Climate-resilient hydropower operations in the Himalayas

Cloud seeding as a tool to manage wintertime precipitation variability

Rainmaker Technology Corporation

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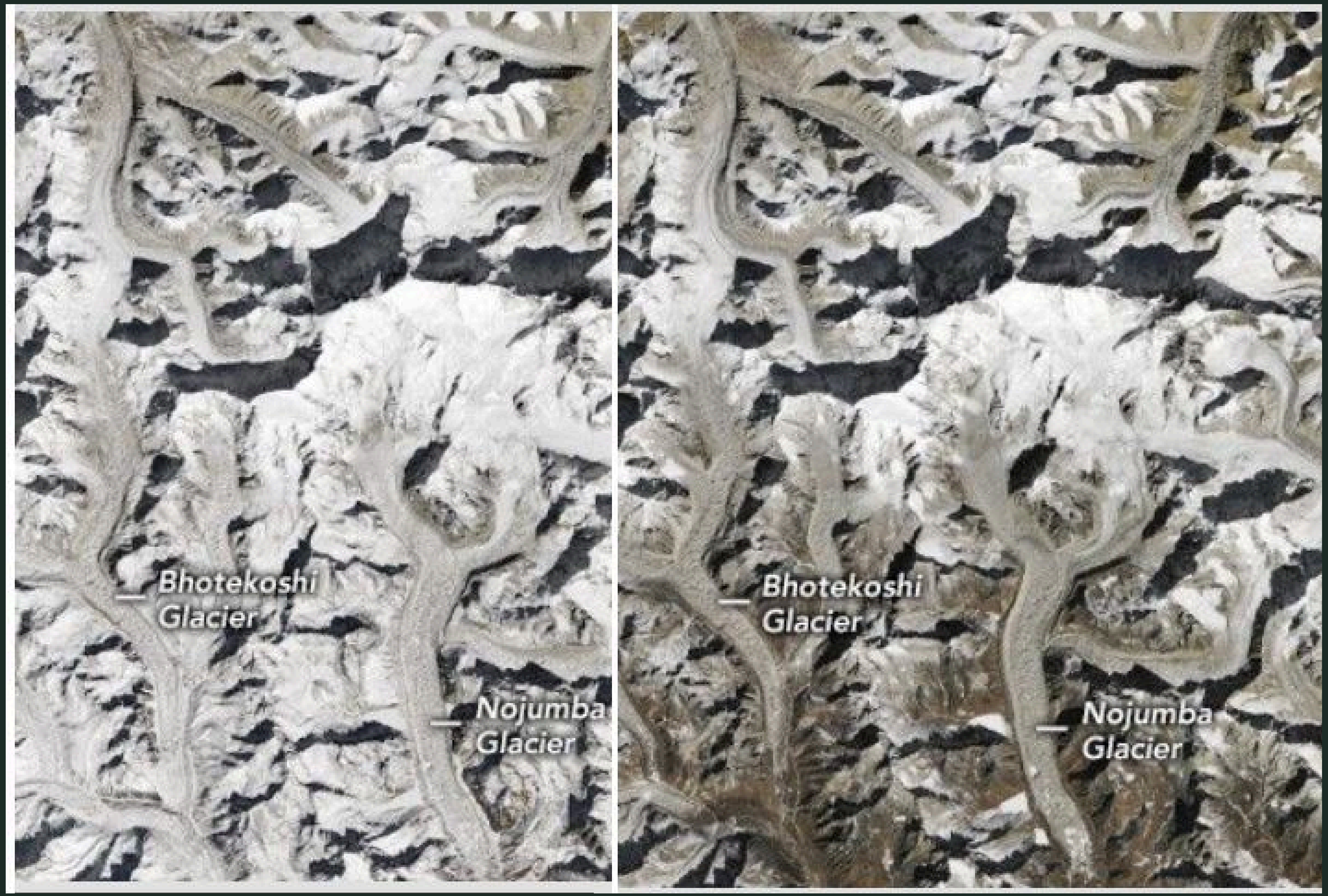
RAINMAKER

Himalayan snowfall is becoming more variable and less persistent

Snowfall in Himalayan regions is reducing in magnitude and persistence, while increasing in variability.



Reducing magnitude

- Snow cover days and area declining by ~1% annually for the past 20 years across HKH region
- >50% further decline projected across Brahmaputra, Ganga, and Indus basins

Reducing persistence

- 4 of last 5 winters have seen below-normal persistence
- 2026-2026 persistence in Indus, Ganges, and Brahmaputra basins at 20-27% below normal

Increasing variability

- >30% swings in snow cover at mid elevations
- Snow droughts hitting every 5 years vs 10 years pre-2000

Hydropower must adapt to changing precipitation regimes

With ~25% of streamflow from snowmelt, changing snowfall partterns pose direct risks to seasonal generation.

Earlier & Weaker Snowmelt Peak

- Peak inflows shift to earlier in the season
- Lower late-spring / early-summer contribution

Reduced Seasonal Water Storage

- Less precipitation stored as snowpack
- More winter runoff, less summer availability

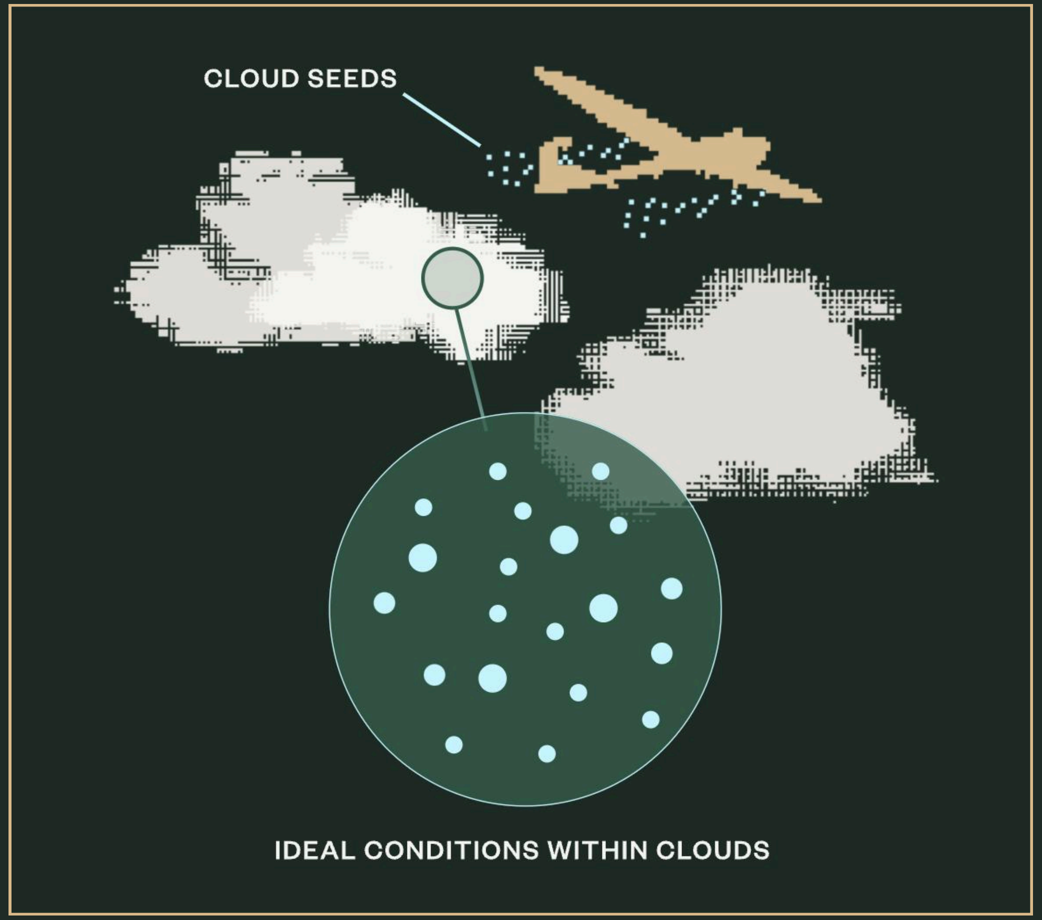
Reduced Baseflow & Groundwater Recharge

- Less sustained meltwater to support dry season flows
- Reduced groundwater recharge and baseflow

For hydropower operators, these shifts translate directly into lower firm energy, tighter operating margins, and higher system risk — unless actively managed.

