Recent activities of cloud seeding of NIMS/KMA

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Research Applications Department

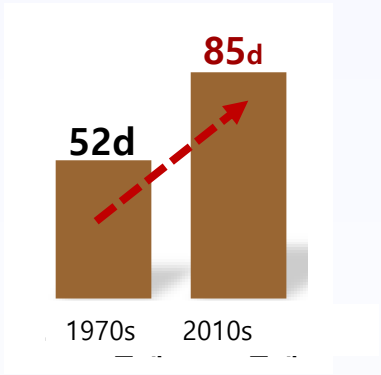
National Institute of Meteorological Sciences

with collaboration of Korea airforce, Korea environment corporation, National Institute of Environmental Research, K-water, and Sunnyair inc.

Need of Weather Modification

Climate change ➔ Increasing trend of **natural hazard related to water shortage**

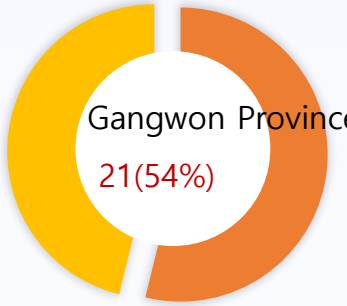
Drought days 1. 6 times increasing!



※ **(Middle of Korea Peninsula) 5.5days ↑**

Forest fire Bigger!

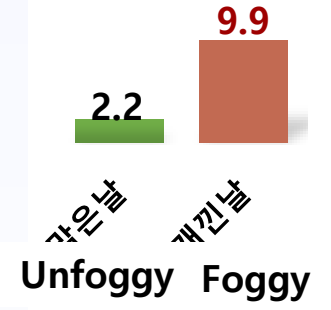
Yearly mean forest fire area
Recent('18~'19) is **2.4 times** more than the past('08~'17): 857→2075ha



※ 1ha = 10,000m^2 (3,400 m^2)

Deep Fog accident ➔ Big traffic death!!

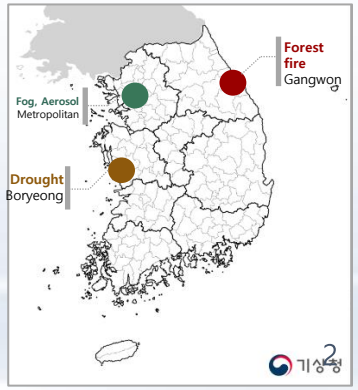
Car accident death: **4.5 times** compared with non-foggy day



※ **Aerosol Concentration recorded No. 1** among OECD nations(2018, 2019, Air Visual)

➔ Need of the advanced cloud seeding skill to reduce Drought, Forest fire, Aerosol, Fog

[Past] **Drought** reduction ➔ [2020~] **Multi-purpose** Exps.
- Drought, Forest fire, Aerosol, Fog reduction

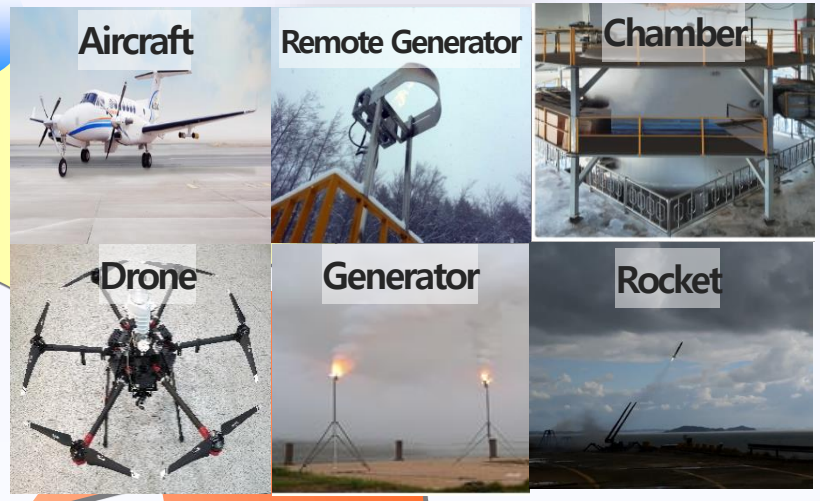


Structure of Weather Modification Research

Experiment

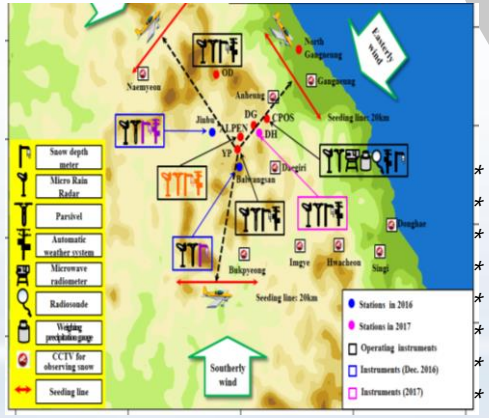
- **Precipitation enhancement**
  - Aircraft/Ground-based Exp.
  - Verification by obs. network

** Hygroscopic seeding: APJAS(2007)*
** Glaciogenic seeding: Adv. Atm. Sci.(2009)*
** Startegy of aircraft oper. : APJAS(2011)*
** Glaciogenic seeding: Adv. Met.(2018)*
** Aircraft seeding: Atm. (2019)*
** Dron-Aircraft: Av. Met. (2022)*
** Pollution reduction (2023)*
** Airforce-Nara sequential seeding(2023)*



Observation

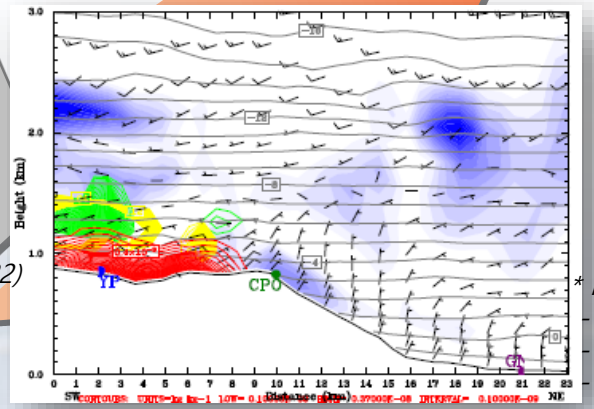
- **Cloud Physics Observation Network**
  - Aerosol, Cloud, Precipitation
  - Microphysical measurement



** CPOS: Atm.(2007), Remote(2010)*
** Raingage: Remote(2008)*
** Radar QPE: JMSJ(2013), APJAS(2022)*
** Hydro.: Adv. Met.(2018), J. Hydrology(2022)*
** Cloud obs.:Remote(2020,2022)*
** Snowfall obs.: Atm.(2019)*
** Disdrometer: APJAS(2020)*
** Seedable hours: Env. Sci(2023)*

Modeling

- **Numerical model simulation**
  - Numerical verification
  - Forecast before seeding



