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(54) **APPARATUS AND RELATED METHODS FOR WEATHER MODIFICATION BY ELECTRICAL PROCESSES IN THE ATMOSPHERE**

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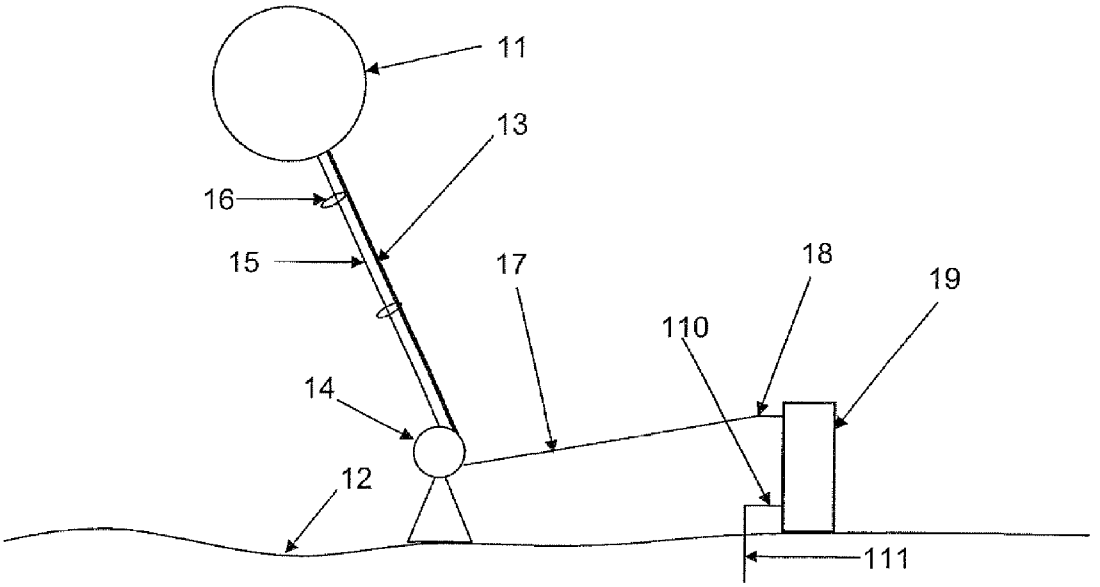
(57) **ABSTRACT**

The present invention provides an apparatus for weather modification. The apparatus comprises an emitter electrode, means for providing the emitter electrode with an electric charge, electrically coupled to the emitter electrode, an insulating support for supporting the emitter electrode at a predetermined height, and means for earthing the apparatus. The emitter electrode comprises a Malter film. According to another aspect of the present invention an apparatus for weather modification is provided, which comprises a lighter-than-air craft suitable for carrying an emitter electrode, means for providing the emitter electrode with an electric charge, electrically coupled to the emitter electrode, and means for earthing the apparatus. According to still a further aspect of the present invention, a method of increasing the amount of precipitation in a target region is provided. The method comprises the steps of providing an emitter electrode, analyzing the meteorological situation in and/or close to the target region, and providing the emitter electrode with an electric charge in response to the meteorological analysis, thereby causing the emitter electrode to ionize the vicinity of the emitter electrode.