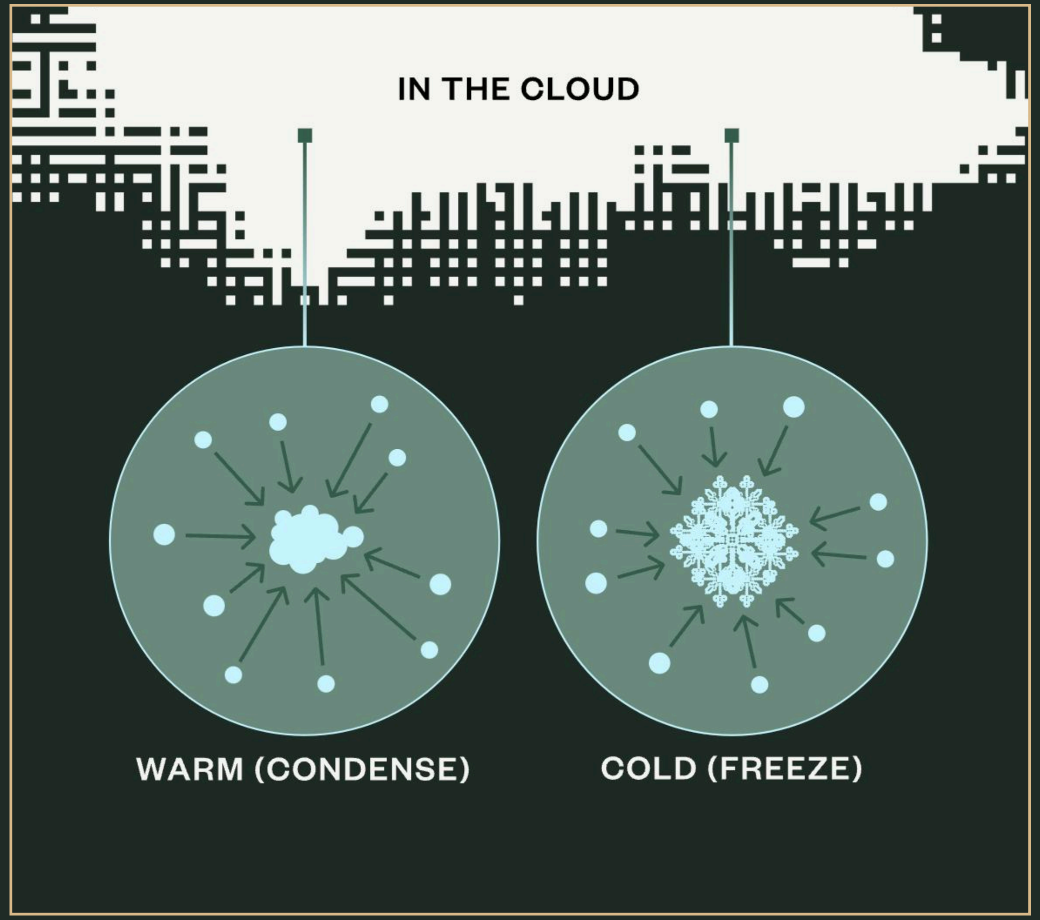
Cloud seeding as a tool in the adaptation toolbox

Cloud seeding mimics **natural precipitation processes** in **existing suitable clouds** to **increase precipitation downwind** by stimulating ice crystal growth and formation.



01 Deliver

Seeding particles are delivered into clouds with the ideal conditions for droplet or ice crystal growth.

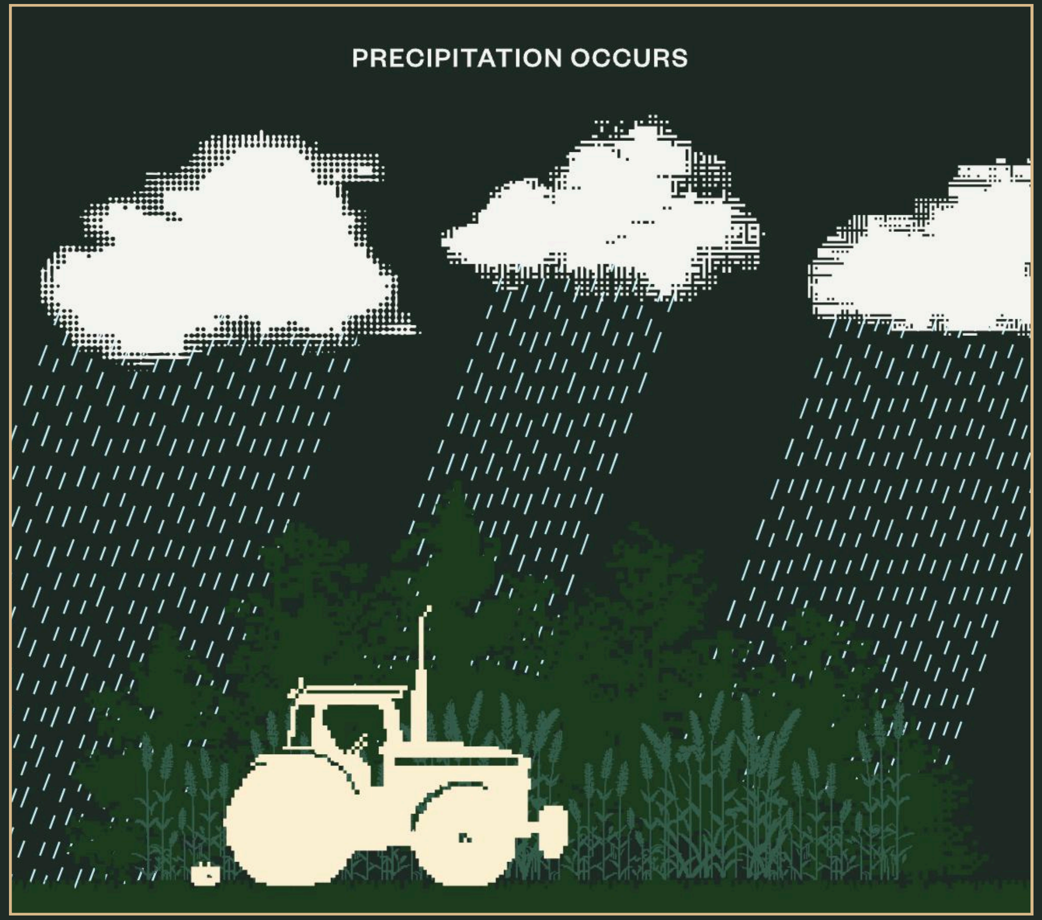


02 Attraction

Small water droplets in clouds are attracted to the seeding particles and condense or freeze onto them.

