

**Method for inducing precipitation by cloud seeding
with meteorological data sensing and an UAV therefor**

5 TECHNICAL FIELD

[001] This invention relates to a method for inducing precipitation by cloud seeding. The method includes gathering meteorological data, analyzing the data for suitability or possibility of inducing precipitation by cloud seeding and,
10 actuating cloud seeding means by discharging condensation nuclei (also known as glaciogenic seeding) or agents thereof into cloud formation.

BACKGROUND ART

15 [002] Since the first successful cloud seeding in 1946, the practice of inducing water precipitation (whether in the form of rain, hail, snow or sleet) has been carried out with manned aircraft. The aircraft may include meteorological data gathering devices such as sensors for detecting or measuring atmospheric temperature, moisture or humidity and wind directions such as updrafts or
20 downdrafts. Cloud seeding agents are typically to induce freezing nucleation, i.e. inducing the formation of ice crystals as nuclei for water particles to condensate round each nuclei to form a larger water particle (whether in liquid droplet or solid snow flake) heavy enough to precipitate from the cloud formation. It is also known as glaciogenic seeding. Such agents include dry

ice (frozen CO₂) or substances which lattice constant is similar to ice, such as silver iodide (AgI) crystals.

[003] These crystals are dispersed into cloud formation which has been
5 identified as suitable for inducing precipitation, i.e. with high moisture content or humidity at supercooled temperatures (below freezing point or sub-zero degrees Celsius). The upward or downward wind draught directions would determine the level of dispersing the agent relative to the cloud formation. Typically, the silver iodide crystals are provided in the form of flares so that the
10 silver iodide particles may be dispersed with the combustion of the pyrotechnics.

[004] Such meteorological instruments-fitted planes are naturally expensive and with trained crew on board, the cost of deployment may run into over
15 USD30,000 per aircraft an hour just to gather information on the suitability of cloud conditions for inducing rain. A separate aircraft would then be deployed for the purpose of cloud seeding. This second aircraft is usually modified to carry combustible flares which would disperse the silver iodide, or to disperse dried ice, at the right altitude in the cloud formation. In the absence of adverse
20 updraft, they are usually dispersed over the top of the clouds so that these condensation nuclei agents may fall through the clouds to induce the water particles in the clouds to condensate and/or coalesce and precipitate. The total cost of gathering data and cloud seeding operation would therefore run in over a hundred thousand U.S. dollars.

[005] As weather conditions are dynamic and may change by the minute, the conditions found suitable for inducing precipitation by the meteorological aircraft in the earlier sortie might have changed by the time the second aircraft
5 carrying the cloud seeding flares is deployed and reaches the position to disperse the condensation nuclei agents.

[006] To reduce meteorological data gathering costs, radiosonde is sent into the atmosphere by hot air balloons, rockets (rocketsonde) or dropped from
10 passing aircraft as parachute through cloud formations (dropsonde). While these methods may reduce sortie costs, often the non-recovery of the radiosondes may still contribute significantly to the cost of meteorological data gathering. Thus, using unmanned aerial vehicle (UAV) that is radiosonde -
equipped has been practised to allow for greater control over the area of the
15 atmosphere to be measured, as well as for better manoeuvring to find a suitable cloud formation for cloud seeding.

[007] Still, the time lag between finding such a suitable cloud and sending a cloud-seeding aircraft to the location remains. As the complex wind and other
20 atmospheric conditions, the inducible patch of cloud formation could have moved in the meantime that a cloud seeding aircraft takes to reach. Moreover, as a single typical UAV sortie might cost in the region of USD6,000 to 10,000, this figure would be doubled even if the cloud-seeding aircraft deployed is also a UAV.

STATEMENT OF DISCLOSURE

[008] It is thus our endeavour to provide for a method of inducing
5 precipitation by cloud seeding which is more time and cost effective. This may
be achieved by providing a single or integral platform for both meteorological
data gathering and cloud seeding operation. With both the data gathering and
cloud seeding capabilities, a decision to perform cloud seeding could be made
right after the data gathered indicates suitable conditions for inducing
10 precipitation.

[009] To this end, we propose a UAV which is equipped with both
meteorological data gathering and cloud seeding means which is capable of
implementing a method according to our invention. With no lag time in
15 performing cloud seeding after a suitable patch of cloud formation has been
identified, the accuracy and chances of successful inducing precipitation would
also be considerably higher than conventional methods in addition to resources
savings.

20 [010] In a general embodiment of our invention, we propose a method for
inducing precipitation by cloud seeding comprising the steps of (a) gathering
meteorological data, including sensing for moisture, temperature, and wind
conditions at about cloud formations; (b) analyzing said meteorological data for
possibility of inducing precipitation by cloud seeding; and, upon reaching within

such possibility, (c) performing cloud seeding means; wherein at least said gathering for meteorological data and performing cloud seeding means are provided on at least an unmanned aerial vehicle (UAV).