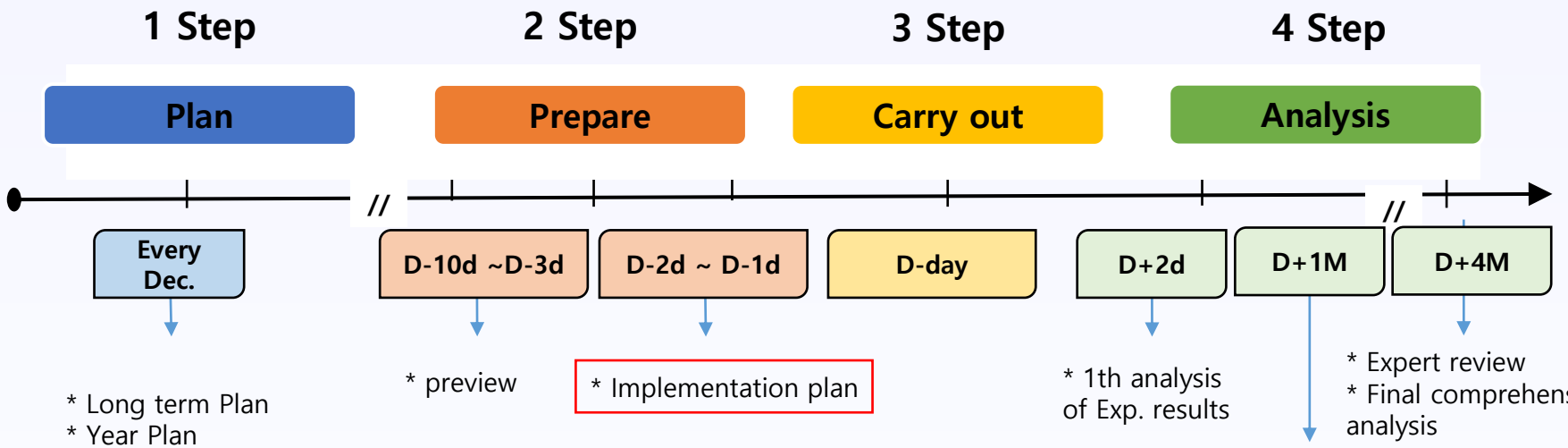
WRF model simulation for ground-based experiment

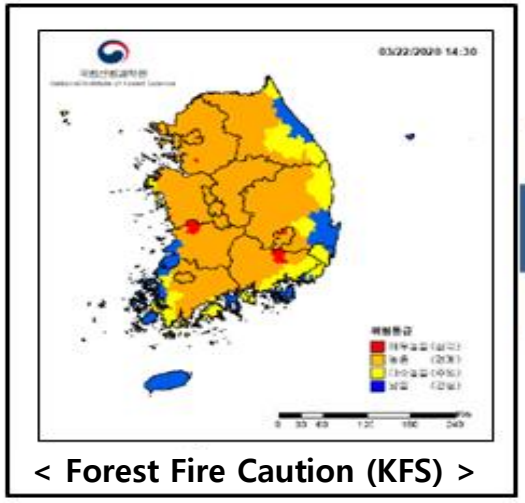
** Modified Morrison Scheme*
- Met. Atm. Phys.(2016)
- Adv. in Met.(2018)
- Atmosphere(2022)

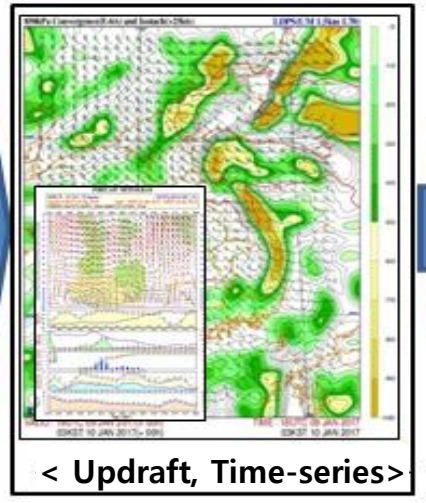
Procedure of Weather Modification Experiment

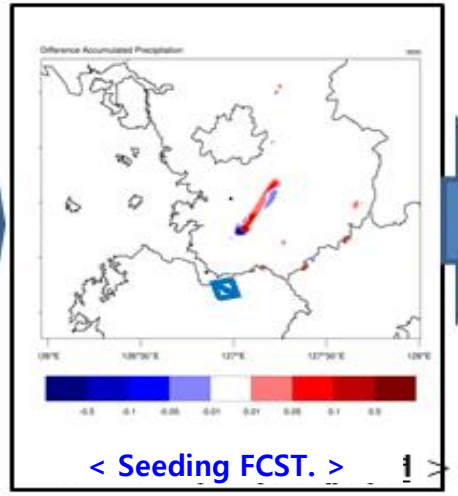
Weather modification experimental process in KMA

※ M: Month, D: Day




< Forest Fire Caution (KFS) >


< Updraft, Time-series>


< Seeding FCST. >

Experiment

Analyses

[D-10d ~ D-2d]

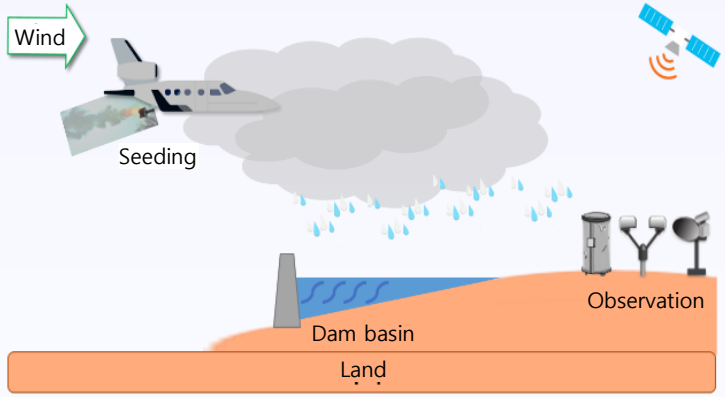
[D-1d]

[D-day]

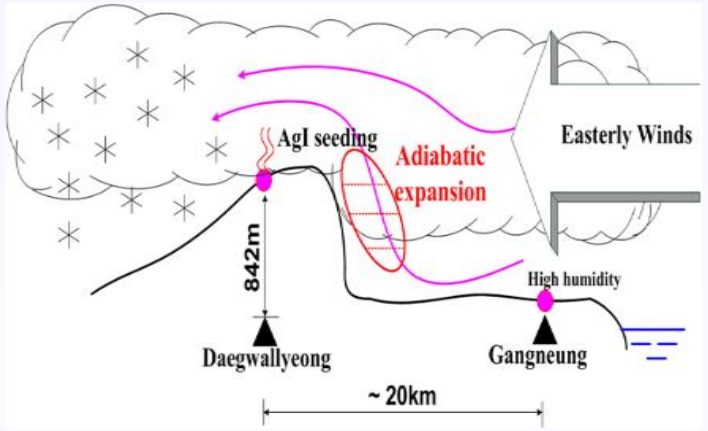
[D+α]

Multi-purpose Cloud Seeding Experiments

Drought reduction

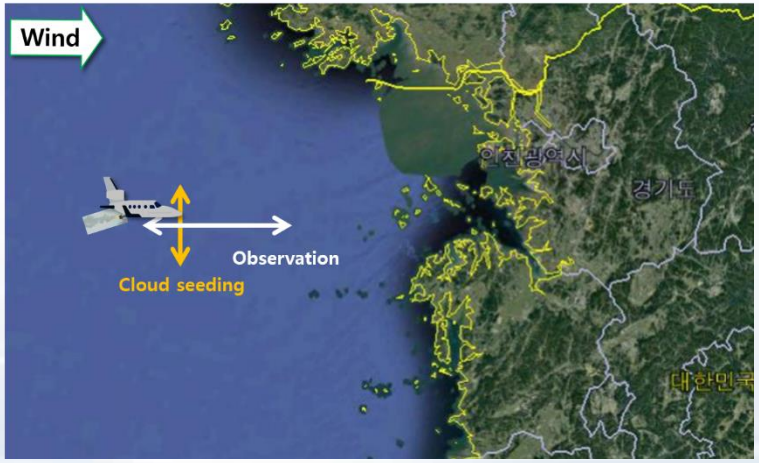


Forest fire prevention



Fog dissipation

Reduction of aerosol



(New tech.) Estimation of enhanced precipitation for each exp.