03 Accretion

The resulting water droplets or ice crystals grow at the expense of surrounding droplets.



04 Precipitation

Once the water droplets or ice crystals grow large enough, they fall as precipitation—rain or snow.

Is it safe and effective? How do we know?

Increases of over 20%

of total annual precipitation

According to the World Meteorological Organization, cloud seeding can deliver hundreds of thousands of cubic meters of water per seeding mission.

05 orders of magnitude

Below levels of environmental safety

Chemical concentrations following multi-year seeding fall 5 orders of magnitude below international safety standards for human and environmental health.

80 Years

of Extensive Field Research

The science and safety of cloud seeding has been extensively validated by research in over 50 countries across nearly 80 years.

Then why isn't it used more widely and frequently?

Complex measurement and validation of outcomes

The complexity and natural variability of cloud make it difficult to precisely measure yields and attribute precipitation outcomes to cloud seeding operations.

Ineffective, imprecise, and expensive hardware

Piloted aircraft are expensive, slow, and dangerous, requiring pilots on season-long standby at nearby airport infrastructure. Pyrotechnic flares introduce heat the impairs efficacy.

Outdated and inadequate software and sensing

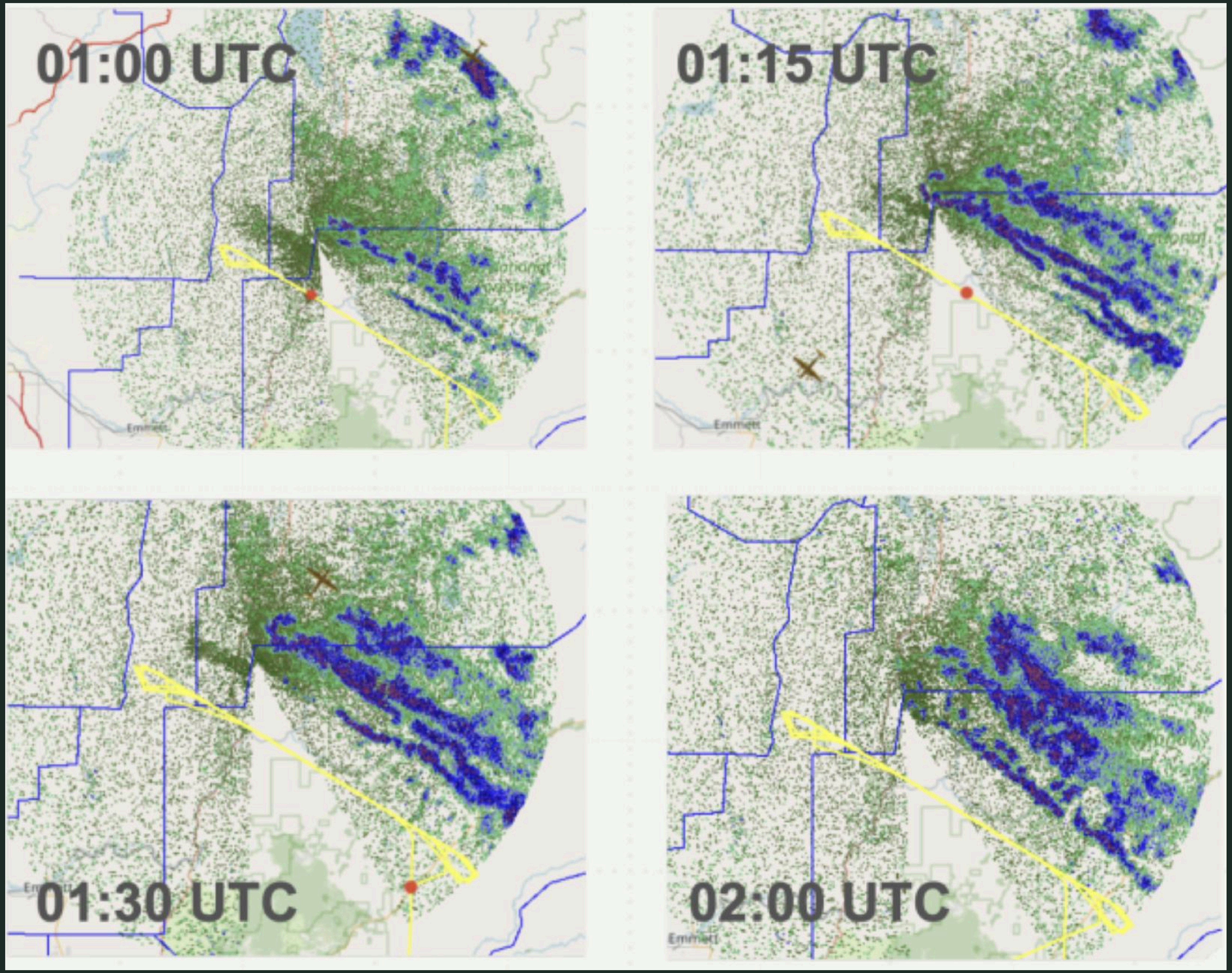
Limited integration of advanced weather data to forecast optimal conditions and cloud targets, and limited used of onboard sensors for precise targeting and measurement.

Radar validation turns cloud seeding into a scalable technique

The Breakthrough: Quantifiable Impact

Landmark studies in the United States and Switzerland proved that anthropogenic rainfall **can be detected and quantified** using advances in dual-polarization radar and signal processing.

Unambiguous “seeding signatures” were detected across 3 flights that produced **704 ML** of precipitation.



Why Now?

Rainmaker builds on this foundation by leveraging innovations in multiple advanced technologies:

- AI-enabled atmospheric modeling
- High-altitude, weather resistant UAVs
- Dual-polarization Doppler radar systems