5 [011] In one aspect of our invention, the meteorological data may be transmitted remotely to a ground control base which analyzes said data and which is also in remote control of said UAV flight. Alternatively, the analyzing of the meteorological data may be performed at the UAV according to preset parameters for actuating the performance of the cloud seeding means. For
10 wider coverage, multiple units of UAV may be deployed, wherein at least a leading UAV has meteorological data sensing means and at least a led UAV has cloud seeding means. The meteorological data collected from a cloud formation considered as possible for precipitation to be induced by cloud seeding includes any one or combination of (i) temperature in the range of -5°
15 to -25° C; (ii) high level of water, moisture or humidity exceeding 60%; and (iii) updraft exceeding 1 metre per second.

[012] In the second aspect of our invention, the UAV proposed to be used with our method is desirable to have meteorological data gathering means; at
20 least a means for transmitting said meteorological data to be analysed for possibility of successful cloud seeding; and cloud seeding means, including means for actuating said cloud seeding means. Preferably, the meteorological data gathering means include conventional radiosonde capable of sensing at least temperature, humidity and wind conditions. Preferably still, the

meteorological data gathered is transmitted to a ground control base. A transceiver may be included for transmitting the meteorological data to a ground control base and for receiving signals to actuate cloud seeding means. As a preferred embodiment, the cloud seeding means may include means for
5 dispersing condensation nuclei into the clouds, including supercooled moisture in cloud formations in the atmosphere.

[013] In the third aspect of our invention, a system for inducing precipitation by cloud seeding may be provided comprising a UAV aforescribed, a ground
10 control base in communication and/or control of said UAV; and a data link between said UAV and ground control base for at least receiving and analyzing meteorological data, and for actuating cloud seeding means.

[014] Details on our invention are further described in the following:

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DETAILED DESCRIPTION OF SPECIFIC EMBODIMENTS

[015] The UAV proposed in our present invention would be provided with at least meteorological data gathering means and cloud seeding means in order
20 to implement our method for inducing precipitation which, in the basic embodiment, would comprise the steps of gathering meteorological data, including sensing for moisture, temperature, and wind conditions at about cloud formations; analyzing said meteorological data for possibility of inducing precipitation by cloud seeding; and, upon reaching within such possibility,

performing cloud seeding means.

[016] The meteorological data gathered may be transmitted wirelessly to a remote ground control base which also controls the UAV at launch, in flight and return or recovery. The ground control base may analyse the data and decide if the particular cloud formation's conditions are ripe for inducing precipitation by cloud seeding. The meteorological data gathering means may be provided in the form of a radiosonde commercially available that is commonly used in meteorological hot air balloon, rocketsonde or dropsonde aforementioned in the Background Art. While these radiosonde are equipped with sensors to measure (i) temperature in sub-zero range (in line with the supercooled water particles in cloud formation), (ii) moisture content or humidity, (iii) wind direction, particularly updrafts and downdrafts, and (iv) pressure, the first 3 parameters are more important in the logic flow decision-making in determining if the conditions are suitable for inducing precipitation. Generally, however, if the temperature detected is in the range of -5° to -25° C, humidity exceeding 60% and an updraft exceeding 1 ms^{-1} , conditions are deemed ripe for a successful cloud seeding.

[017] In another embodiment, the UAV may be made more sophisticated by having microprocessors or programmable logic controllers (PLC) that have been pre-programmed with logic routines to actuate cloud seeding by igniting the silver iodide flares to begin dispersing the AgI crystals into the clouds upon reading the meteorological data to meet preset parameters. For example, the

logic flow of the microprocessor or PLC may be pre-programmed to ignite the flares and actuate cloud seeding operation upon the UAV detecting the following 3 conditions – (i) humidity exceeding 60% in which the water particles in the cloud formation has been (ii) supercooled to a range of -5° to -25° C, and
5 that (iii) an updraft is also detected at at least 1 metre per second (i.e. at least at about 200 ft/min).

[018] We might explain the reason for the need to have an updraft above as the UAV envisaged to be used are mostly of small to medium sized platforms,
10 in which the maximum altitude reachable by the UAV will be a limitation. It is known in the art that cloud seeding by dispersing condensation nuclei are carried out at either the top or bottom or base of the cloud formation, bearing in mind the altitude difference between the top and the base of a cloud formation could be substantial.

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[019] For cloud top seeding, a much higher altitude is required whereupon the silver iodide flares are ignited to spray the AgI crystals to fall through the cloud from the top by way of gravity. Preferably, however, the spray of AgI crystals is assisted with the presence a downdraft since the crystal particles are
20 too small to fall effectively through the cloud by gravity alone. For a relatively small aircraft such as a UAV, the advantage it has in that it could be launched from a relatively small clearance such as from the roof top of a tall building, rather than requiring an airfield, is diminished somewhat by the proportionate lower power of drive or engine that its small chassis is capable of carrying.

Accordingly, for a UAV available in the market presently, the highest altitude that it can practically reach is the cloud base and hence part of our method would rely on the presence of an updraft, preferably exceeding 1 ms^{-1} , to assist
 5 in the dispersal of the AgI crystals upwardly into the cloud formation. It could be envisage that, in the future, when more powerful UAV becomes available, our cloud seeding method could be practised as top cloud seeding.