◈ **(Motive)** It is difficult to estimate enhanced prep., when mixed with natural precipitation.

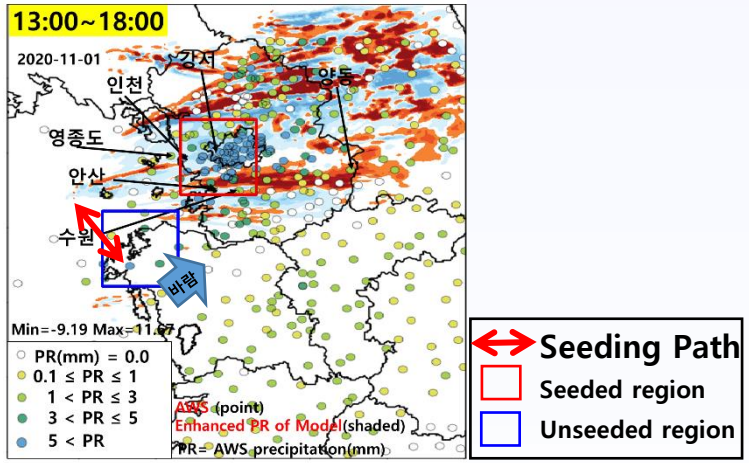
➔ **(New Method) Under similar convergence situation,**

Enhan. Prep. = (Prep. in seeded region) – (Prep. In unseeded region)

⇒ Published in Adv. in Met. (Sep. 2013)

< 1 Nov. 2020>

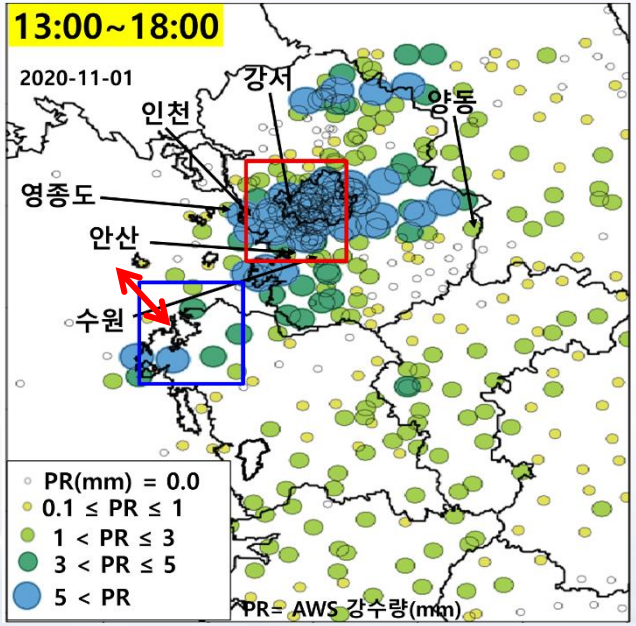
1) Select Seeded/Unseeded region(2,500km² box)



2) Select raingages in Seed/Unseed regions

- No. of Raingages in seeded box: 61
- No. of Raingages in unseeded box: 9

* Raingages > 300 m (mslp) are excluded in analyzing



< Accumulated Precipitation (13~18 LST) >

3) Estimation of Enhan. Prcp.

Accmu. Prep.	Local Time(12:00~18:00)		
	Seeded	Unseeded	Seed – Unseed
Max.(mm)	24.0	8.5	15.5 (+)
Ave.(mm)	7.2	3.9	**3.3 (+)**
Standard Dev.(mm)	4.65	1.26	-

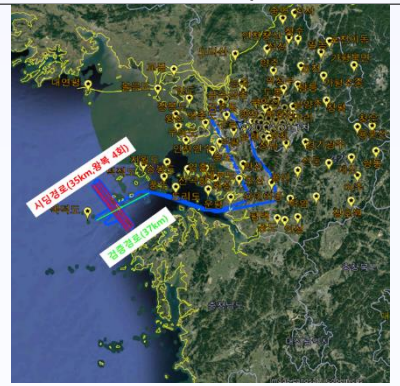
(New tech.) Aerosol reduction by seeding (1/2)

◈ **(Motive) Rainfall can reduce the PM10/PM2.5(Wei, 2015; Tomasz 2016)**

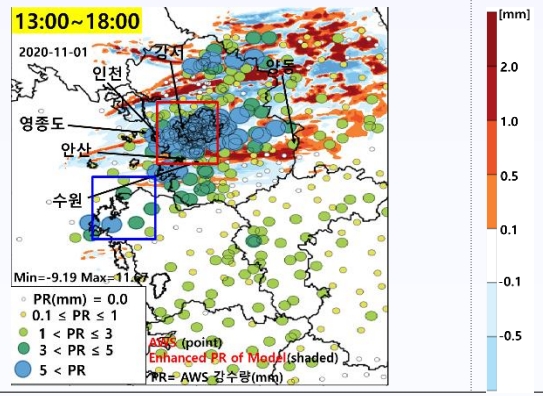
➔ **(New Method)** Seeding⇒ Enhancing Rainfall/Cloud⇒ Enhancing the reduction of aerosol

◈ (Case study) **11 Dec. 2020**, for reducing the polluted particles in basin

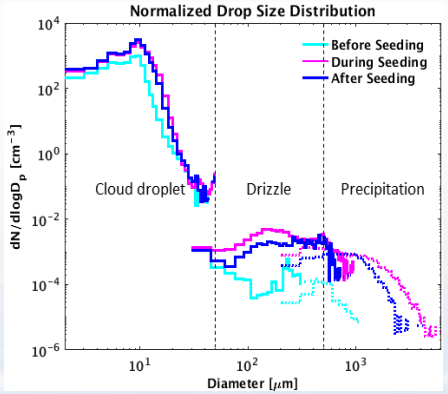
1) **Enhanced rainfall (estimated 3.3 mm)** is spatio-temporally coincided with the simulated results
2) Cloud particle size increases after seeding
3) Radar rainfall shows well the abrupt increase in the simulated region (Seoul)