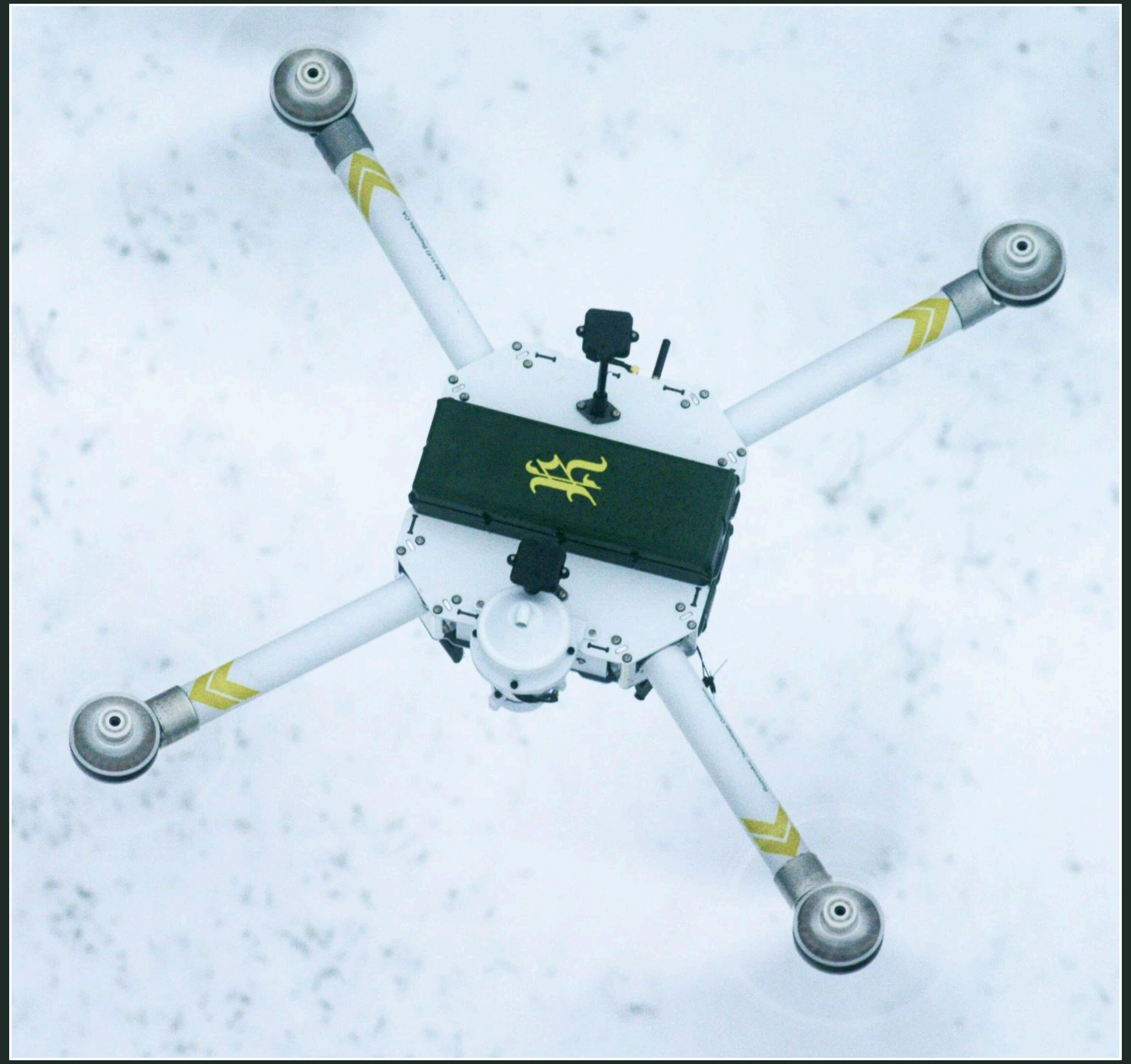
Rainmaker's core technologies for cloud seeding

01 Predict

Numerical Weather Modeling & Forecasting

Our integrated mission control platform provides full awareness of atmospheric conditions and seeding outcomes.

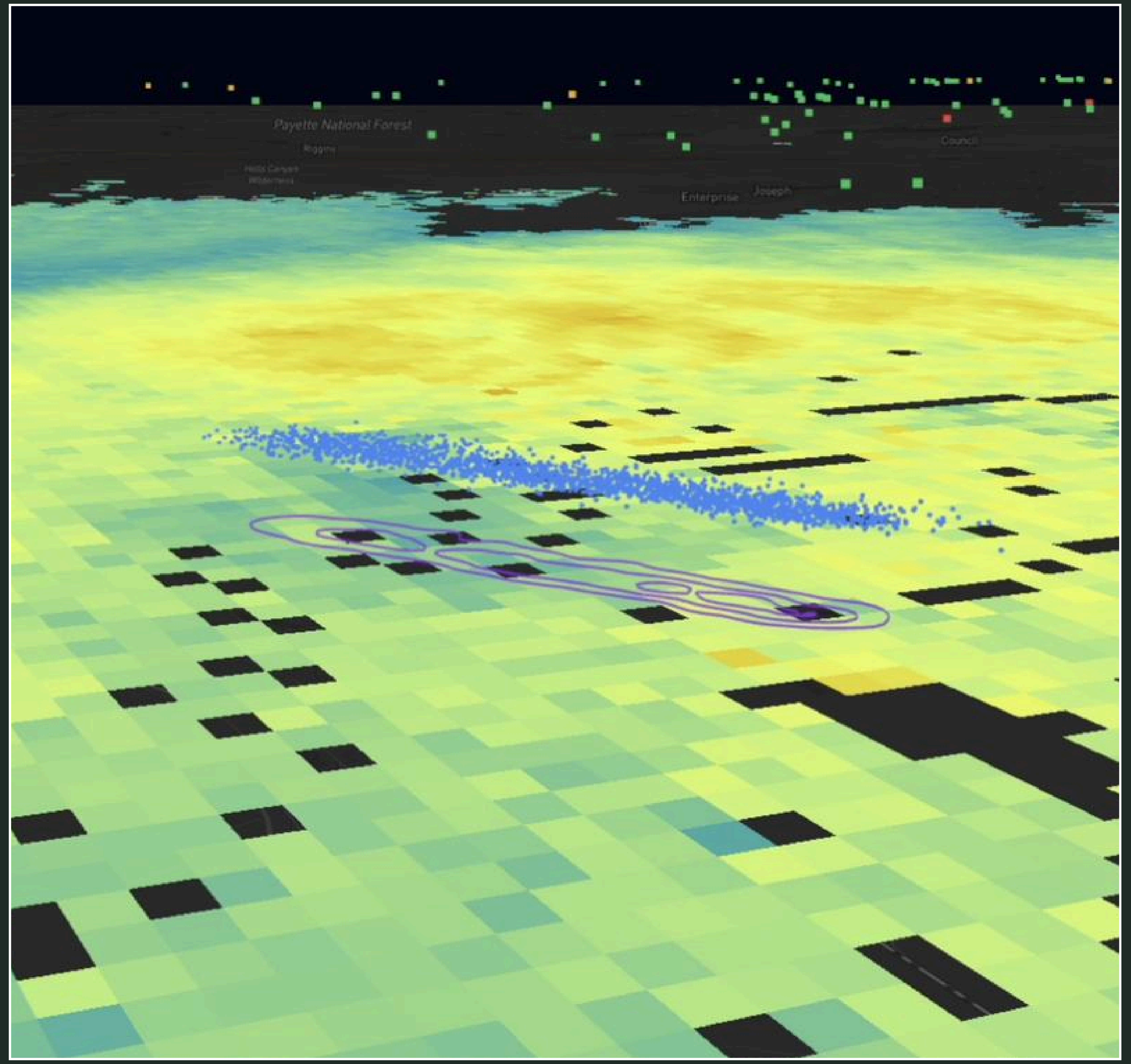
02 Target



Weather-Resistant, High-Altitude UAVs

Our drones are rapidly deployable, affordable, and safe. On-board instrumentation provides insight into cloud microphysics in real time.

