Laser-induced Mist and Particle Formation from Ambient Air: A Possible New Cloud Seeding Method

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A new method of water condensation is reported. A UV laser induces seed formation from the air itself for water mist or ice particles depending on the temperature of the ambient air. The possible mechanism of this new phenomenon is proposed with photochemical radical formation and following reactions. This may offer the new prospect of a simple and environmentally harmless way to create artificial rain and snow.

Laser-assisted aerosol and liquid formation of metal particles and organic substances have been reported since mid 1970s.[1–4] The nucleation of water in the atmosphere is a particularly important issue for weather modification and has a long history of research. In 1947 microscopic crystals of silver iodide (AgI) was found to nucleate water vapour to ice at low temperatures.[5] It has almost exactly the same atomic distance of Ag–I and O–O and so can serve as a nucleus for the growth of ice.[5] Other than this hygroscopic materials like NaCl and cooling material like dry ice were used as cloud seeding substances.[6] Since the original proposal numerous attempts were made with the same principle of adding different kinds of chemicals as seeding materials. Currently attempts to create artificial rain are made (with greater or lesser success) all over the world, primarily for agricultural purposes and human life in general.

Environmentally, it would be ideal to produce seeds from the air without adding any foreign materials to it. Here, we report a new method of UV laser-induced seed formation from the air itself, for water-droplets or ice particles, depending on the temperature of the ambient air. This may offer the new prospect of a simple and environmentally harmless way to create artificial rain and snow.

In order to simulate atmospheric conditions, a quartz vessel (a tube) of 150 mm in diameter and 150 mm in height was made and filled with ambient air. On the bottom of this vessel a water pan is placed and on the top a pan filled with cooling materials. The top and bottom correspond to the cold sky and ocean, respectively. The temperature of water is at 18–24 °C. The top cover is a flat metal pan containing either ice/water or dry ice/ethanol. The measured temperature at the surface of the top pan facing the vessel is 0–3 °C for ice/water and −63 °C for dry ice/ethanol. For a reference experiment a pure air from a cylinder (Sogo Gas Co.) by bubbling through pure water (Wako/Dojin, deionized, filtered water) was used and we observed the same phenomenon. An ArF laser light (193 nm, Lambda Physik COMPex 102) is introduced without focusing to the vessel through a quartz window which is transparent at 193 nm. The reaction vessel is located about 40 cm after the exit of the laser. The output energy is 150–250 mJ/pulse with a pulse width of 10 ns and a beam size of $24 \times 10\ \mathrm{mm}^2$. The center of the laser beam is at 30 mm from the bottom of the top pan. Mist or fine particles are formed by laser irradiation and the Mie scattering of mist/particles can be readily observed visually with a torch. For a better record, we use an Ar ion laser (488 nm) which is stretched to 2D by a pair of a cylindrical and convex lens. The beam hight is ca. 50 mm and is directed at the center of the ArF laser beam. The dynamics of mist or particle formation are recorded by a digital camera (Panasonic DMC-FZ5) in movie mode.

When the top pan contains ice/water, a light scattering due to mist formation starts to appear soon after laser excitation, at various spots on the bottom of the top pan. It moves down by convection flow and disappears quickly. This phenomenon repeats and continues for more than 10 min. Figures 1a–1c show light scattering observed at 12, 30, and 45 s after the first laser pulse, operated at 5 Hz for 10 s (50 shots). The temperature of the water at the bottom pan was 24 °C. Similar phenomena occur many times between the times shown in Figures 1a–1c. Upon laser excitation, an invisible species seem to be produced and by convection flow move to the cold top pan and form mist.

When the temperature on the top pan is lowered by dry ice/ethanol, a strong scattering of numerous particles appears. Figures 2a–2c show light scattering at 4, 10, and 35 s after the first laser pulse, in operation at 10 Hz for 5 s (50 shots). The figures indicate that the scattering occurs everywhere during the laser excitation and increases even after the excitation has been terminated. The particles move vigorously by convection flow and often form a whirlpool. Figures 3a and 3b show details of the scattering pattern, when the top pan is filled with ice/water and dry ice/ethanol, respectively. Figure 3b shows scattering of many fine particles and moving traces, and is quite different from the homogeneous pattern of Figure 3a. Ice particles can be produced by this method.