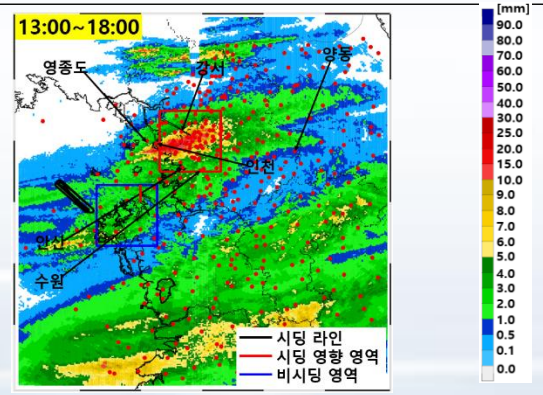
[Fig. 1] Seeding path(11:26~12:20 @ 0.7km)
*Red: Seeding path, Blue: Cloud obs. before/after seeding



[Fig. 2] Observed(circles) and simulated(colors) rainfall



[Fig. 3] Cloud DSD before/after seeding



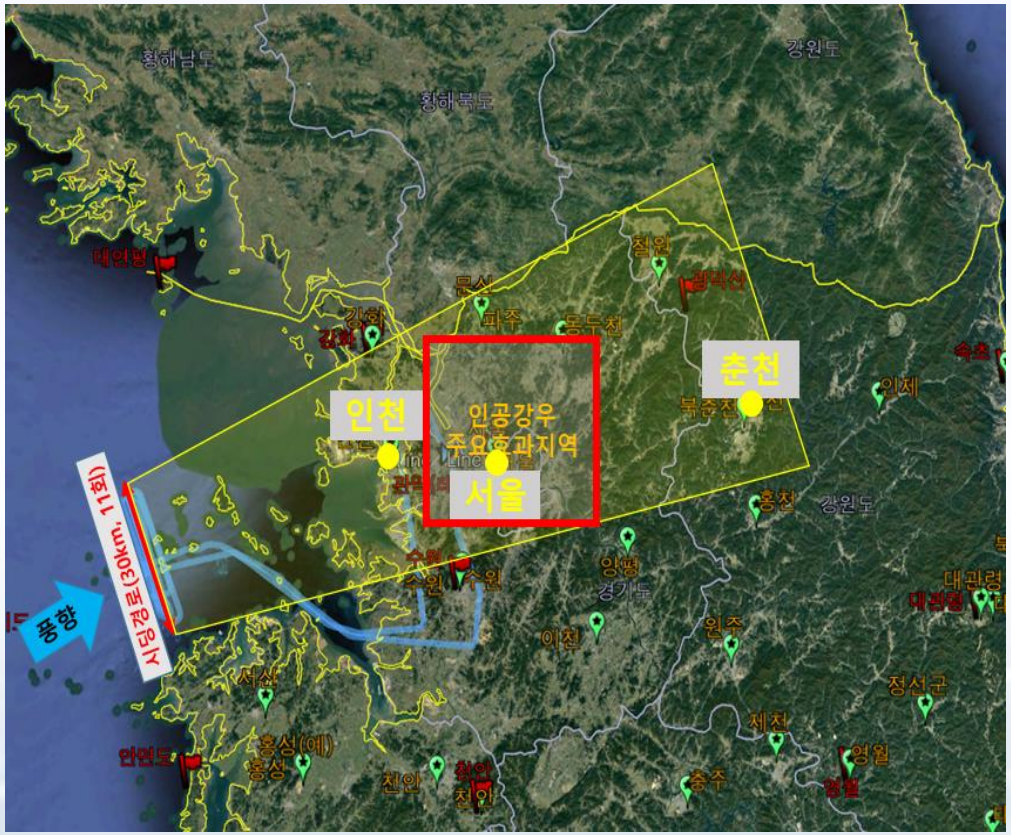
[Fig. 4] Radar rainfall(estimated enhanced: 3.3mm)

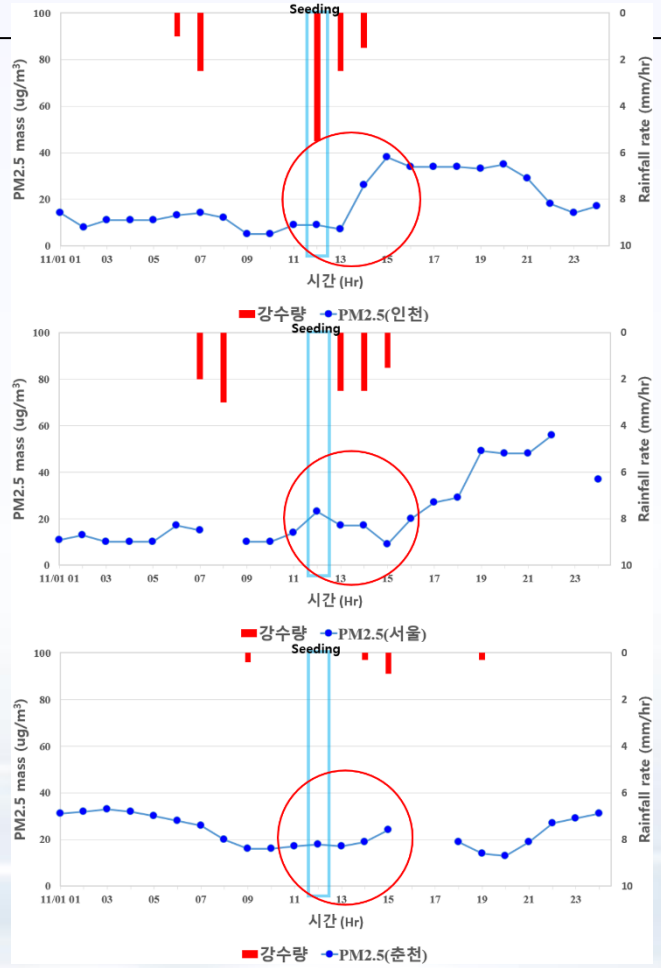
(New tech.) Aerosol reduction by seeding (2/2)

○ **(Effect of cloud seeding)** Seoul, the estimated enhanced rainfall = 3.3mm

○ **(PM2.5)** Seoul shows the reduction of aerosol, by comparing with the other regions (Incheon, Chunchun)

⇒ Published in APJAS(Jan. 2013)





(New tech.) Direct verification by rainfall chemistry

◈ 【Chemical component analysis Results】

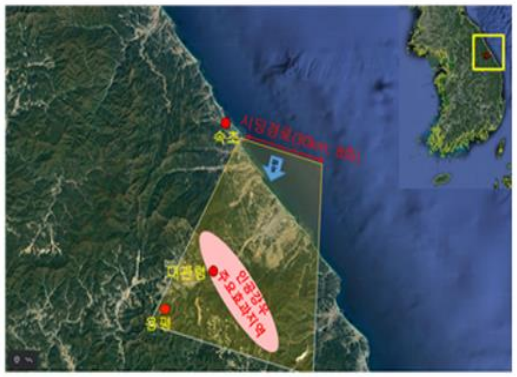
- Aircraft experiment for prevention of forest fire(25 Sep. 2020)

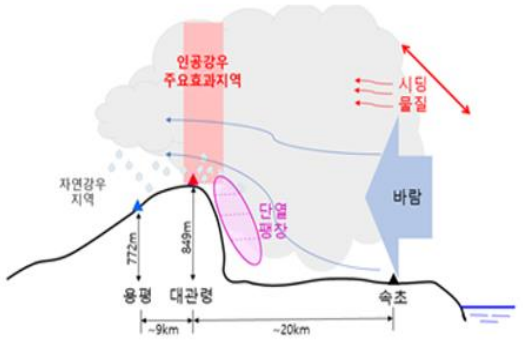
⇨ **Increase of Ca ion concentration in effect area**