03 Validate



Advanced Radar Sensing & Validation

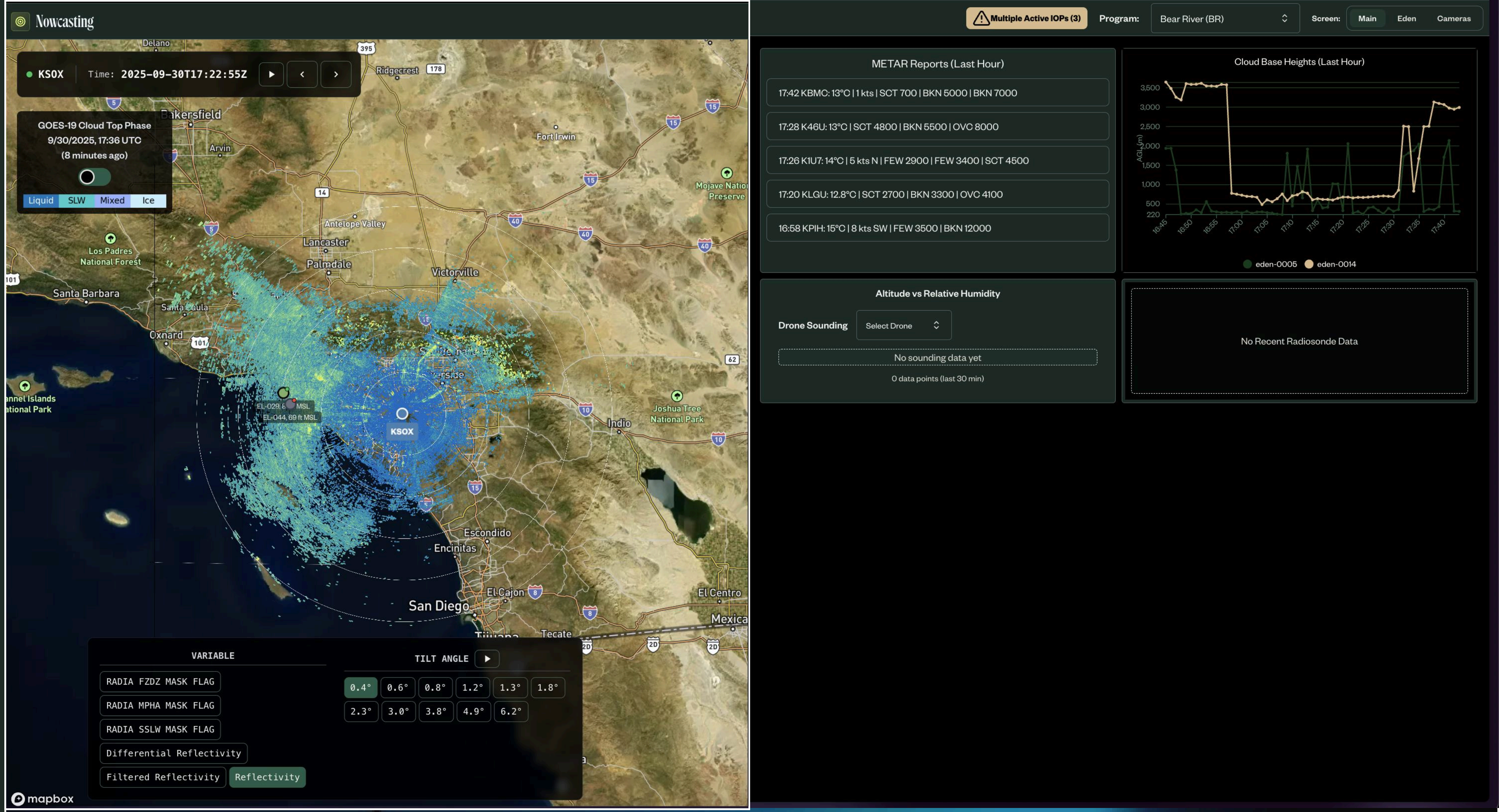
Detection of dynamic phase changes in clouds unlocks validation —and allows us to quantify the total volume of seeded precipitation.

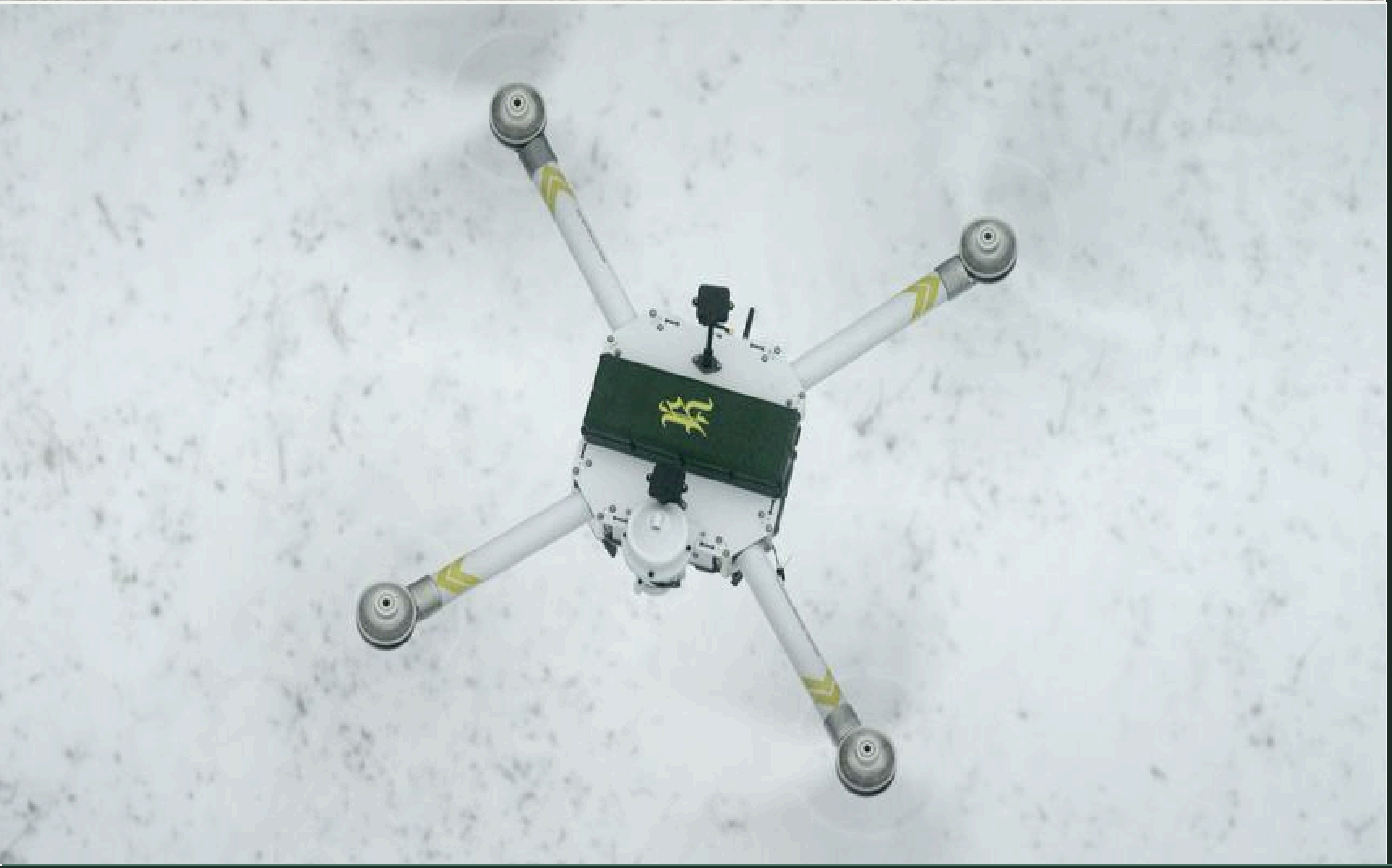
Numerical Weather Modeling & AI-Enabled Forecasting

Flexible Continuous and low-cost monitoring of cloud conditions.

Real-Time Integrates a variety of dynamic and localized sources of weather data.

Accurate High accuracy forecasts of optimal conditions for seeding operations.





