Cloud Seeding: Weather Modification Technology

□ Definition

 Cloud seeding is a weather modification technique that artificially induces rainfall by dispersing certain chemical substances into clouds to encourage condensation of water vapour into raindrops.

Scientific Principle

- Works on the principle that water vapour condenses onto particles called Cloud Condensation Nuclei (CCN).
- The seeding agents act as **nuclei** around which moisture condenses to form droplets, eventually leading to precipitation.

□ Common Seeding Agents

- 1. Silver iodide (AgI)
- 2. Potassium iodide (KI)
- 3. Dry ice (solid CO₂)
- 4. Liquid propane
- 5. Calcium chloride (CaCl₂) used in some Indian experiments (e.g., Solapur).

Conditions Required for Effective Cloud Seeding

- 1. **Pre-existing Clouds:** Seeding cannot create clouds it only enhances rainfall from existing ones.
- 2. **Tall, Moist Clouds:** More vertical development increases seeding effectiveness.
- 3. **Low Wind Conditions:** Prevents dispersal of seeding material before it acts.
- 4. **Appropriate Humidity and Temperature:** Ensures condensation and droplet formation.

Different Cloud Seeding Methods

Type 1. Hygroscopic Cloud Seeding	Technique Salts like NaCl or CaCl ₂ are sprayed using explosives into the lower portions of warm clouds.	Key Feature Promotes condensation by providing large nucle	Example/Use Used in Solapur experiment, i.Maharashtra.
2. Static Cloud Seeding	Chemicals like silver iodide crystals are dispersed into cold clouds.	Induces ice crystal formation that grows and falls as rain/snow	
3. Dynamic Cloud Seeding	Aims to strengthen vertical air currents to enhance moisture uplift.	Leads to formation of omore droplets → more rainfall.	Used in large-scale e experiments in the USA, China.

□ Applications of Cloud Seeding

1. Increasing Rainfall

- Used in **drought-prone regions** to augment natural rainfall.
- Supports agriculture and water security.

2. Geoengineering & Climate Research

 Studied as a climate engineering tool to counter regional droughts or mitigate local warming.

3. Weather Regulation

• Suppresses hail, disperses fog, and can modify cyclone intensity.

4. Pollution Control

 Artificial rain helps wash out pollutants and reduce particulate matter (PM2.5 & PM10) concentrations in the air.

5. Aviation Applications

 Used to disperse supercooled fog near airports to improve visibility and ensure flight safety.

△ Limitations of Cloud Seeding

- 1. Not a Drought Solution: Can only supplement, not replace, long-term water resource management.
- 2. **Cloud Dependency:** Cannot work without moisture-bearing clouds.
- 3. **Environmental Concerns:** Silver iodide and other chemicals may contaminate water and soil.
- 4. **Weather Imbalance:** Excessive rainfall in unintended areas may cause **flash floods or soil erosion**.
- 5. **[Health Impact:** Toxic compounds (like AgI) can harm ecosystems and human health.
- 6. **Potential Climate Effects:** Some agents may contribute to **greenhouse gas** accumulation.

□□ Cloud Seeding Experiments in India

- Karnataka: Seeding done under "Varshadhare Project" for drought relief.
- Maharashtra: Solapur experiment using hygroscopic seeding (CaCl₂ flares).
- Tamil Nadu & Andhra Pradesh: Experiments during weak monsoon years.
- **Delhi (Proposed):** To mitigate **severe winter air pollution** through artificial rainfall.

□ Delhi Air Pollution: A Context for Cloud Seeding

□ Current Status

- Delhi experiences hazardous air quality every winter.
- In early **2025**, it was ranked **India's 2nd most polluted city** (Centre for Research on Energy and Clean Air CREA).

□ Major Causes of Delhi's Air Pollution

1. **||Vehicle Emissions**

- Accounts for ~40% of winter PM2.5 levels.
- High diesel vehicle usage worsens emissions.

2. **Industrial Emissions**

 NCR industries emit SO₂, NOx, and PM2.5, particularly from power plants and manufacturing units.

3. ||Construction and Demolition Dust

 Major source of **PM10**; poor dust control mechanisms increase coarse particulate matter.

4. **□** Waste Burning

Open burning of garbage and plastic adds toxic pollutants.

5. **□Stubble Burning**

 Crop residue fires in Punjab, Haryana, and Western UP elevate pollution levels each autumn.

6. **Weather Inversion (Winter Inversions)**

- A layer of warm air traps cooler air near the ground.
- Pollutants remain suspended close to the surface, worsening smog conditions.

□□Why Cloud Seeding is Considered in Delhi

- To **artificially induce rain** and **wash pollutants** (especially PM2.5 and PM10) from the atmosphere.
- Acts as an emergency short-term measure to improve air quality during severe pollution episodes.
- Previous attempts (2018, 2023 proposals) faced technical and meteorological limitations due to **lack of suitable cloud conditions**.

□Significance for UPSC

□ Prelims Relevance

- Concept of weather modification and cloud seeding agents.
- Basics of particulate matter and air inversion phenomena.

□[Mains Relevance (GS Paper 3)

• **Environment & Pollution:** Innovative technologies for pollution control.

- Disaster Management: Addressing drought and extreme weather.
- Science & Tech: Application of atmospheric sciences.

□□Way Forward

- 1. **Scientific Validation:** Need long-term, evidence-based studies on effectiveness.
- 2. **Environmental Safety:** Use eco-friendly seeding agents.
- 3. Integrated Approach: Combine with emission reduction policies and green energy adoption.
- 4. Weather Forecasting Infrastructure: Improve cloud monitoring through Doppler radars and satellite data.
- 5. **Public Awareness:** Clarify that cloud seeding is a **temporary supplement**, not a permanent solution.

□ In Summary

Cloud seeding is a scientifically innovative but limited tool for rainfall enhancement and pollution mitigation.

While it holds potential for **short-term relief**, sustainable pollution control in Delhi requires **structural reforms** in transport, energy, agriculture, and waste management.

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