· **(Effect area)** Daegallyeong

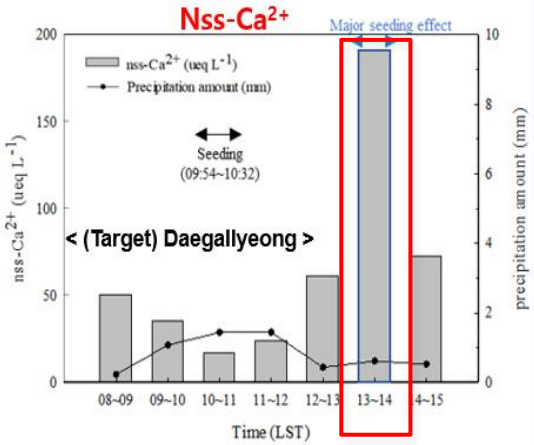
· **(No-effect area)** Sokcho, Yongpyong

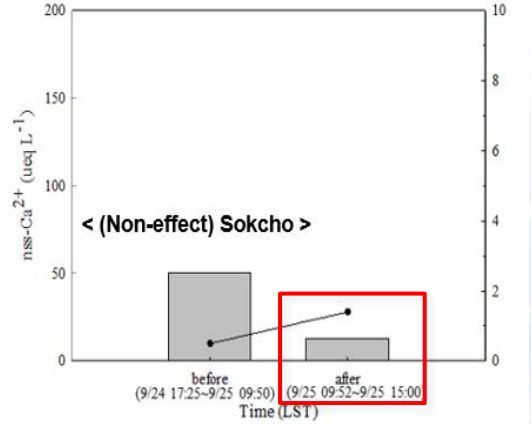
◈ **Results**

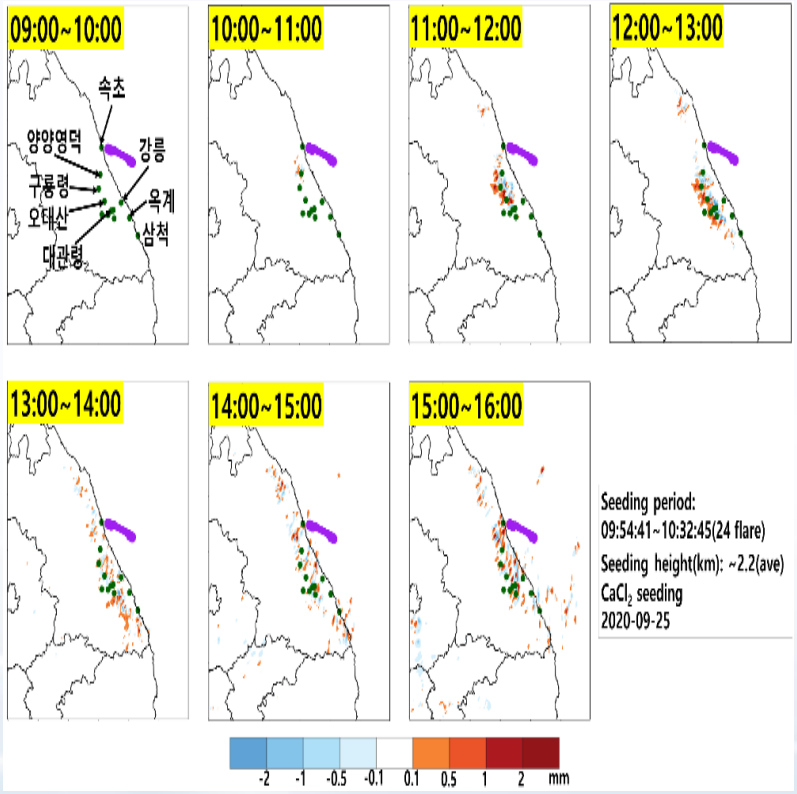




< Schamatics of exp. >





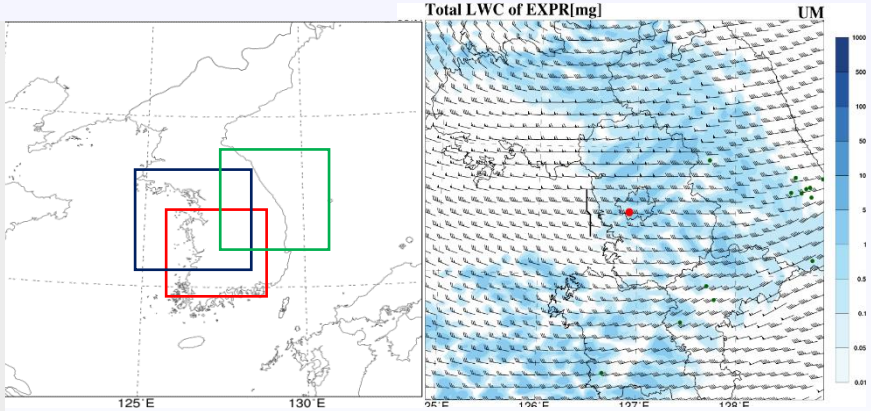


< Simulated enhanced precipitation >

(New tech.) Automatic numerical prediction of cloud seeding

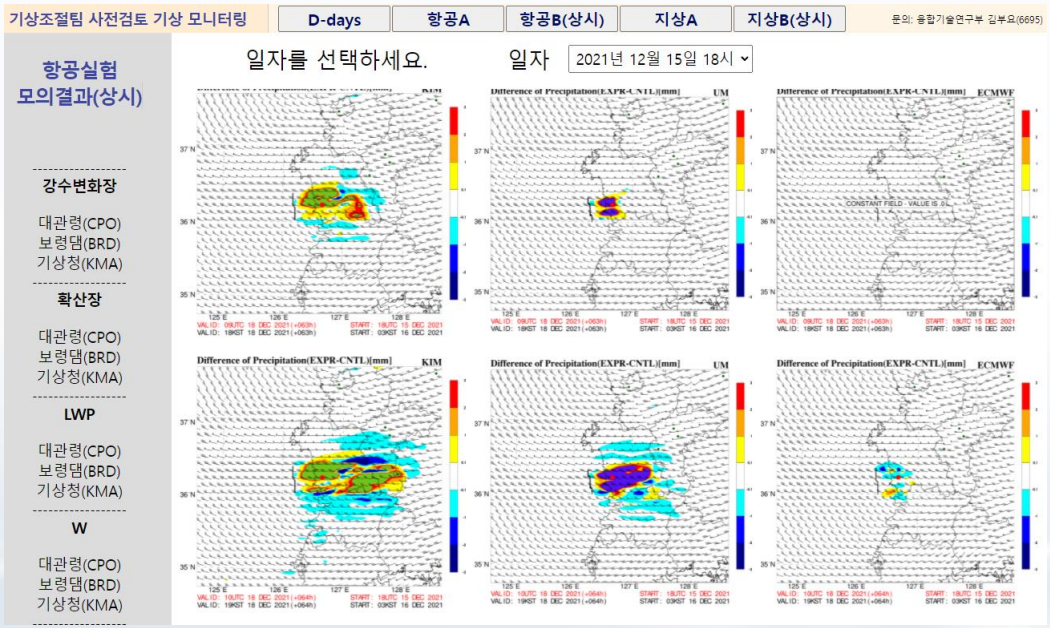
◈ Daily numerical predicted results

O Automatic determine of proper seeding line
1) Read data from CNTR result
2) Decide LWP max time and height at Target site
3) Seeding directing(theta(θ)) is determined with wind data at a fixed time and altitude.
4) Calculate center of the seeding line and distance from a target area.