At the present stage one can think of several possible mechanisms including photochemical dissociation reaction of oxygen and/or water.[7] Oxygen molecule dissociates to atomic oxygen (^{3}P) at 193 nm. The atomic oxygen quickly reacts with oxygen molecules to form ozone.[7,8] Then the second photochemical reaction by ozone takes place to form atomic oxygen (^{1}D), since it has a strong absorption at 193 nm. It efficiently reacts with H_2O to produce OH radical.[7–9] The direct photodissociation of water at this wavelength to produce OH radical is also possible.[7,10] Most recently OH–H_2O complexation has been identified spectroscopically.[11,12] The OH reacts with ozone to produce an HO_2 radical[13] and this is known to give a complex with water, HO_2–H_2O.[14] Further, two HO_2 radicals form hydrogen peroxide (H_2O_2) and O_2. Hydrogen peroxide is a stable molecule and has similar atomic distances as water and is known to be hygroscopic. Thus, it has a high capture rate of water molecule and can form a nucleus for water condensation. Two-photon ionization of water is another possibility. In this case a large dispersion force of ion serves to collect neutral molecules.[15]

In order to apply this method to the real field one must con-

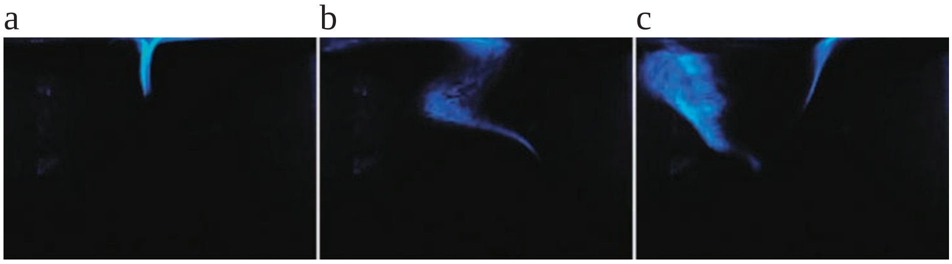

Figure 1. Light scattering by UV laser-induced mist from ambient air when the top pan is filled with ice and water. The photos show an area of about 8 × 6 cm^2. Three figures from left to right show light scattering at 12, 30, and 45 s after the first laser pulse. Laser light is emitted at 5 Hz for 10 s (50 shots).

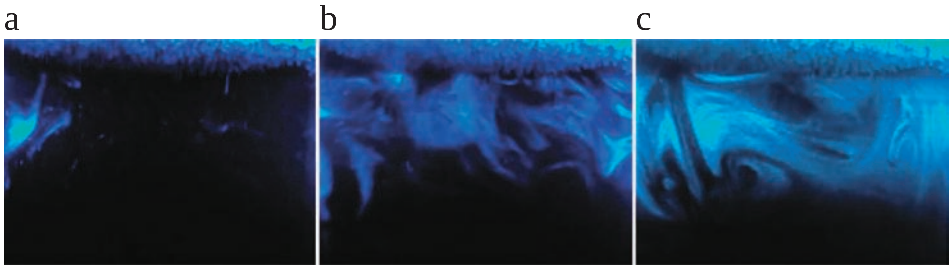

Figure 2. Light scattering by UV laser irradiation of ambient air when the top pan is filled with dry ice and ethanol. Three figures from left to right show light scattering at 4, 10, and 56 s after the first laser shot. The laser light is emitted at 10 Hz for 5 s (50 shots).

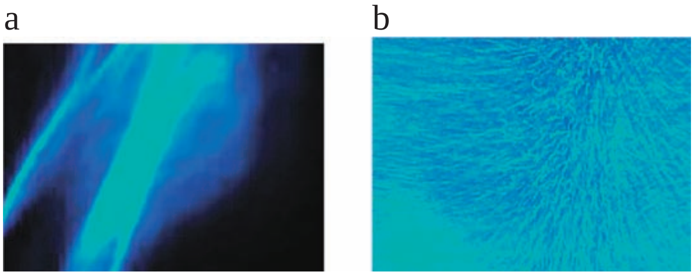

Figure 3. Details of typical light scattering patterns observed at different temperatures. The left figure shows the rather homogeneous pattern when the temperature of the top pan is about 0 °C and the right figure shows the pattern of moving fine particles and their traces when the temperature of the top pan is about −63 °C. The photo shows an area of about 3 × 2.3 cm^2.

sider dynamics of cloud formation and growth of rain/snow and require much meteorological considerations. The laser operating conditions (intensities, wavelengths, repetition rates, etc.) should be tuned to optimal conditions.

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