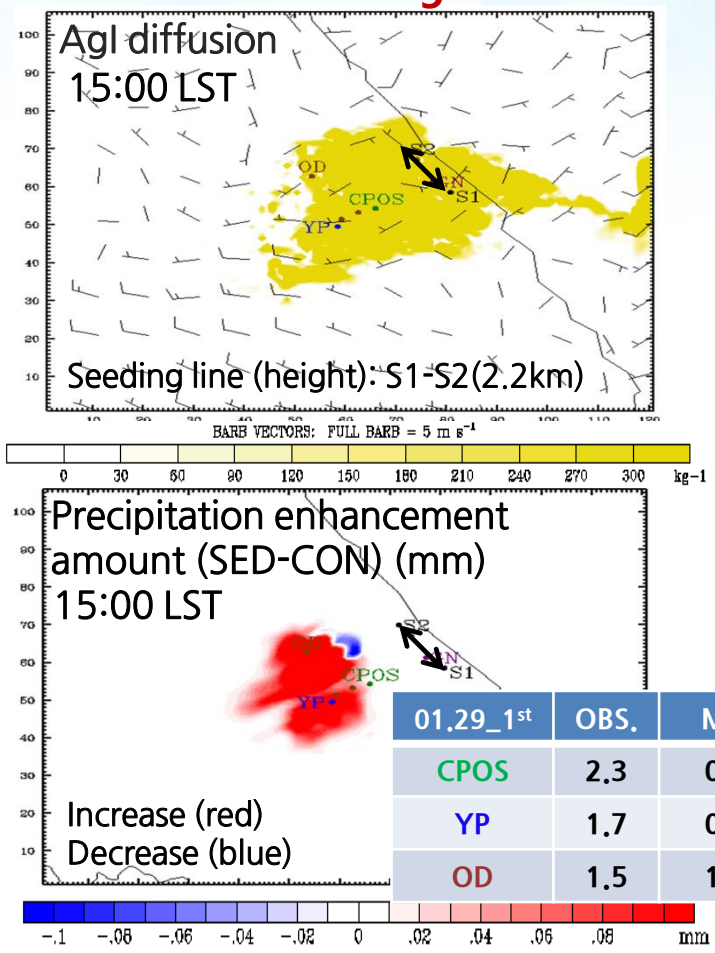
- MMS(Modified Morrison Scheme including Deposition, Contact and Condensation Freezing):
  1) A priori simulation 3 hrs before cloud seeding experiment
  2) Validation for snow enhancement experiments

Ground-based cloud seeding- 2014.01.04 event



(violet: deposition, green: contact, violet: condensation)