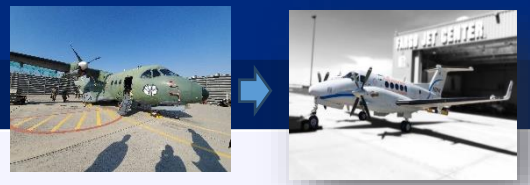


< (a) 3 Domains and (b) LWP>

◈ Daily numerical predicted results



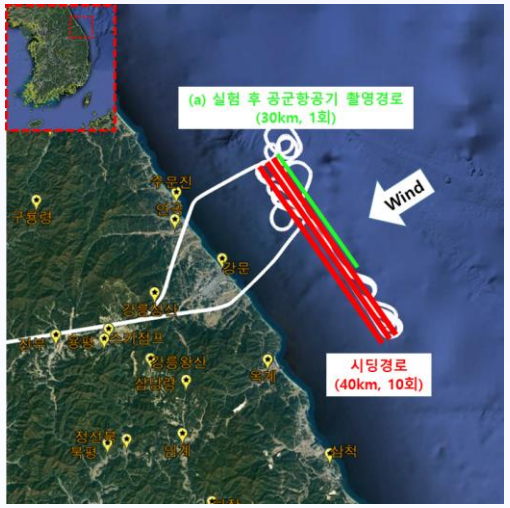
(Two aircraft) Sequential Exp. (4 Mar. 2022)

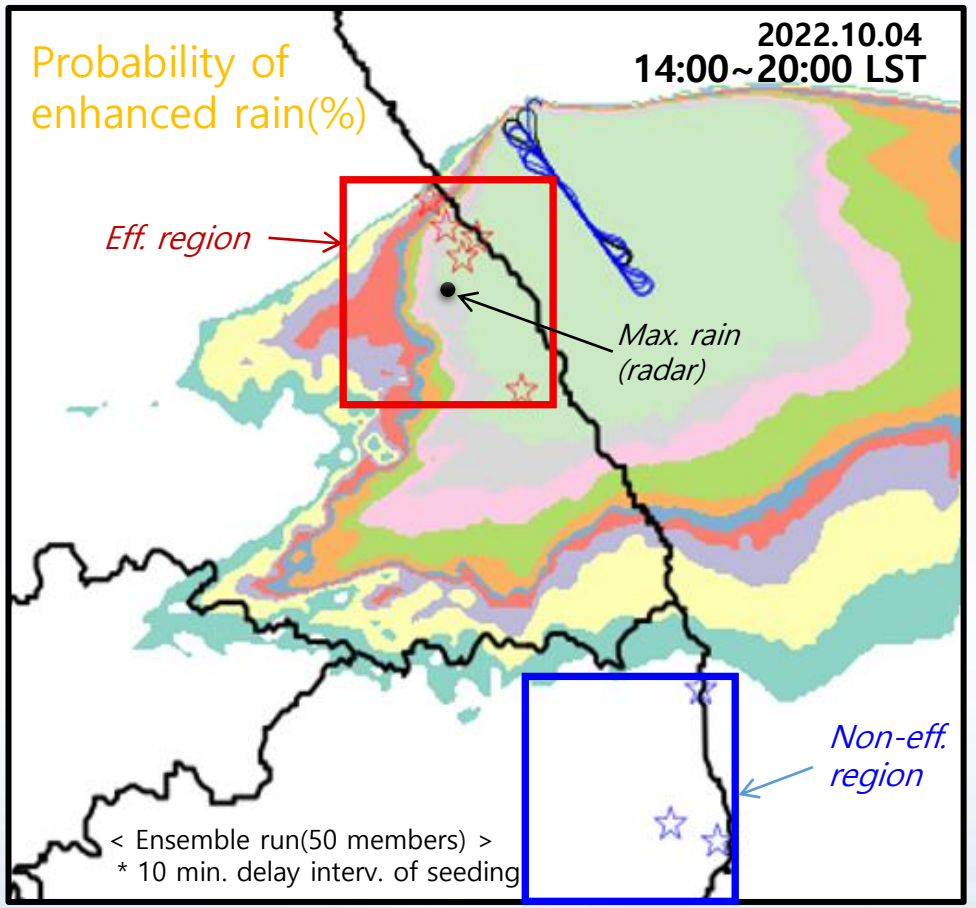


Airforce seeding: 13:48~15:20(92min.)
KMA seeding : 16:29~17:26(57min.)

◈ 【Airforce-KMA sequential aircrafts seeding】

$$※\boldsymbol{Enhanced\ rain} = \frac{1}{N}\sum_{i=1}^{n}(Eff.\ region\ rainfall)_i - \frac{1}{N}\sum_{i=1}^{n}(Non-eff.region\ rainfall)_i = (3.69mm) = \boldsymbol{3.7mm}$$





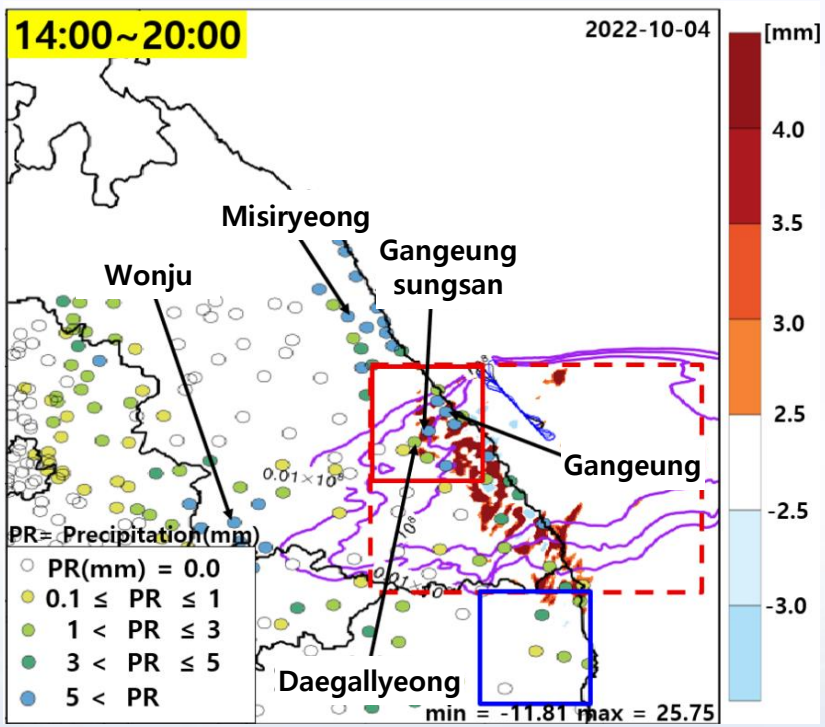
※ Consider **raingages below 150 m**(MSL) to minimize the orographical effect