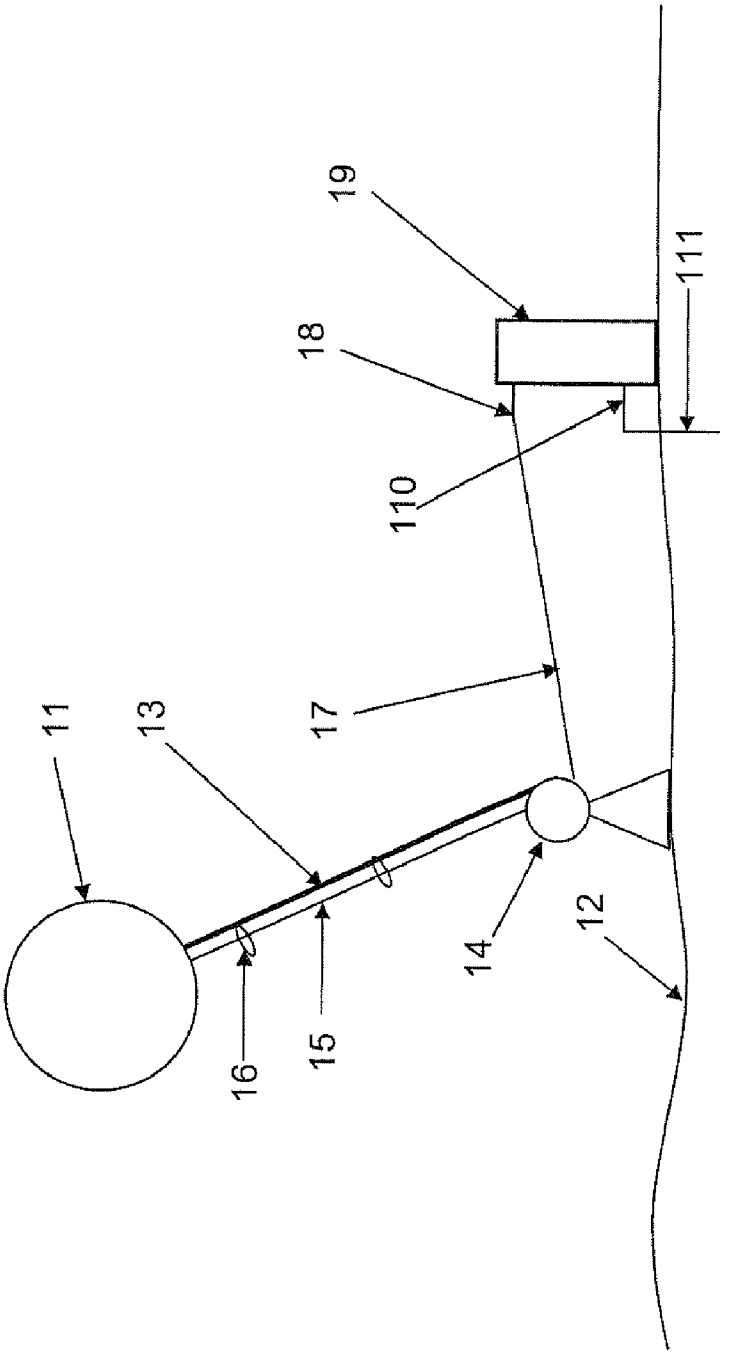


Fig. 1

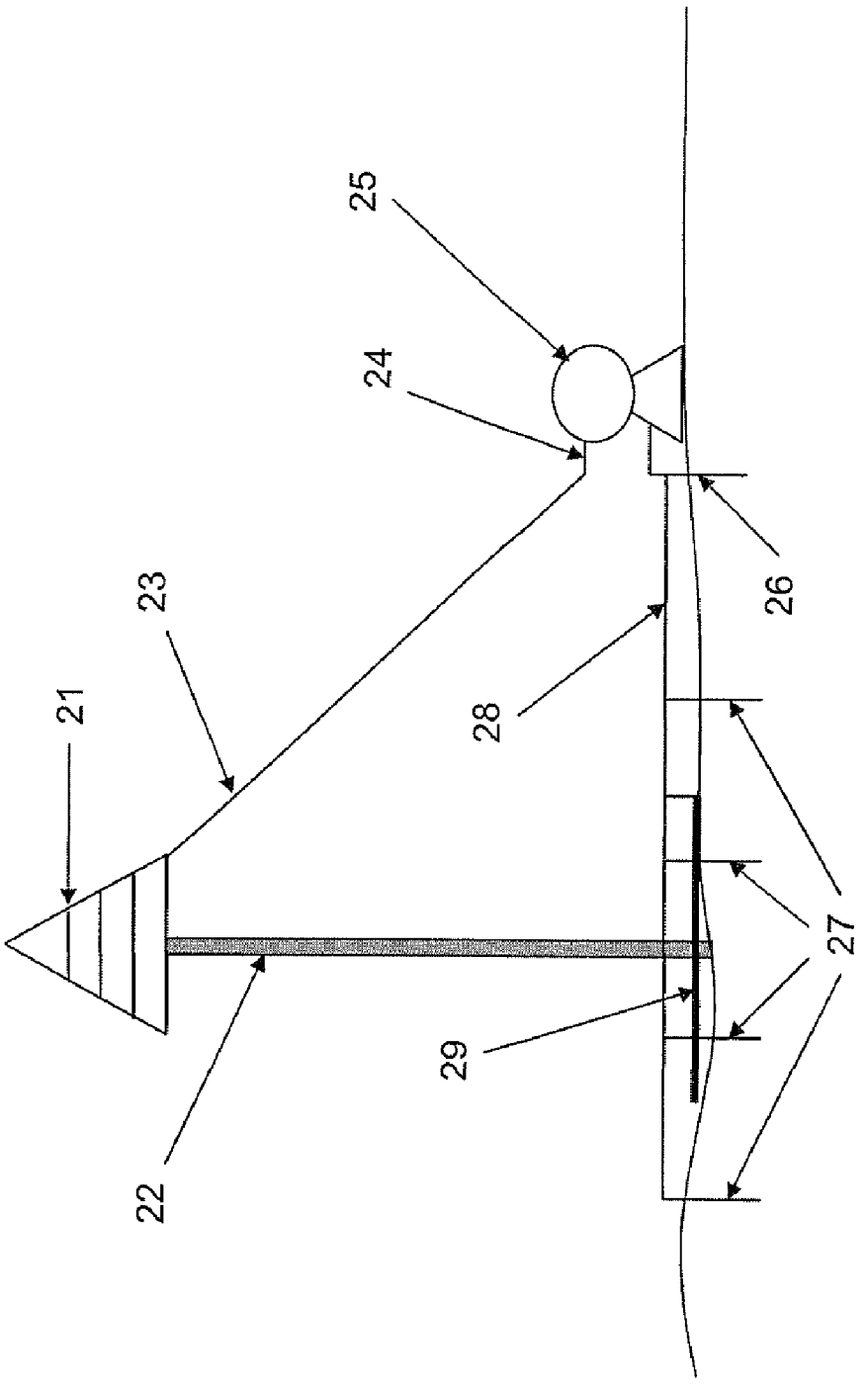


Fig. 2

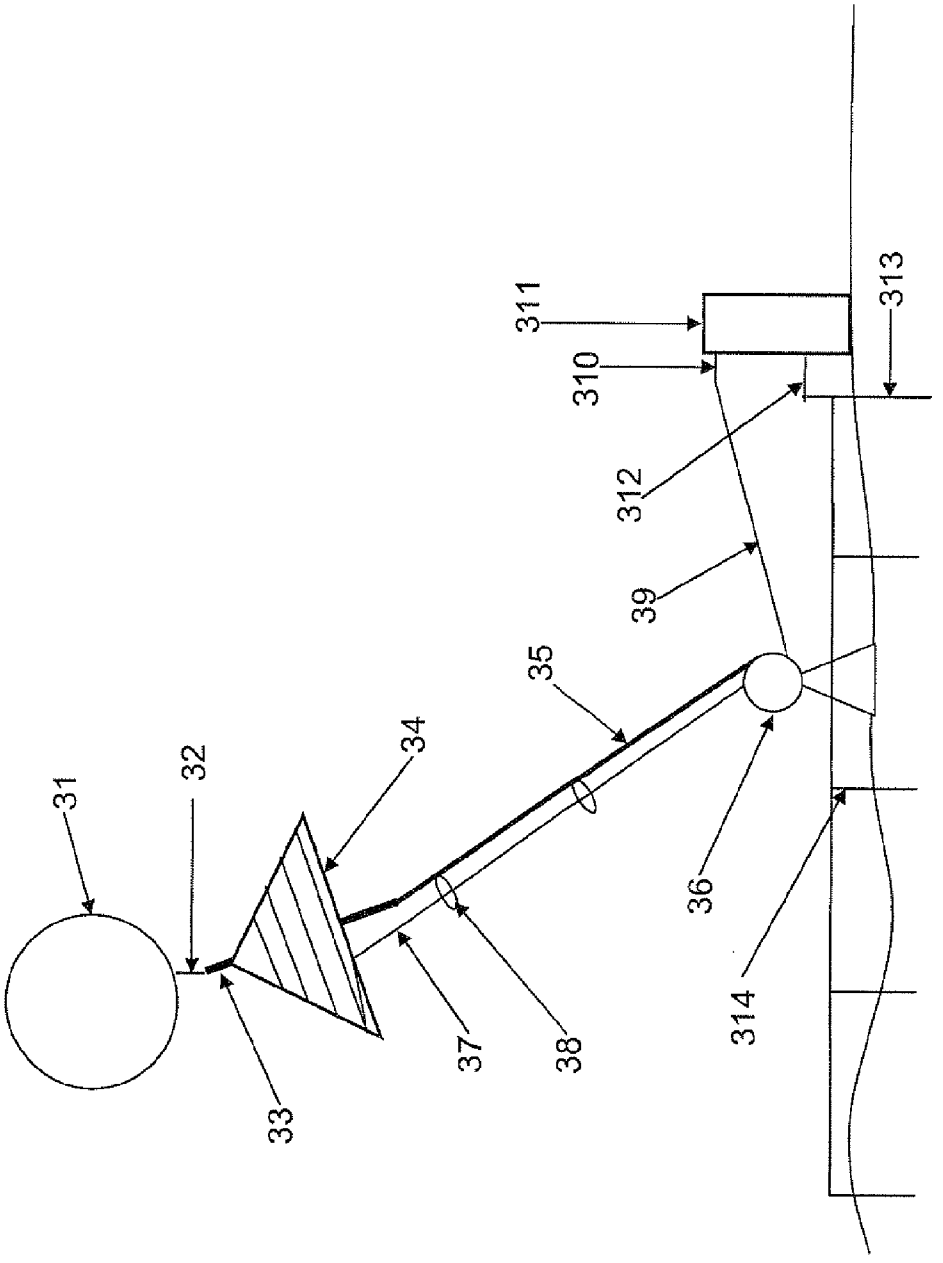


Fig. 3

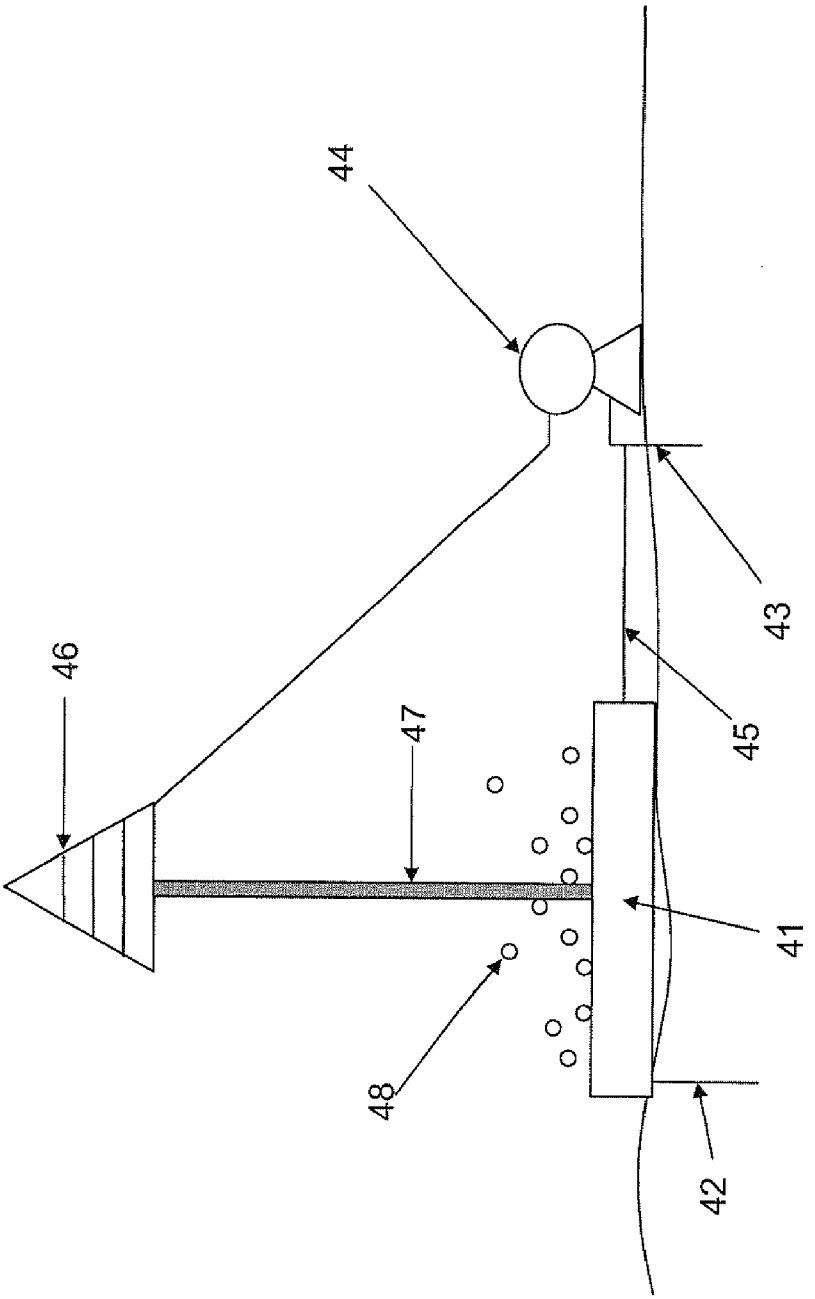


Fig. 4

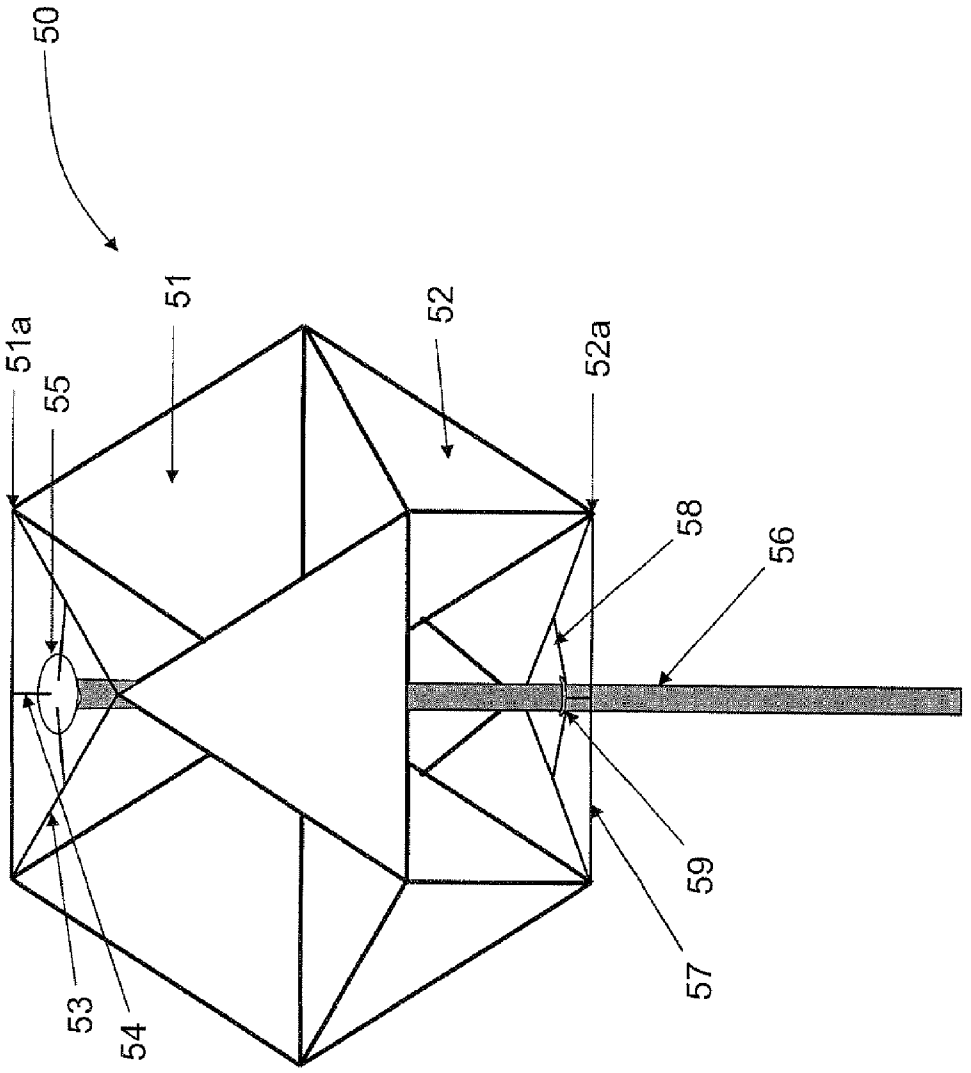


Fig. 5

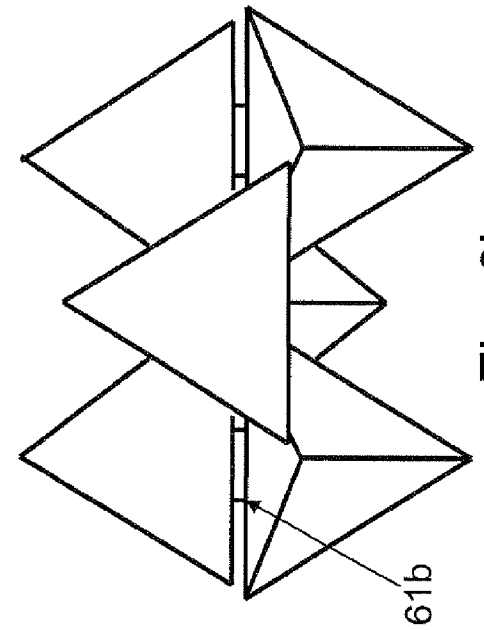


Fig. 6b

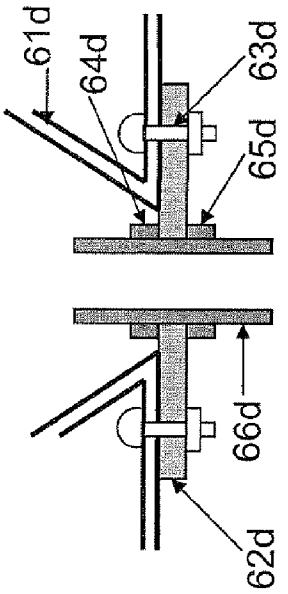


Fig. 6d

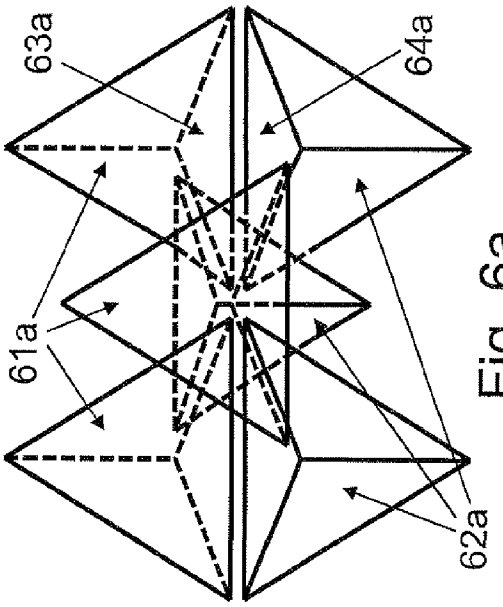


Fig. 6a

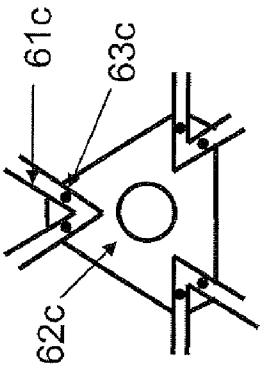


Fig. 6c

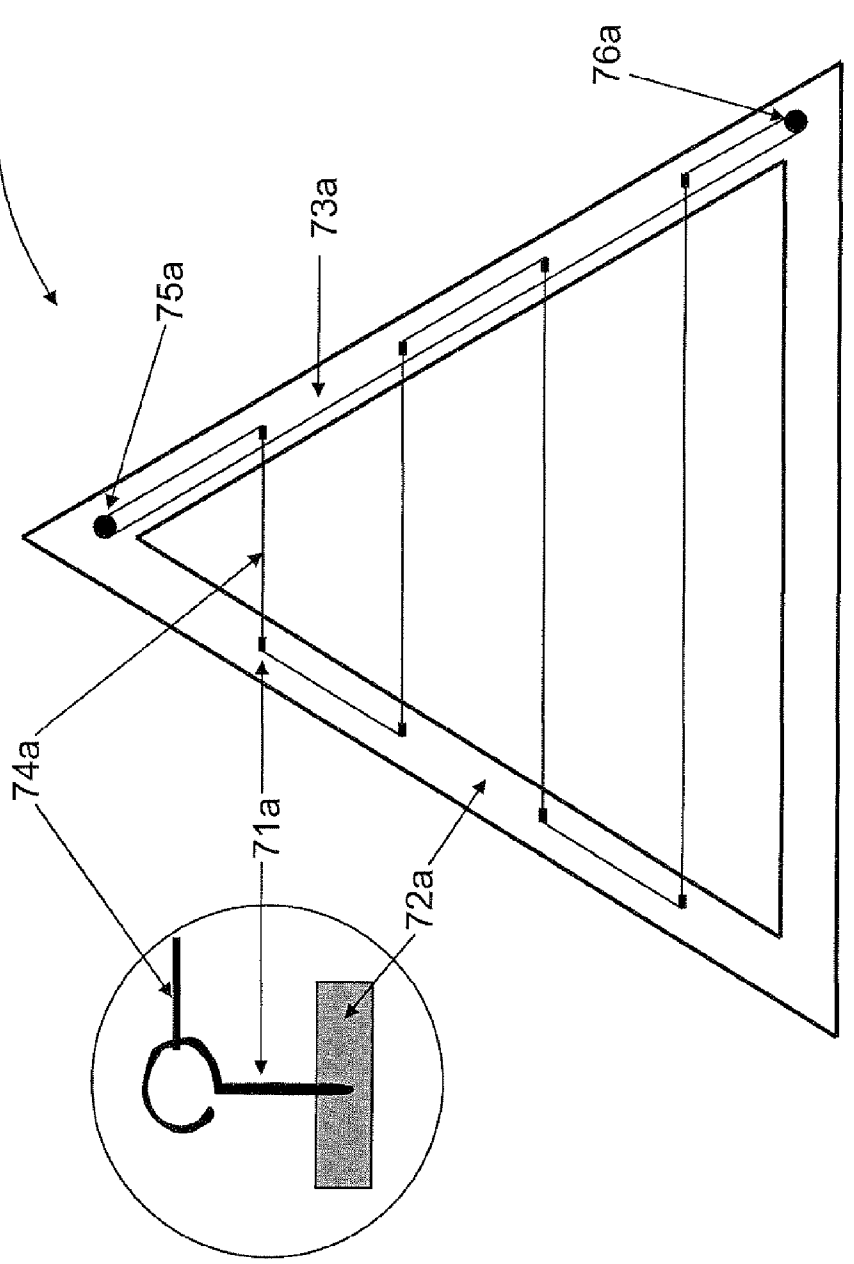


Fig. 7a

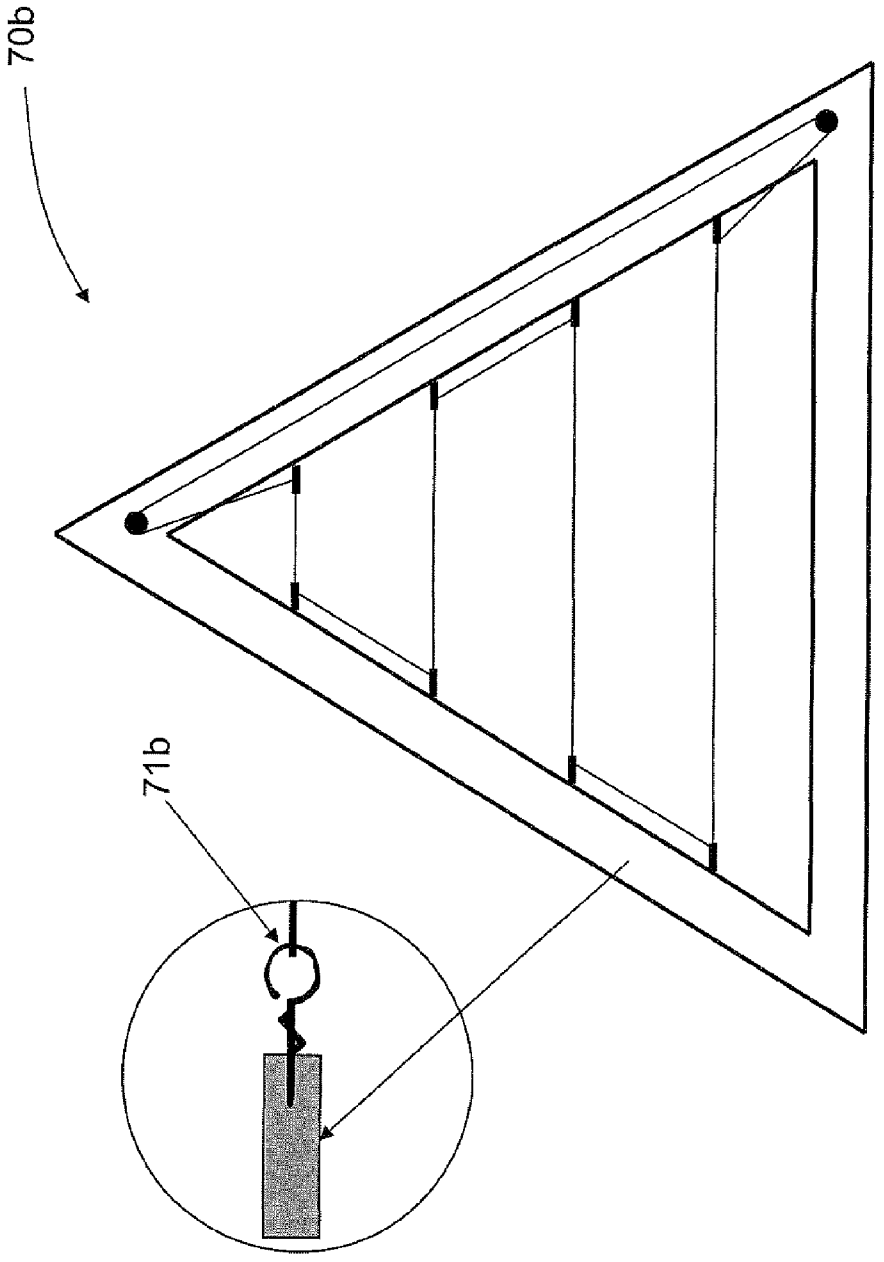


Fig. 7b

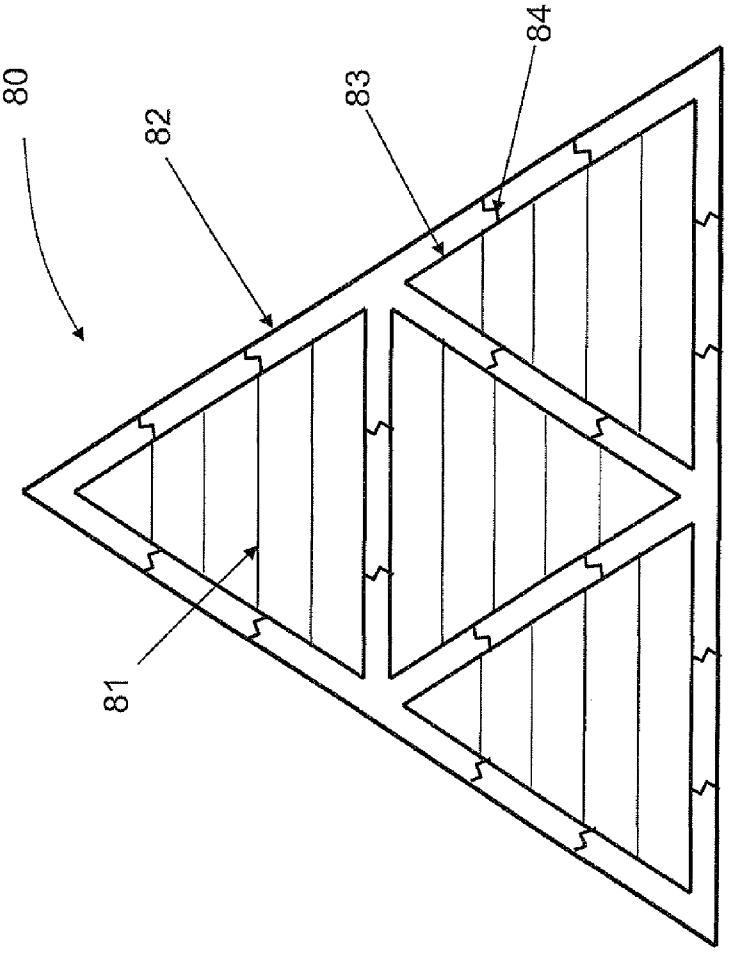


Fig. 8