[020] Each UAV is expected to be able to carry about two 40 g silver iodide
 10 flares to be ignited and dispersed into the clouds. However, should more areas of the cloud formation is to be seeded, additional UAVs may be launched into the same area to tail the first UAV. These subsequent UAVs need not carry any radiosonde and may rely on the findings of the first UAV for a decision whether to perform cloud seeding.

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[021] A key component of our glaciogenic seeding method is the transmission of the meteorological data gathered to be analysed for suitability or possibility of successful induction of precipitation. The analysis may be performed on board the UAV by a microprocessor or programmable logic
 20 controller receiving the data transmitted short range from the radiosonde component, or transmitted wirelessly to a ground control base. In the latter configuration, a data link system comprising a transceiver may enable the data gathered by the UAV to be so transmitted and analysed, and upon a decision being made to perform cloud seeding, a signal may sent by the ground control

base to fire the silver iodide flares.

[022] For more advanced models of UAV, the PLC or microprocessor on board may be programmed to automatically manoeuvre towards positions in the cloud formation where the gradient of temperature is lowering, humidity rising or presence of updraft. Upon entering an area in the cloud formation having such conditions, the logic processing may then automatically fires the silver iodide flares. Alternatively, a person remotely controlling the flight of the UAV from the ground control base may manually guide the UAV to manoeuvre towards such favourable conditions in the cloud formation based on real-time meteorological data received. Yet another alternative is to pre-programmed the UAV to fly along waypoints predesignated by ground control base in search of a suitable location in a cloud formation. With the use of powerful antennas, the range of communications and control of the UAV with the data link system from the ground base station may be extended from the typical 50 km radius for conventional VHF radio range to 150 km.

[023] A skilled person in the art of cloud seeding would also be able to make adaptations to our invention to perform hygroscopic seeding (e.g. using salt to induce coalescence of water drops), nucleation with biological agents (such as using nuclei of lichens and fungi) and other cloud seeding methods apart from glaciogenic seeding. Even with glaciogenic seeding, expansive cooling method such as the use of liquid propane generator, may be adapted to be installed in a UAV to be used in our method. Such modifications, adaptations, alternative

parts and components and other precipitation induction means which may be adapted to be implemented in our method by a skilled person, are to be considered as falling within the letter and scope of our invention as defined in the following claims.

CLAIMS

What we claim are:

- 5 1. A method for inducing precipitation by cloud seeding comprising the steps of:
 - (a) gathering meteorological data, including sensing for moisture, temperature, and wind conditions at about cloud formations;
 - (b) analysing said meteorological data for possibility of inducing precipitation
10 by cloud seeding; and, upon reaching within such possibility,
 - (c) performing cloud seeding meanswherein at least said gathering for meteorological data and performing cloud seeding means are provided on at least an unmanned aerial vehicle (UAV).
- 15 2. A method for inducing precipitation according to Claim 1 wherein the meteorological data is transmitted remotely to a ground control base which analyses said data and which is also in remote control of said UAV flight.
- 20 3. A method for inducing precipitation according to Claim 1 wherein the analysing of the meteorological data is performed at the UAV according to preset parameters for actuating the performance of the cloud seeding means.

4. A method for inducing precipitation according to Claim 1 wherein multiple units of UAV are deployed.

5. A method for inducing precipitation according to Claim 4 comprising a plurality of UAV including at least a lead UAV having meteorological data sensing means and at least a led UAV having cloud seeding means.

6. A method for inducing precipitation according to Claim 1 wherein the meteorological data collected from about a cloud formation considered as possible for precipitation to be stimulated by cloud seeding includes any one or combination of

- temperature in the range of -5° to -25° C;
- high level of water, moisture or humidity exceeding 60%; and
- updraft exceeding 1 metre per second.

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7. An unmanned aerial vehicle (UAV) capable of flight to at least the height of the base of cloud formation, comprising:

- meteorological data gathering means;
- at least a means for transmitting said meteorological data to be analysed for possibility of successful cloud seeding; and
- cloud seeding means, including means for actuating said cloud seeding means.

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8. A UAV according to Claim 7 wherein the meteorological data gathering means include conventional radiosonde capable of sensing at least temperature, humidity and wind conditions.

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9. A UAV according to Claim 7 wherein the meteorological data gathered is transmitted to a ground control base.

10. A UAV according to Claim 7 including a transceiver for transmitting the meteorological data to a ground control base and for receiving signals to actuate cloud seeding means.

11. A UAV according to Claim 7 wherein the cloud seeding means include means for dispersing condensation nuclei into the clouds, including supercooled moisture in cloud formations in the atmosphere.

12. A system for inducing precipitation by cloud seeding comprising

- a UAV according to any one of Claims 7 – 11;
- a ground control base in communication and/or control of said UAV; and
- a data link between said UAV and ground control base for at least receiving and analyzing meteorological data, and for actuating cloud seeding means.