High Altitude, Weather-Resistant UAVs

Robust	Rapidly deployable in hard-to-reach terrain without the need for airport infrastructure.
Safe	Optimized for flying in any condition without risking pilot lives (e.g., mountainous terrains).
Low-Cost	Significantly lower capital and operational costs than legacy manned aircraft.
Rigorous	Capable of in-cloud measurements via onboard sensors to validate outcomes.
Precise	More nimble and adaptable flight patterns for cloud targeting in icing conditions.

Real-Time, Ground-Truth Weather Sensing

A deployable atmospheric lab built for real-time, remote targeting and validation.

All-in-One Sensing

Integrated K-band radar, laser ceilometer, and weather sensor unit in a rapid deployable unit.

Sensor Capabilities

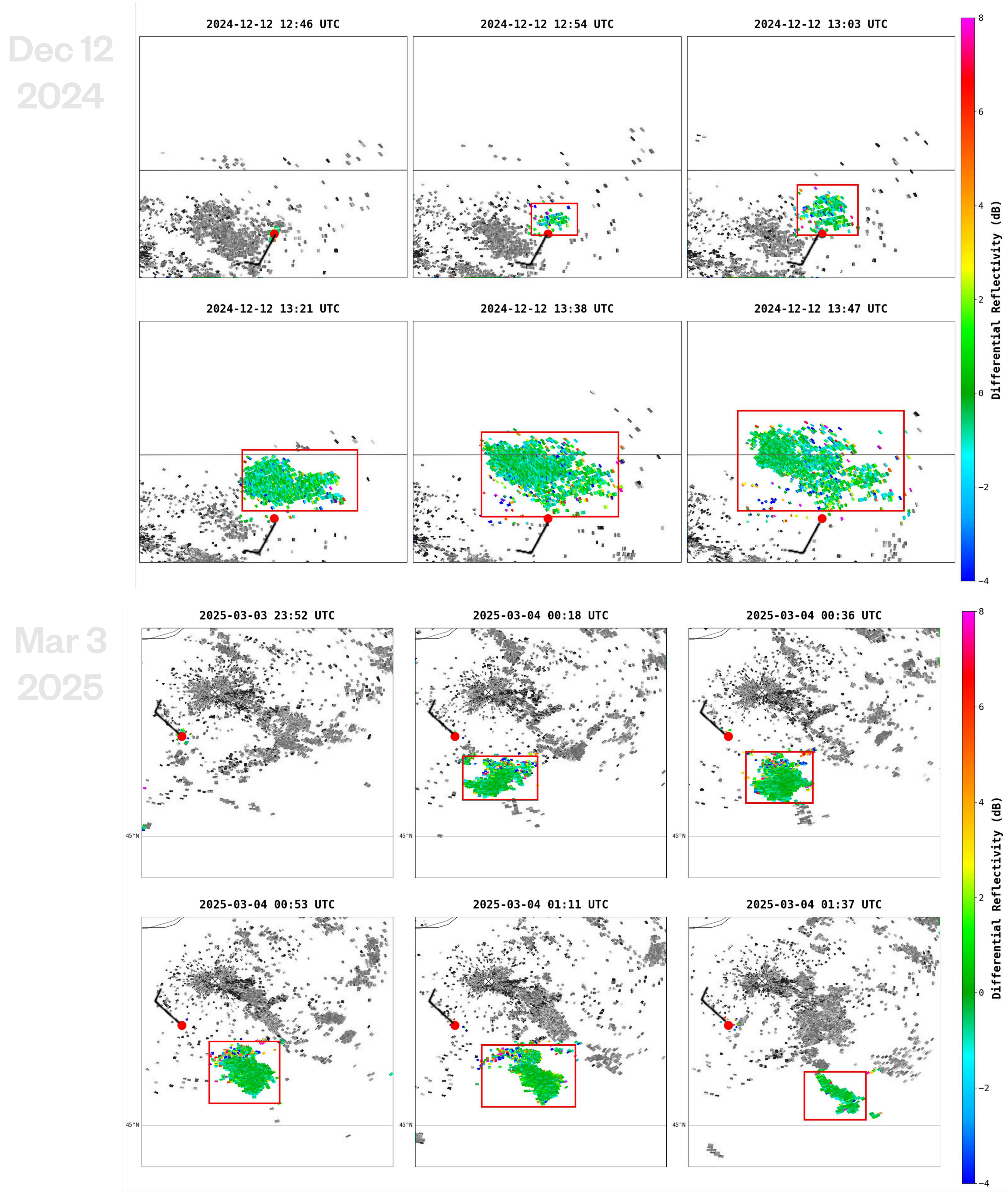
- Precipitation
- Pressure
- Temperature
- Humidity
- Wind Speed
- Wind Direction
- Air Quality

Advanced Validation

Integrate Deployable weather stations ingest live data from atmospheric instruments.

Target Dynamic tracking of weather and water phase changes during missions.

Validate High fidelity measurements of precipitation yields from operations.



Rainmaker is the world's highest-precision, lowest-cost cloud seeding service

There are approximately one dozen government-run (China, Indonesia, Malaysia, Russia, Saudi Arabia, Thailand, UAE) or privately-run (IAA, Mettech, WMI Inc.) cloud seeding programs worldwide, all relying on less effective, higher cost cloud seeding technology.

	Ground-Based Seeding (Mettech, WMI Inc., China, Russia, UAE)	Manned Aircraft Seeding (WMI Inc., China, India, Indonesia, Saudi Arabia, Thailand, UAE)	UAV-Based Seeding (Rainmaker, China)	Rainmaker's Advantage
Capital Expenditure	₹42 lakh per unit	₹33 crore - ₹65.5 crore per unit	₹16.2 lakh per unit	**2x - 200x Lower Capex**
Operational Expenditure	₹3,300 per hour	₹20,600 per hour	₹3 per hour	**983x - 6130x Lower Opex**
Operational Precision	Seconds: Low targeting precision	Seconds: Low targeting precision	Minutes: Precise in-cloud idling	**10x More time in cloud**
Operational Flexibility	Tens of minutes: Requires mountains	Hours: Requires pilots, airstrips	Minutes: Directly dispatchable	**10x - 20x Faster Deployment**
Weather-Resistance	N/A	15-30 minutes in icing conditions	30-45 minutes in icing conditions	**1x - 3x Higher weatherization**
Validation & Measurement	Low feasibility	Medium feasibility	High feasibility	**Higher validation and measurement**
Training & Safety	N/A	High training costs High aviation safety risk	Minimal training No aviation safety risk	**Lower training and lower risk**

We manage the largest and longest running cloud seeding program in the United States.