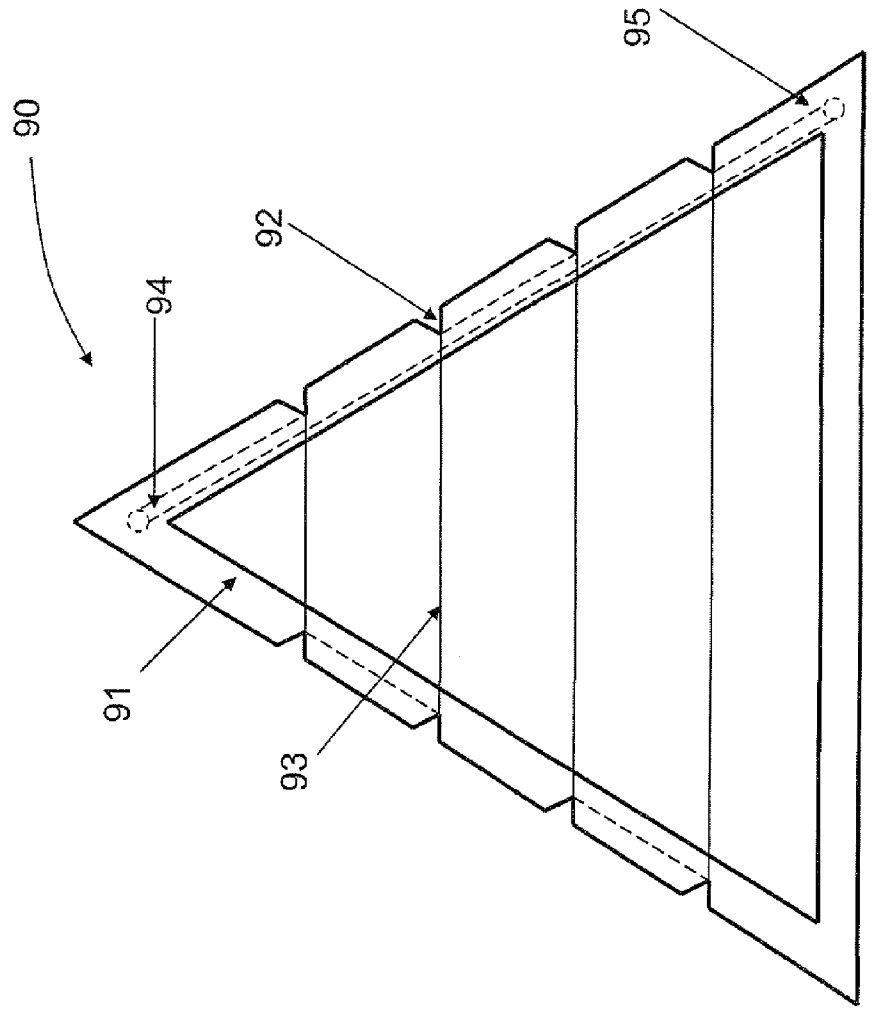


Fig. 9

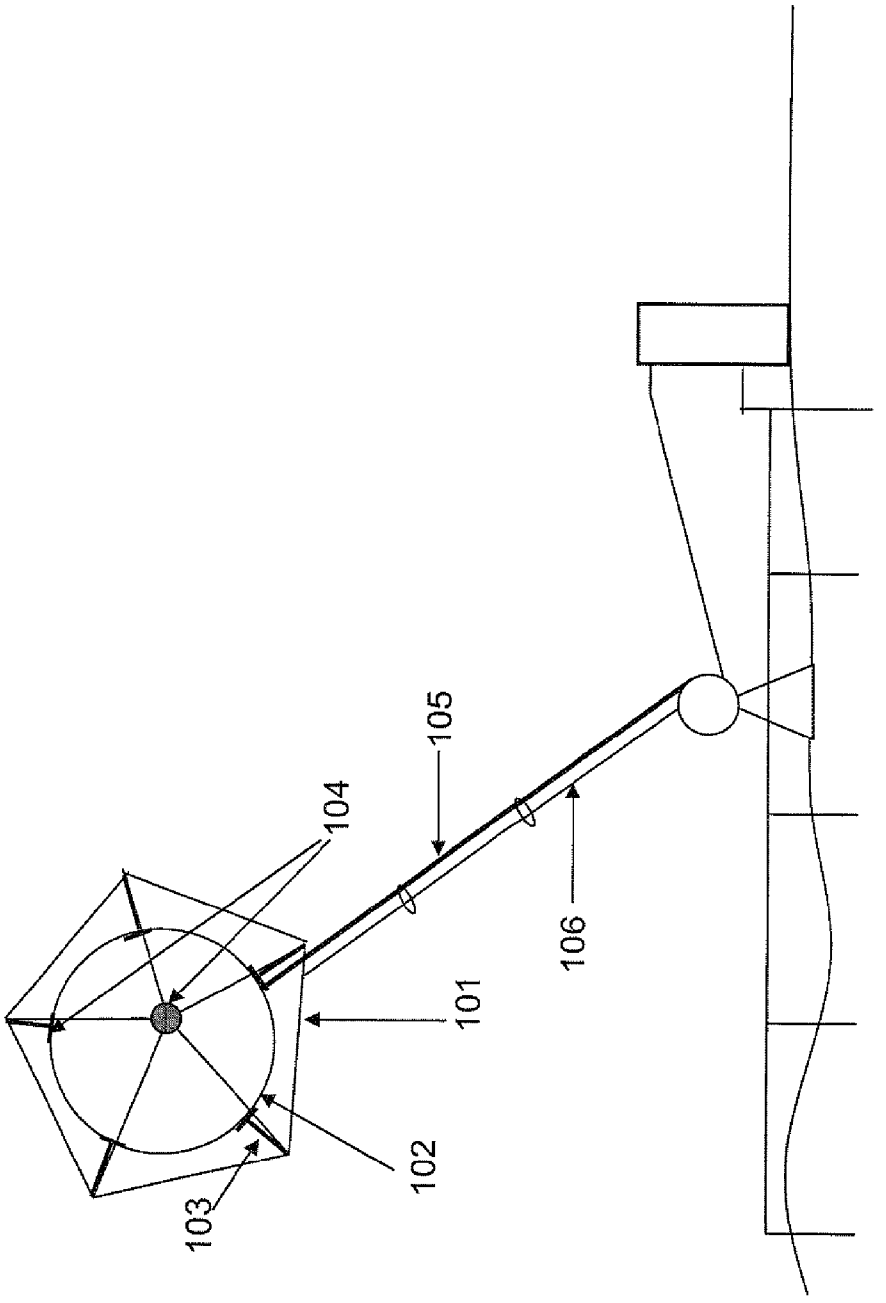


Fig. 10

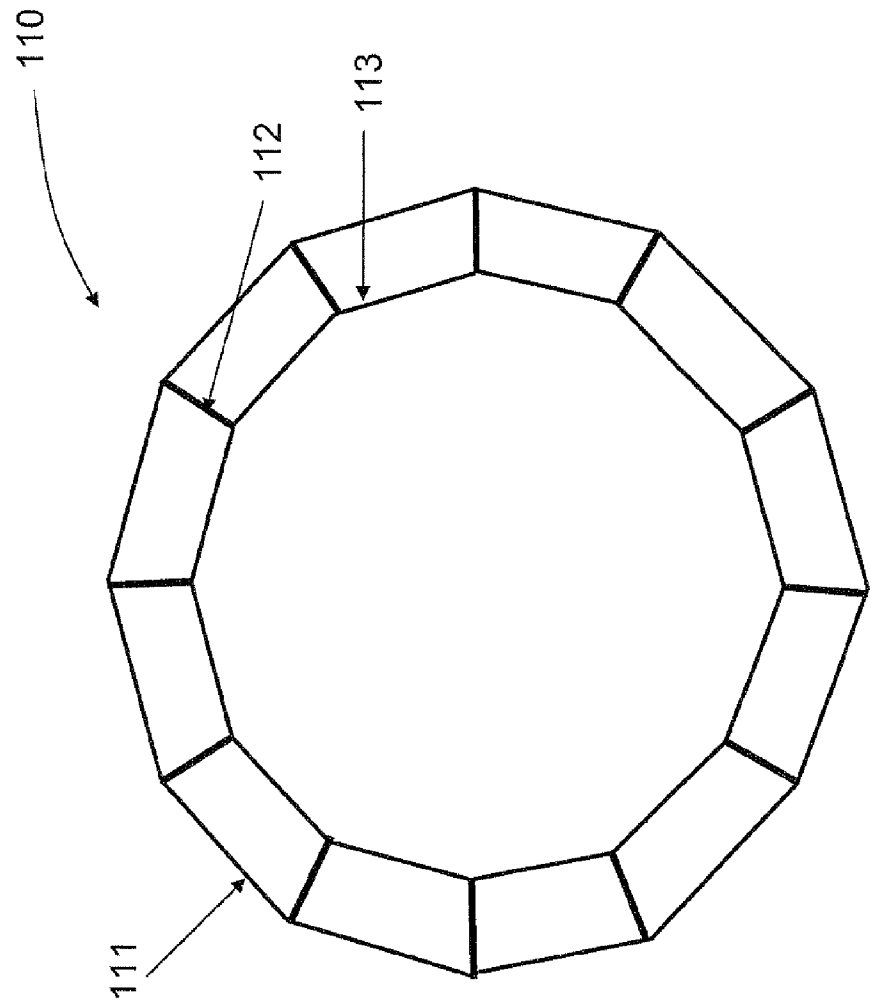


Fig. 11

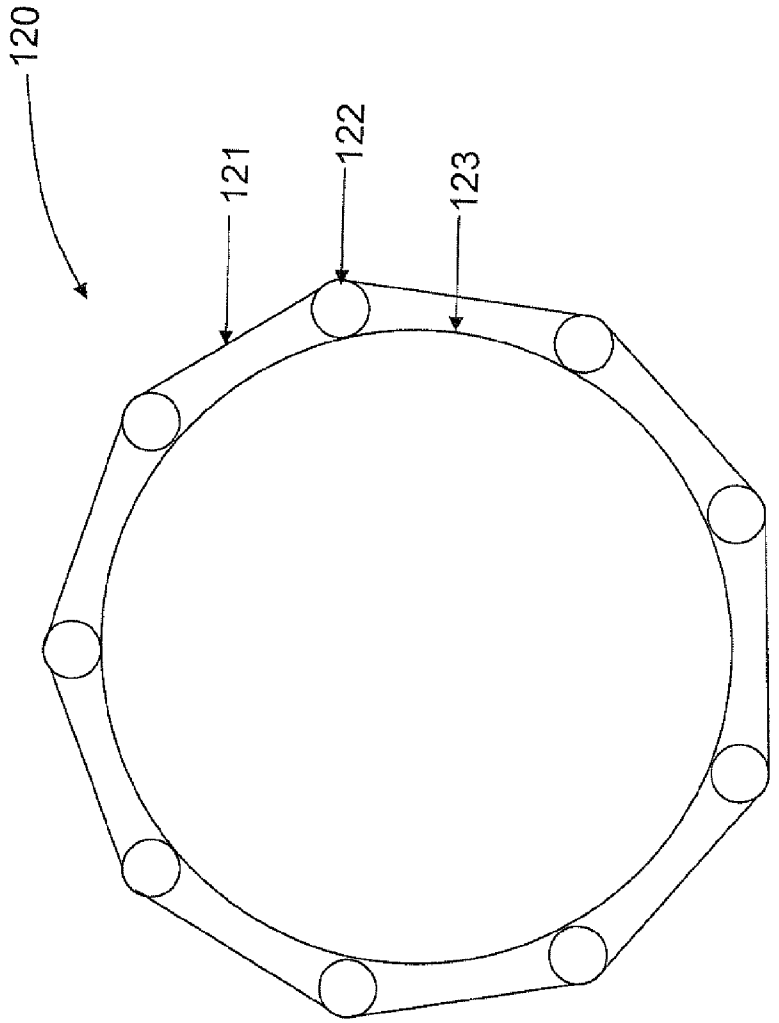


Fig. 12

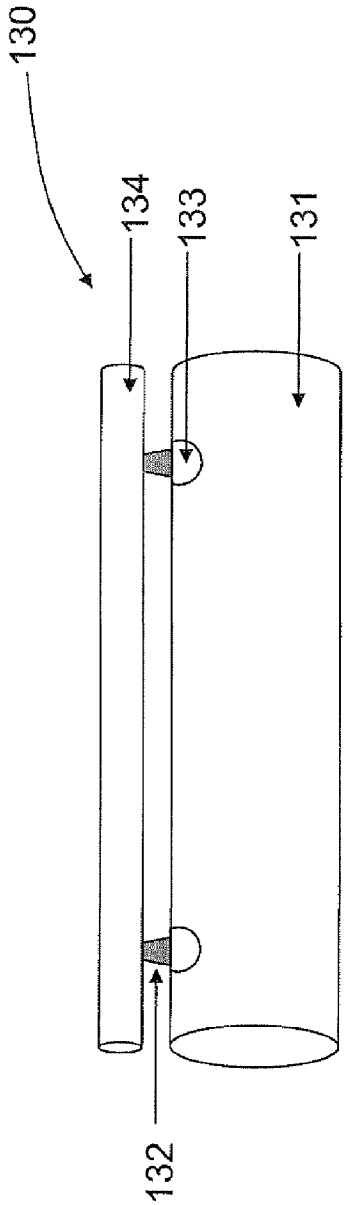


Fig. 13

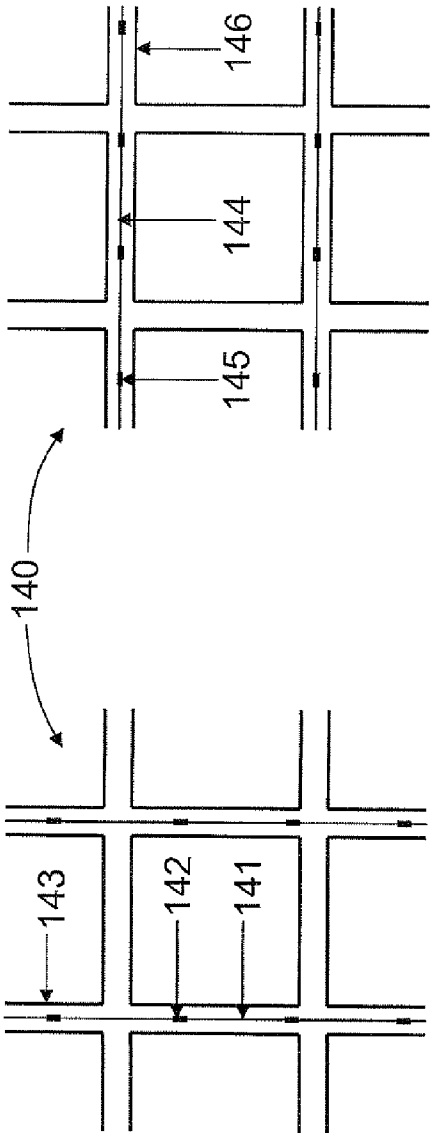


Fig. 14

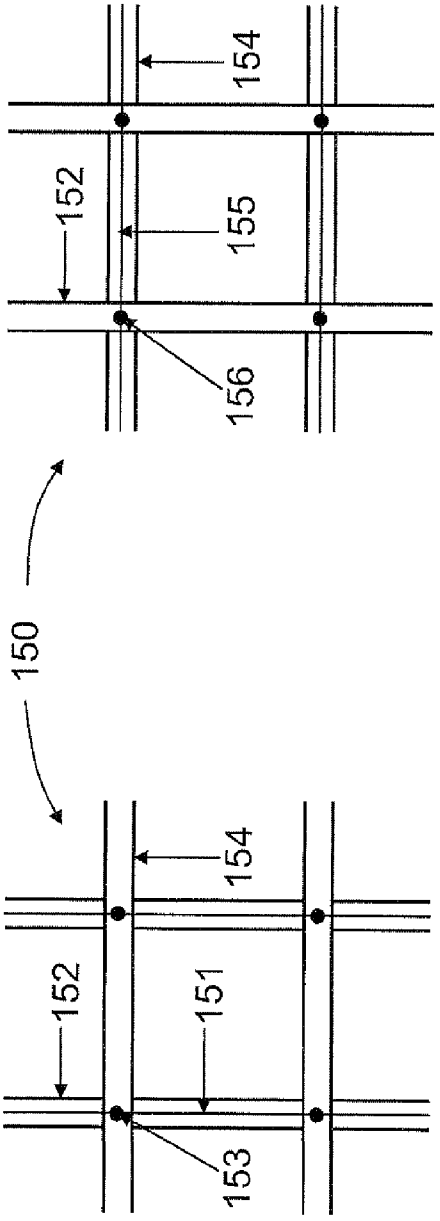


Fig. 15

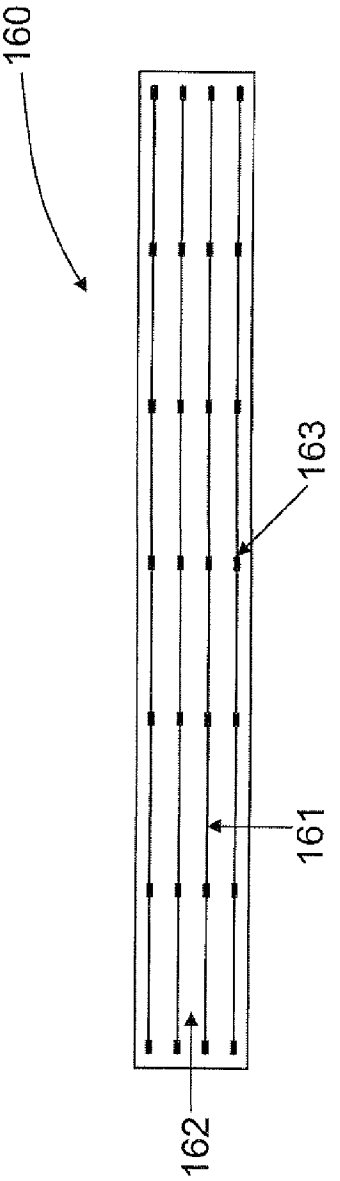


Fig. 16

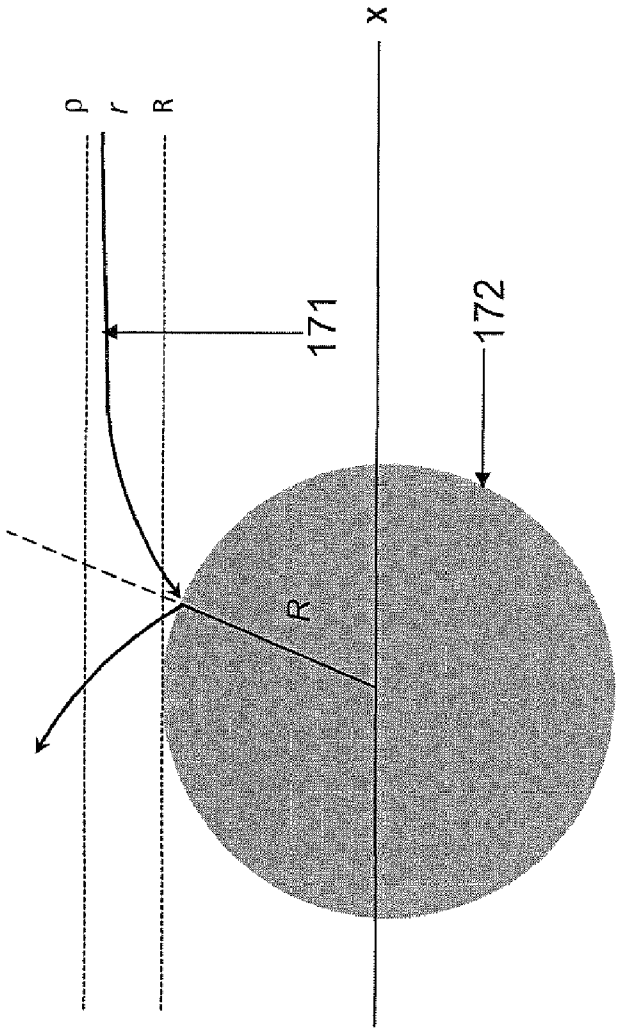


Fig. 17

APPARATUS AND RELATED METHODS FOR WEATHER MODIFICATION BY ELECTRICAL PROCESSES IN THE ATMOSPHERE