Airborne cloud seeding- 2016.01.29 event

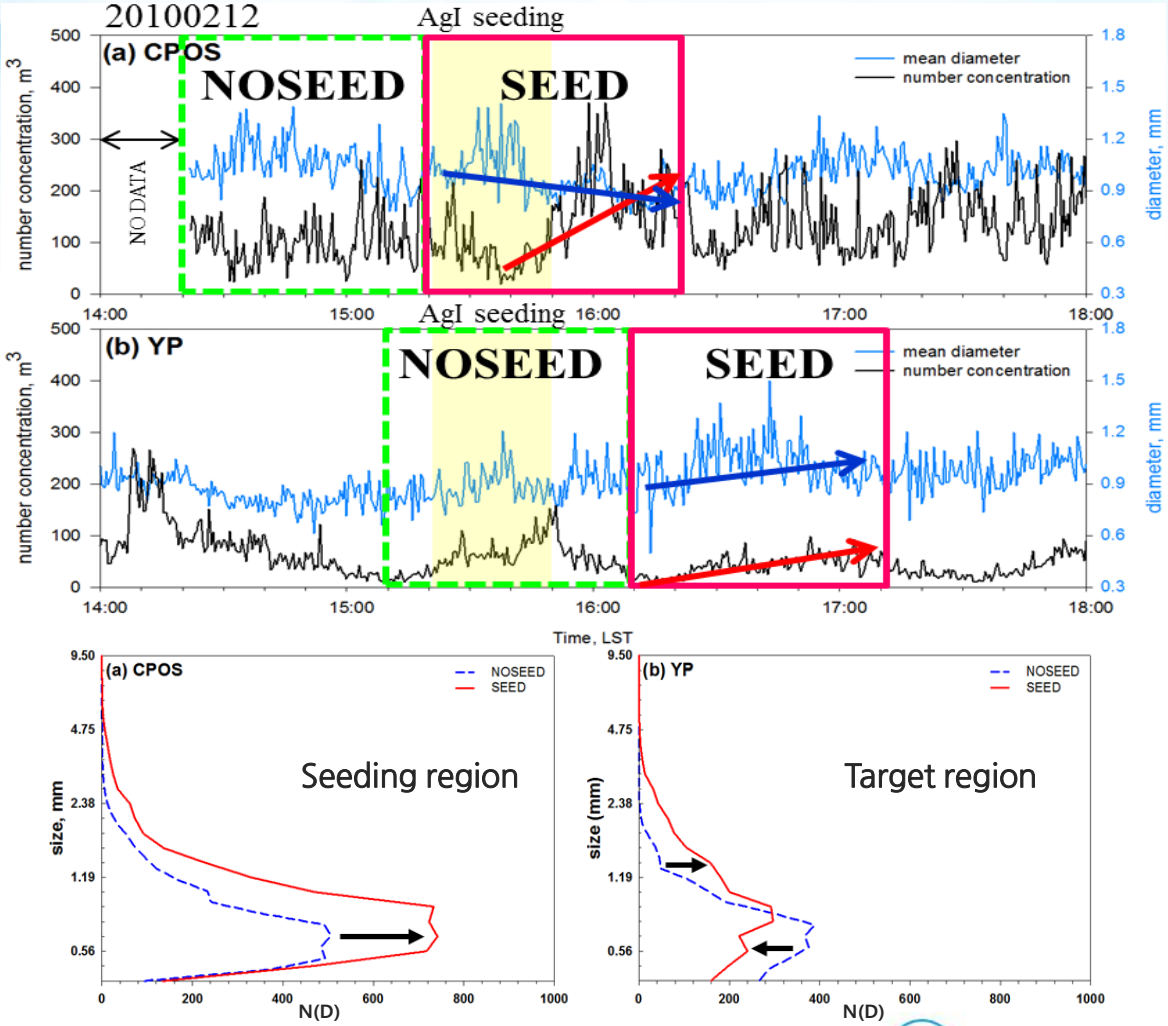


01.29_1st	OBS.	Model
CPOS	2.3	0.022
YP	1.7	0.224
OD	1.5	1.365

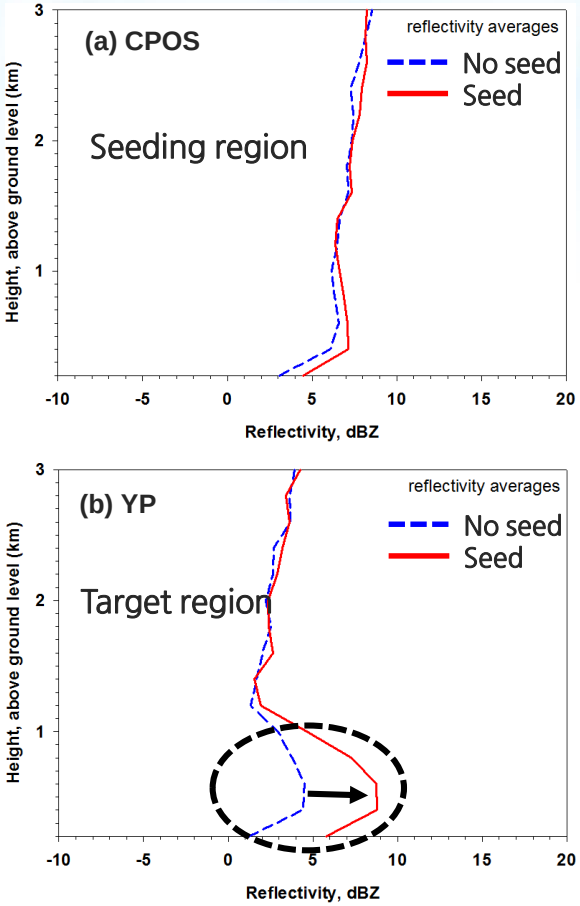
Microphysical Validation of Ground-based Seeding