Delivering Scalable Water Security

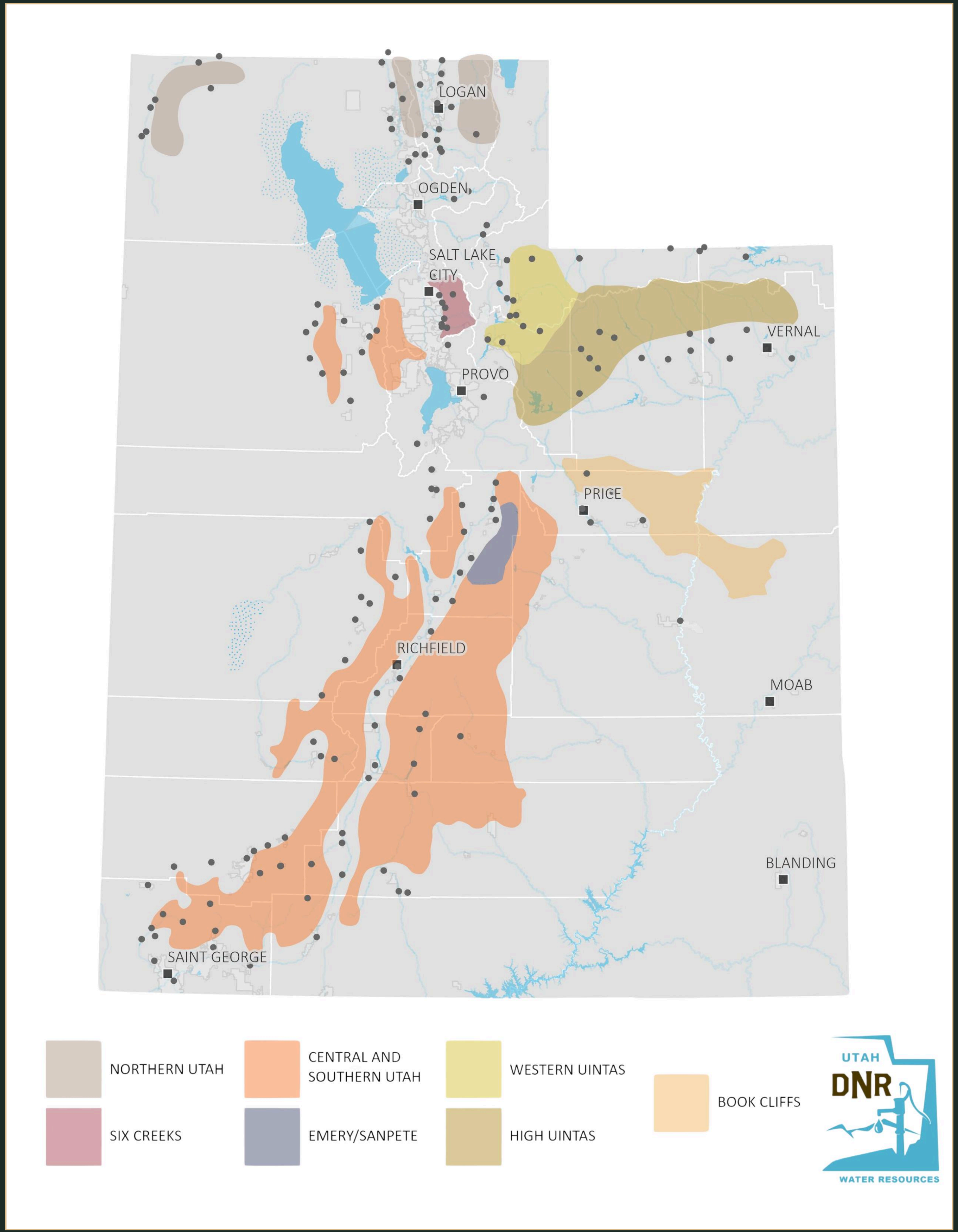
According to the Utah Department of Natural Resources, Rainmaker's seeding yields approximately **230 million cubic meters of additional water annually**.

The represents **2.4% of Utah's total annual water** consumption for a $300B economy and population of 3.5 million people.

Delivering Affordable Water Security

At a cost of approximately **0.01 USD per cubic meter**, cloud seeding delivers over **$24 in value for every $1** invested.

As we deploy next-generation technology, we expect the yields to increase and costs to decrease considerably.



Cloud seeding as an operational hedge against inflow uncertainty

By increasing winter precipitation, cloud seeding enhances snowpack, improves meltwater, and increases generation reliability.

1

More winter precipitation

Cloud seeding increases cold-season rainfall and snowfall in targeted catchments.

2

Snowpack accumulation

More snow stored naturally at high elevation throughout the winter.

3

Improved meltwater inflow

Higher and more reliable runoff supports reservoir refill, inflow timing.

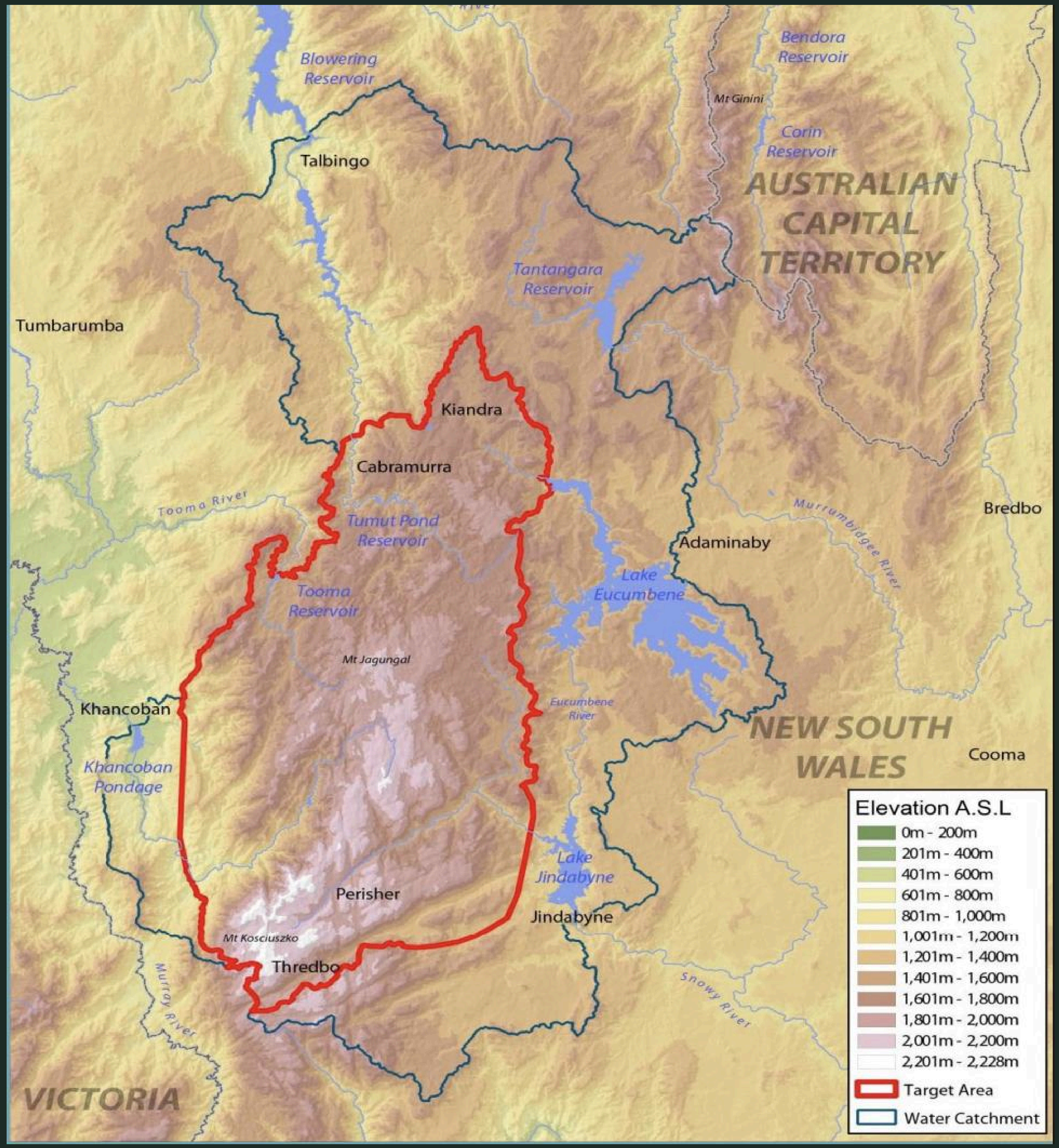
4

Improved reliability

More predictable and resilient generation and firm energy.