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit and priority to and is a U.S. National Phase of PCT International Application Number PCT/EP2009/004905, filed on Jul. 7, 2009. This application claims the benefit and priority to U.S. Provisional Application No. 61/085,366 filed Jul. 31, 2008; U.S. Provisional Application No. 61/097,362 filed Sep. 16, 2008; U.S. application Ser. No. 12/332,273 filed Dec. 10, 2008; U.S. Provisional Application No. 61/121,847 filed Dec. 11, 2008 and U.S. Provisional Application No. 61/122,651 filed Dec. 15, 2008. The disclosures of the above-referenced applications are hereby expressly incorporated by reference in their entirety.

FIELD OF THE INVENTION

[0002] The instant invention relates to methods and devices for modifying atmospheric conditions, known in this context as weather modification, by enhancing electric forces exerted on and between particles of atmospheric air such as water particles, aerosols, molecular clusters, and water molecules possessing their own electric dipole moment. Particular applications of weather control require specific methods and devices for their implementation. Certain embodiments, for example, relate to controlling, increasing or decreasing the amount of precipitation. The term "precipitation" means any product of the phase change of atmospheric water vapor that, due to gravitational forces, is deposited onto the surface of the Earth, and such a product may be presented in any form, such as, rain, drizzle, snow, graupel, and so forth. Using electrical methods of weather modification for other purposes such as dispersion of fog, which is cloud located on or near the surface of the Earth; increasing cloud coverage over selected regions, particularly the ocean; and increasing oceanic moisture inflow inland, would in general require specific methods and parameters of embodiments.

SUMMARY OF THE INVENTION

[0003] In this invention, devices and methods are described for the particular weather modification application of increasing or decreasing the amount of precipitation in a target region. The term "target region" means a region where it may be desirable to change the local atmospheric conditions which, in the context of this application, means controlling the amount of precipitation. Unless stated otherwise, controlling the amount of precipitation hereinafter means increasing the amount of precipitation. Deploying the described devices for some other weather modification applications is also considered, whereby specific methods are provided and the device parameters are optimized for a particular weather modification.