- The microphysical effects are well shown in seeding and target regions

Size distribution of PARSIVEL disdrometer



Vertical Reflectivity after seeding



Exp. for 2018 Winter Olympics

〈Goal〉

- ❑ Development of cloud seeding technique using new atmospheric aircraft
- ❑ Improvement of the verification of cloud seeding experiments

Semi-operational exps. for snow enhancement in the Pyeongchang region

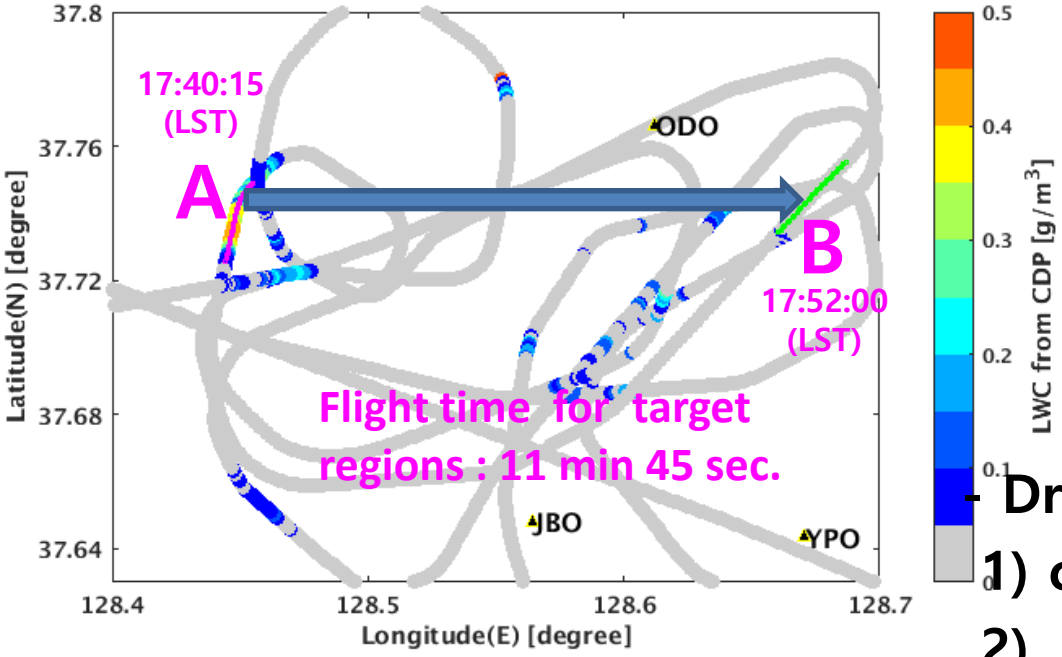
· Rental aircraft → Atmospheric research aircraft · Easterly ~ Northerly → Random direction

- Support of 2018 Pyeongchang Winter Olympics
- Alternative tool for supporting the water resources