(Direct Verification) Chemistry of rainfall

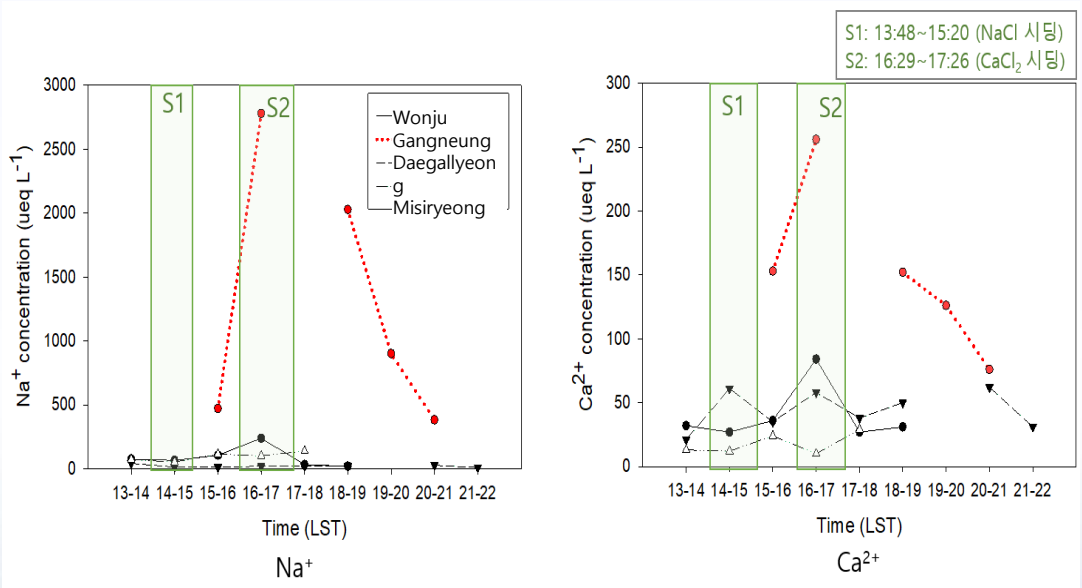
◈【Chemical analysis of the sampled rainfall】

- Increase of seeding components(Na^+,Ca^{2+}) in the sampled rainfall in the simulated effective region after seeding, comparing with ones in the non-effective regions.

⇒ **Direct verification** of cloud seeding effect !! (J. Env. Sci. Interational, in press)



< Simulated enhanced rainfall>

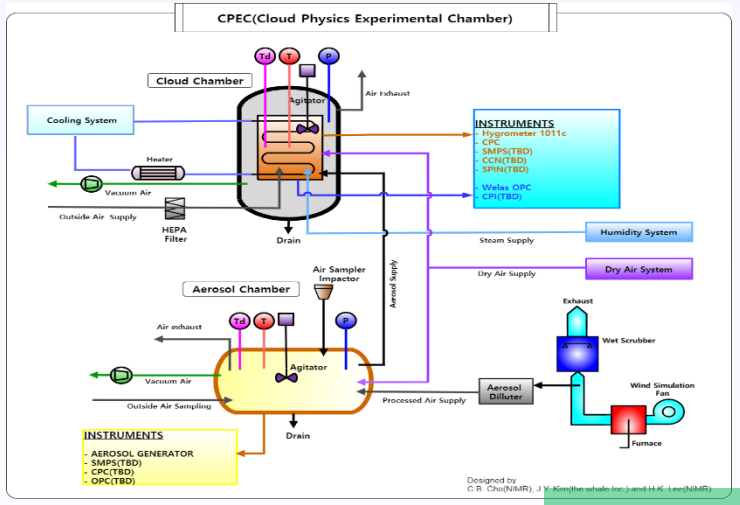


< Timeseries of ions(Na^+,Ca^{2+}) in sampled rainfalls >

(New material) Develop. Cycle: Chamber ⇒ Modeling ⇒ Exps. ⇒ Improve

Cloud/Aerosol Chamber (K-CPEC)

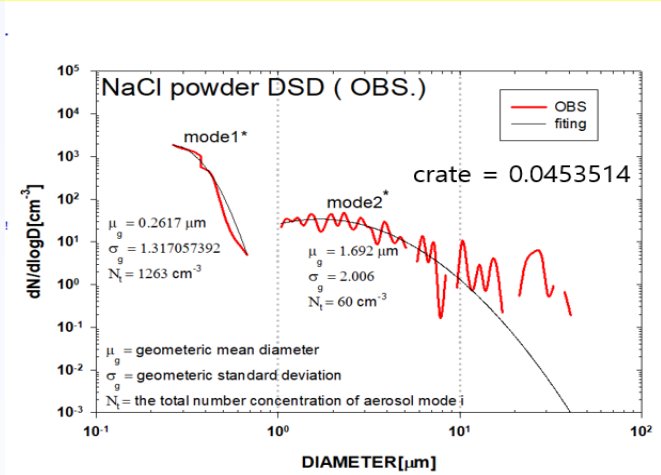
- **New flare or powder test** using by of K-CPEC
- Cloud physical observation by controlling the pressure and temperature



Observe

Parameterization for Numerical Model of cloud seeding

- Fitting the observed aerosol/cloud DSD to the simulation parameters of cloud seeding model



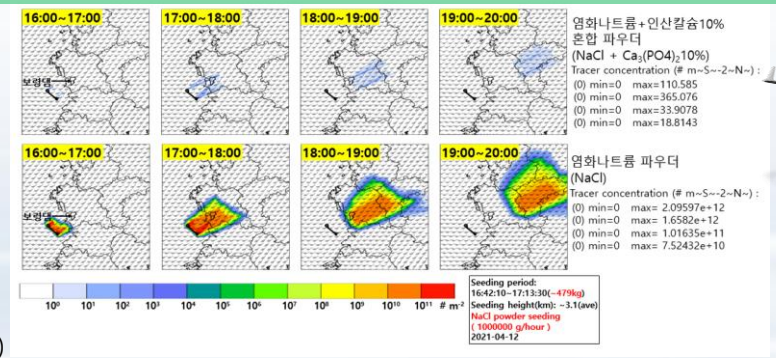
Apply

Application of Parameterized Numerical Model to New-material Exps.