Example use case: SNOWY Hydro (Australia)

2004–2023 operational program | Snowy Mountains, NSW | Ground-based silver iodide seeding



What they did

Objective
- Offset declining snowpack → increase winter runoff for hydropower + irrigation supply

How it worked
- 23 ground generators (no aircraft)
- Target area: ~2,110 km²
- Seasonal window: May–Oct
- Only seeded when snow likely ≥ 1,400 m (risk control)

Seeding agent
- Silver iodide (AgI) as ice nucleant
- Remote-controlled operations from Cooma Control Centre

What it achieved

+14% precipitation
- Under suitable storm conditions (statistically robust in key subset)

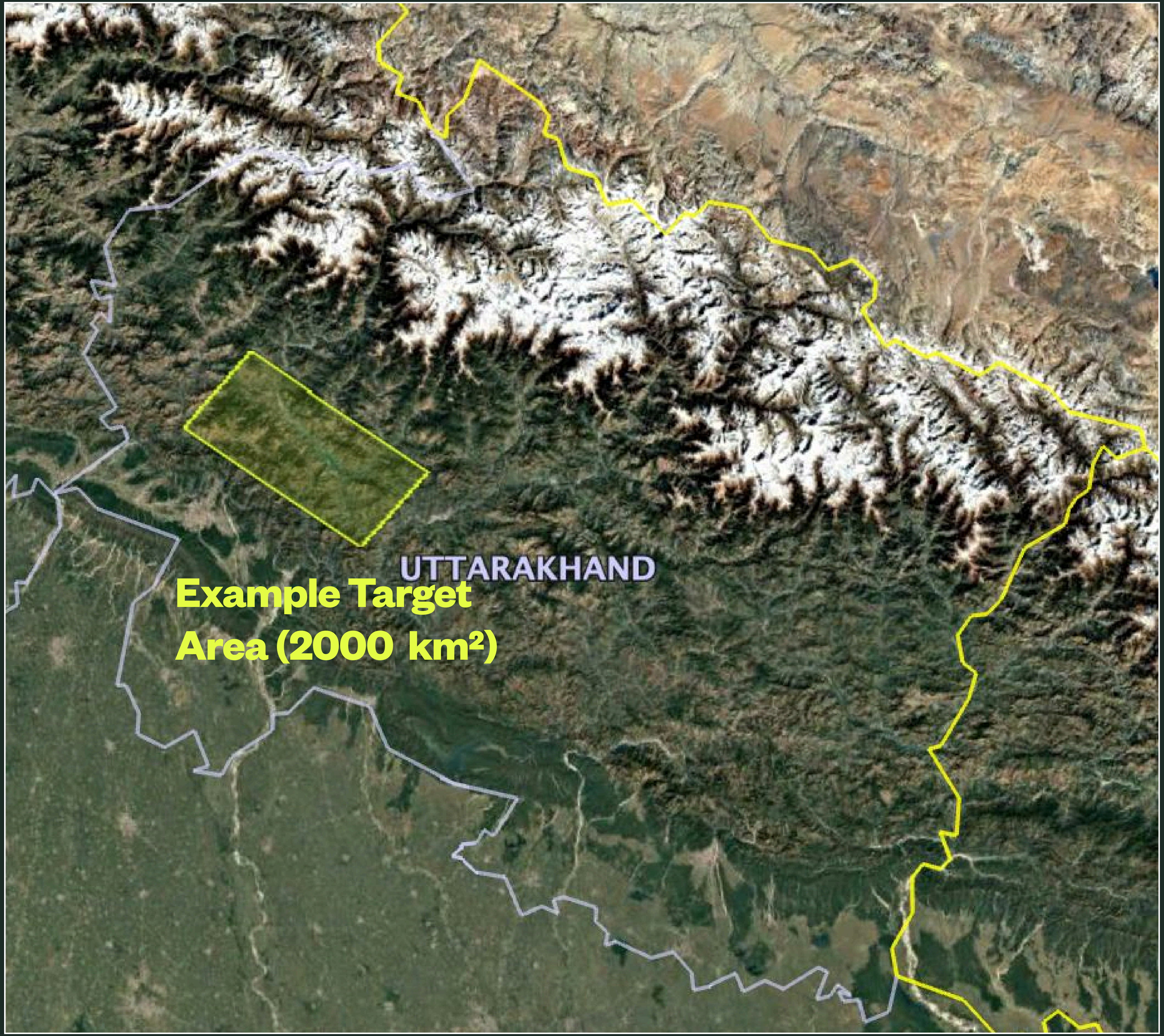
Validated targeting
- Seeded snow showed **~300% higher AgI concentration** vs unseeded snow

No downwind penalty detected
- No measurable reduction to lee-side regions (important for social license)

Cloud seeding can increase snow-derived hydropower inflows - and modern drones + radar validation can drive economic value + make verification easier

Himalayan states present the ideal initial testing grounds in India

Focus on seedable winter / spring systems upstream of priority dams and river basins with most suitable conditions, highest ROI



Climatological Conditions

- Frequent presence of supercooled liquid water (SLW)
  - Relative humidity > 85%
  - Cloud temperatures of 0° C to -10°C
  - Wind speeds below 35 m/s
  - Freezing levels below 6 km above ground level
- Prevailing winds that traverse mountains
- Updrafts that enhance circulation and precipitation

Infrastructure and Logistics

- Hydrology enables snowpack storage and runoff
- High value creation and capture (e.g., major rivers, reservoirs, hydropower plants, etc.)
- Nearby radar coverage and weather stations

Safety Considerations

- Low population density

Example pilot scoped to demonstrate feasibility, cost, and scalability

A dual-season cloud seeding pilot aimed at **enhancing wintertime precipitation into major hydro river basins**

Objective

Demonstrate measurable, validated wintertime precipitation enhancement using Rainmaker technology

- Quantify precipitation increase with causal physical chain
- Benchmark cost per m^3 vs other water infrastructure projects
- Link increased precipitation to winter + spring generation

Geography

1,500 - 3,000 km^2 catchment area at key feeding zones for major hydropower river basins :

- Orographic cloud systems driving winter precipitation
- Catchments that translate precipitation into inflows

Execution

Rainmaker: Meteorological analysis, FDE recruitment, training, test flights, operational implementation, and monitoring, reporting, and verification

Partner: Watershed selection

Timeline

Q1: Meteorological analysis, site selection
Q2: CONOPS, recruitment, training
Q3: Import, clearance, licensure, test flights
Q4: Start of full time operations for ‘26-’27 season

Call to action

Interested operators are invited to co-design a monitored winter cloud seeding pilot for hydropower resilience (2026–27).

Next steps

1. Identify priority snow-fed basins
2. Conduct rapid feasibility assessment (2–3 weeks)
3. Co-design a monitored pilot + evaluation framework for 2026–27

What we need from partners

1. Snow-fed basin or project of interest
2. Access to historical data (where feasible)
3. Operational priorities (firm energy, refill timing, drought resilience)

Contact

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