PyeongChang 2018™

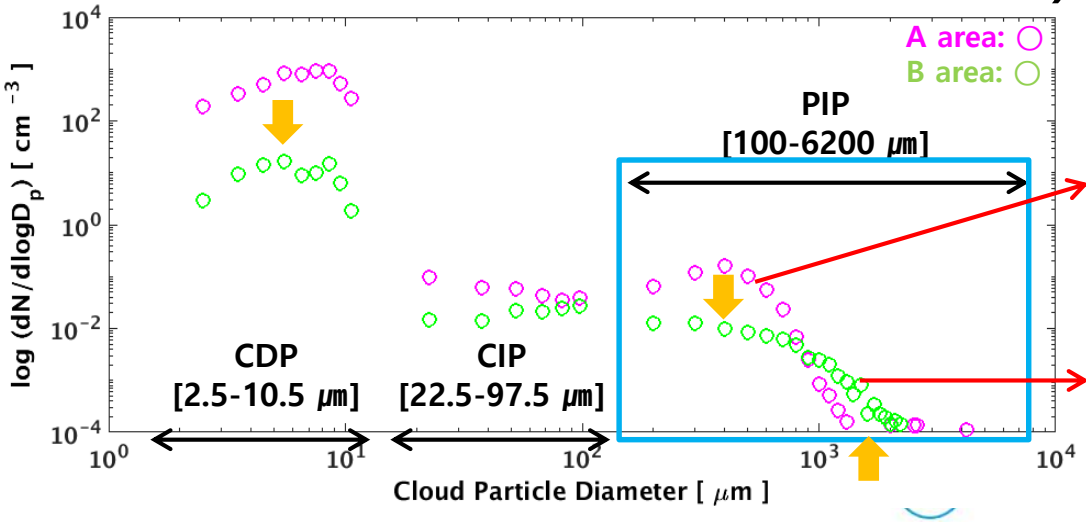
Results of Aircraft Obs. In 2018

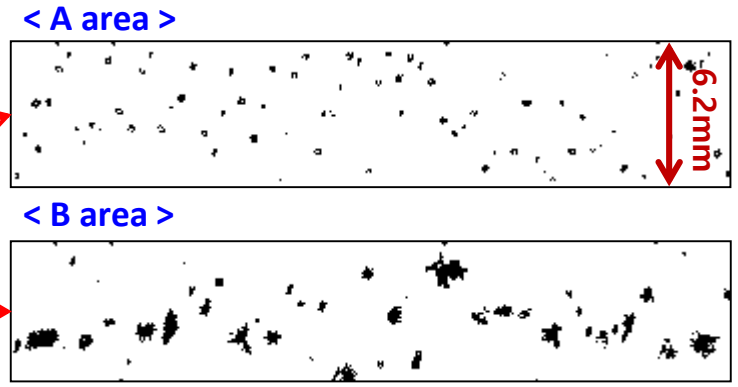
- **Drop size distribution of cloud and rain (Jan. 30 2018)**



· 17~18LST Avg. WD : 277°,
· Avg. WS : 24 m/s
· A↔B distance : 18 km
→ Dispersion time of AgI
: 12 min. 30 sec

- **Drop number conc. after seeding**
1) cloud and small rain drop ↓
2) large rain drop ↑





4. Major Scientific Achievement and International Cooperation

Major Scientific Achievement

KMA operation	Paper	Patent	Book	Technique transfer to industry
3	65	26	2	2
3	SCI: 29 Domestic: 35	Register: 18 Submit: 8	2	2

〈Papers and patents〉

〈Book〉

*Reference : Eye obs.	Corr. Coeff. (R^2) All day/night
ACOS(V3.0)	0.91/0.90
Ceilometer	0.58/0.65

〈Automatic cloud observation system〉

International Cooperation

International Workshop

2003, Seoul

2006, Beijing

2010, Daegu

2016, Daegu

Invited Seminar

NCAR, USA

CAO, Russia

CAMS, China

NU, Japan

Collaboration Research (Russia, 2013~2015)

〈 NIMS-CAO Collaboration Research Agreement Conclusion('15)〉

Hebrew Uni., Israel

Thank you for your attention!!!

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Aircraft (2017. 11~)

< Atmospheric research aircraft >

- Model: King Air 350HW (Beechcraft, U. S. A)
- Capacity/instruments: 13 Persons / 26 kinds of 14 species
- Flight height/time: Max. 10km / 7 hr
- Application: 1) Monitoring of high impact weather
  2) Monitoring of climate change and air quality
  3) Study on cloud physics and weather modification

Equipment of Aircraft for Cloud and Rain

Instrument		Operating Principles	Primary Measurements	Range
DMT, CCN-200 (Cloud Condensation Nuclei Counter)		Air Sampling	Condensation Nuclei	0.75~10 ㎛
DMT, CCP (Cloud Combination Probe)	CDP (Cloud Droplet Probe)	Forward Light Scattering	Cloud Droplet Concentration Spectrum	3~50 ㎛ (30 channels; Liquid Water Content Derived)
	CIP (Cloud Imaging Probe)	Shadowing of Diodes	Cloud Droplet Concentration Spectrum	7.5~930 ㎛ (resolution, 15 ㎛)
	LWC (Liquid Water Content Sensor)	Hot Wire Sensor	Liquid Water Content	0~5 g/m^3 (resolution, 0.01 g/m^3)
DMT, PIP (Precipitation Imaging Probe)		Shadowing of Diodes	Cloud Droplet Concentration Spectrum	100~6,200 ㎛ (resolution, 10 ㎛)
SEA, *WCM-2000* (Water Content Measurement)		Hot Wire Sensor	Liquid Water Content, Total Ice Water Content (Ice Water Content Derived)	0~6 g/m^3 (LWC) 0~10 g/m^3 (TWC)