- Numerical model with newly fitted parameters is applied for **understanding of seeding exps.** with new material

Improve

Year	Material	Type	Ave. size	GCC N ratio	Enhanced rainfall (Analyzed)
2022	NaCl,CaCl2	powder	~80um	1.7%	3.7mm
2023	CaCl2	powder	~16um	17%	4.1mm



* CaCl2 Flare(ICE): GCCN ~ 0.1%, Max. analyzed enhanced: 3.5mm(`20~`23)

Now and Future for the cloud seeding

O Results during the 4 years(2020~2023)

- **No. of exps. : 101**
- **Validated no. of exps. : 71(70%)** *73% reported(India 2022, no. of exps: 78)

*** Validation method:** Precipitation and cloud enhancement are simultaneously detected within the simulated seeding effective region

- **Ave./Max enhanced precipitation: 1.4/4.5 mm** *USA: Max. 5.0mm(Pokhrel, 2014)
- **Ave. seeding effective region: 1,028 km²** (Simulated enhancement above 0.5mm)

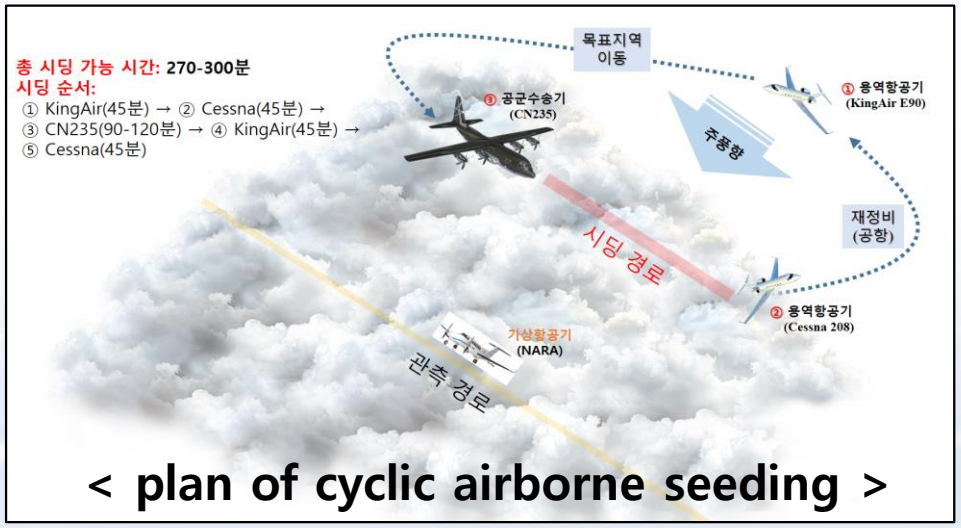
Elements	Past (`08~`19)	Present (`20~`23)	Future (`24~`27)
Aircraft	very small (Sessna205)	small (Kingair350)	**Small 3~4** (Kingair 350, 90, Airforce)
Stage	Basic (1h seeding)	Research (1h seeding)	Demonstration (**3h> seeding**)
Ave. Enhan. Prcp. per 1-hr seeding (mm)	**0.5**	**1.4**	**1.4**
Ave. effective area(km^2)	**1,260(Assume)**	**1,028(Simuation)**	**1,028(Simulation)**
Annual no. of exps./ Validation ratio (%)/ Annual enhan. prcp. (mm)	**3/33/0.5**	**25/70/23.1**	**100/70/92**
Annual reducible days of forest fire * 1mm→0.21 reducible days(Forest Admin., 2021)	**0.1**	**5**	**19**
Annual enhanced water(M ton)	**0.2**	**19.6**	**95**

< Past, present, and future of cloud seeding in Korea >

Plan after 2024

- **Demonstration project of cloud seeding operation (2024-2028, 5 yrs.)**

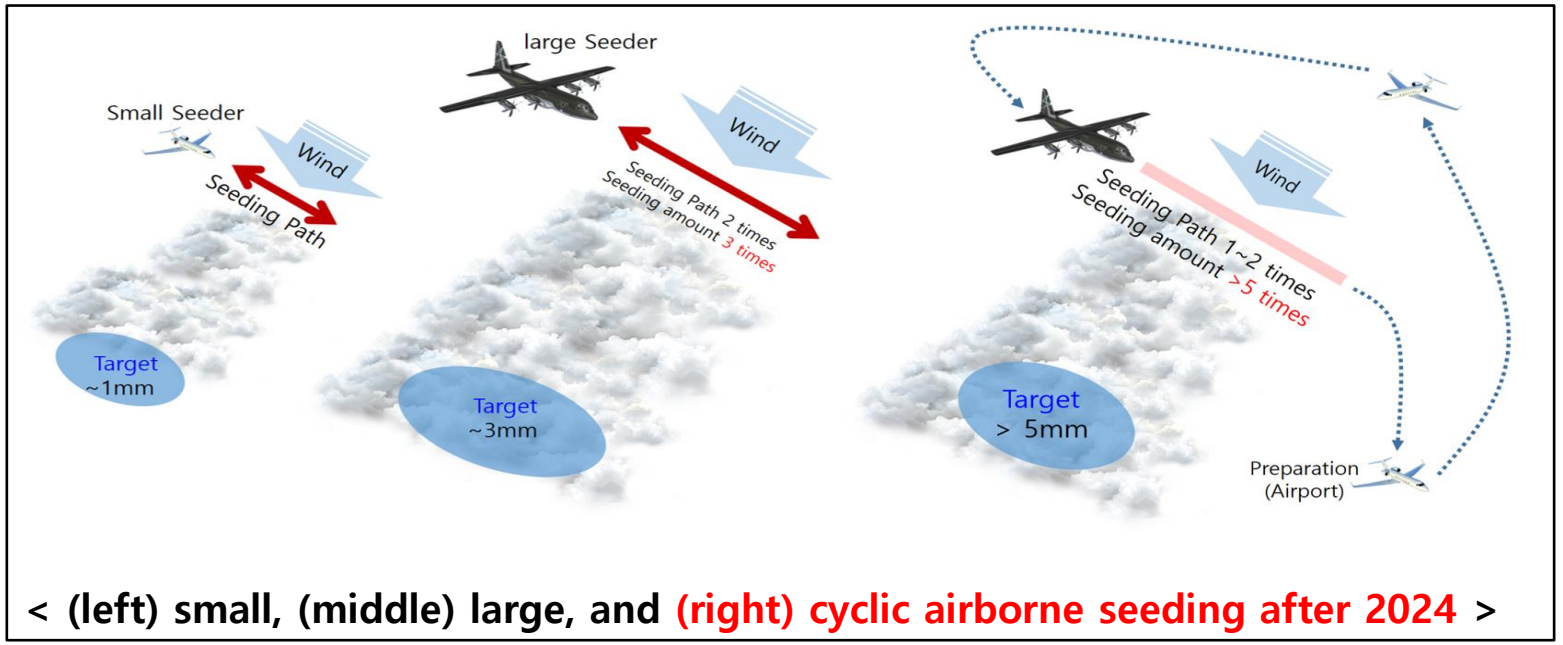
  - (Plan) above 100 exps./yr ⇨ Enhan. prcp. >100mm/yr. (7% of yearly precipitation)
  - (Command center) Kimpo airport office(7 persons)
  - (Facilities) 4 aircrafts + 6 ion-component rain sampler (2 mobile)
    - 1 Airforce(cn-235): 1~3 tons of powder type ptls.
    - 1 NARA(kingair 350): 24 flares and 101 ejectables, airborne radar
    - 2 company(2 kingair 90): 2 C90(48 flares, 303 ejec. and 350kg powder) moidified by WMI
      - * E90/caravan(350kg powder): additionally added
      - **Sat. Comm. including message/data exch. : all aircrafts, CWIP sensors: 2 C90
  - (Training) Preparing the Univ. (meteo./pilot) courses, NIMS training (analy. adapt), and participation of ND&WMI exps.



< plan of cyclic airborne seeding >

< plan for the command center>

Thank you so much



< (left) small, (middle) large, and (right) cyclic airborne seeding after 2024 >