[0004] The objective of this invention is to provide new and improved methods and devices for weather modification applications whereby the microphysical processes in the atmosphere are affected by electrical influences. Based on recent advances in atmospheric physics and better understanding of how ambient atmospheric electricity naturally affects the weather and climate in a non-thunderstorm environment, the concept of weather modification by augmenting the natural charging of non-thunderstorm clouds (remote cloud charging or RCC) and/or locally increasing atmospheric instability by an electrical process which re-distributes atmospheric moisture is introduced. Based on this concept, a number of improved and new embodiments are proposed. Compared to embodiments of the prior art, the proposed embodiments are superior in performance, scalability, mobility, and ease of deployment and maintenance.

[0005] In nature, microphysical processes of precipitation formation from gaseous water, i.e. water vapor, can be broadly categorized in two groups. The first group includes thermodynamic phase change processes of gas-to-liquid, known as condensation, and gas-to-solid, known as vapor deposition or sublimation. Liquid water droplets may grow by condensation from small airborne (aerosol) particles with suitable (wettable) surfaces, called condensation nuclei (CN), when the actual amount of gaseous water in a volume of air exceeds the maximum amount of that water the air can hold at a given temperature, i.e. when the air is supersaturated with vapor. The amount of vapor in the air can be expressed in terms of (partial) pressure of vapor. Accordingly, the air is supersaturated when the pressure of vapor exceeds its saturation pressure. As the vapor saturation pressure decreases with temperature, the moist air gets supersaturated when sufficiently cooled. At temperatures below freezing point, ice particles in supersaturated air may grow by vapor deposition from frozen droplets and aerosol particles with suitable surfaces, called ice nuclei (IN). Areas of atmospheric air laden with droplets and ice particles appear as clouds.

[0006] Processes of the second group are cloud particle merging processes. At a certain stage of droplet growth in a cloud, the merging of droplets into larger ones by collisions, known as the collision-coalescence process or simply coalescence, becomes more efficient than growth by condensation. Due to the forces of gravity and air viscosity, droplets which have grown larger descend faster than small droplets. As they descend, larger droplets, called collectors in this context, collide with smaller droplets. Ice and liquid particles may also be merged in a similar way. In its classic definition, where only gravitational forces are governing droplet motions, coalescence is rather a simplified model of the real droplet merging processes in the atmosphere. Droplets can be moved in different directions with different velocities by turbulent air motions. Under such conditions, droplets of a similar size may also be coalesced. As in the case of classical coalescence, however, the presence of large droplets, even in a small number concentration, may significantly enhance coalescence in a turbulent environment, also known as turbulent coagulation (Riemer and Wexler, 2005).

[0007] Methods of cloud modification currently used are generally based on augmenting the targeted mechanism of cloud formation by introducing (seeding) particles of a specific media into the clouds. Such methods are known as cloud seeding methods. Seeding media are typically delivered to clouds by carriers such as airplanes or rockets. Under certain conditions, airborne seeding media can also be delivered by the ascending of air caused by the wind hitting a mountain slope. This technique is known as orographic seeding.

[0008] One of the processes which can be augmented by cloud seeding is the Bergeron process of ice particle growth by vapor deposition. In cold clouds, i.e. in clouds at temperatures below freezing point, droplets of pure water can remain liquid (super-cooled) even down to temperatures near −42° C.

and thus co-exist with ice particles. The vapor saturation pressure over ice is lower than that over liquid water (Bergeron, 1935, 1939). As the water vapor is consumed by growing cloud particles, its partial pressure decreases. When the partial pressure of vapor falls below the vapor saturation pressure for liquid droplets, the air becomes undersaturated for droplets while still being supersaturated for ice particles. At this point, ice particles will continue to grow at the expense of evaporating droplets. In this process, which is more efficient than condensation, a larger fraction of the available vapor can be potentially converted into precipitation. In cold clouds, however, the number concentration of natural IN decreases quasi-exponentially with temperature down to freezing point, making the process slow at temperatures just a few degrees below the latter. Under such conditions, enhancing the production of ice and, consequently, precipitation, is achieved by seeding clouds with artificial ice nuclei such as crystals of silver iodide (AgI), the surface characteristics of which are similar to those of ice crystals. This method is currently the most common in weather modification.

[0009] Particles of substances which evaporate at temperatures much lower than that of atmospheric air are another type of seeding media. Pellets of solid carbon dioxide, known as dry ice, and small drops of liquid nitrogen, which take heat from and thus cool the surrounding air while evaporating, are examples of such seeding media. In cold clouds, higher degrees of supersaturation and super-cooling around those particles may lead to a higher initial growth rate of droplets and ice particles and an increase in the number concentration of IN due to enhanced droplet freezing. In warm clouds, higher supersaturation and thus the enhanced condensation achieved near the cooling particles may lead to the production of larger droplets. In turn, those droplets may enhance coalescence by acting as more efficient collectors in this process.

[0010] Another method is based on seeding clouds with fine particles of salts, the vapor saturation pressure over the water-based solute of which is lower compared to that of pure water. Solute droplets which are grown by condensation from such CN or from droplets which have acquired salt particles by attachment may achieve sizes larger than water droplets and thus enhance coalescence as mentioned above. This method is known as hygroscopic seeding.

[0011] There is a large body of evidence suggesting that the presence of an intense electric field, sufficiently high electric charges on cloud particles, or a combination of both may significantly affect multiple microphysical processes of cloud development, including those directly or indirectly responsible for the formation of precipitation. One effect of electric charges is augmented scavenging (i.e. acquisition by attachment) of charged aerosol particles by charged and neutral cloud droplets. Although not obvious, the net electric force at a short distance between cloud particles of even the same sign charge is always attractive due to electrostatic image forces (Tinsley et al., 2000). For such particles of like charges, there is a long-range repulsive force, but air flow forces may bring particles within the range of the dominating image force. If two cloud particles under consideration are aerosol particle and liquid droplet, the effect of attractive net electric force may result in the successful scavenging of aerosol particle by liquid droplet, otherwise not possible geometrically.

[0012] If the aerosol particle is an ice nucleus, its scavenging by a liquid droplet will result in the instant freezing of the latter. Such a mechanism of ice particle production, known as contact freezing, was found to be a particularly efficient mechanism (Sastry, 2005), competing with the Bergeron process. In contrast to the latter, an ice particle can be instantly formed from a liquid droplet by contact freezing, bypassing the relatively slow Bergeron growth of the ice-forming nucleus, which involves liquid droplet "re-processing" via evaporation. In turn, the produced ice particle may continue to grow either by vapor deposition or by further merging with and freezing the next super-cooled droplet, and so on.

[0013] Seeding artificial ice nuclei into a cold cloud enhances both Bergeron and contact freezing processes. Enhancement of the latter is due to the increased probability of ice nuclei scavenging because of their increased number concentration. Introducing too many ice nuclei, however, may result in the formation of too many ice particles becoming small as they compete for the available vapor. This problem is known as over-seeding. In contrast, augmentation of contact freezing by electro-scavenging of natural ice nuclei is advantageous as it may result in a more efficient usage of the latter and, ultimately, the production of fewer but larger ice particles which may precipitate.

[0014] Another effect of attractive electric forces is the increase in collection efficiency of droplet coalescence, which is especially important for rain formation without ice processes in warm clouds. If a charged droplet is to be collected by a larger neutral droplet or a larger droplet charged with either sign in a coalescence event, the latter can be successful even being geometrically impossible without the attractive electric force. Another aspect of electrically enhanced coalescence is an increase in coalescence efficiency, i.e. the probability that not only collision but permanent collection of a droplet occurred during coalescence, which means that the droplet did not avoid collision by being deflected by airflow, coalesced temporarily and then separated, possibly breaking into a number of smaller droplets. The enhancement of coalescence due to electric forces was studied in many works, both experimental (Sartor, 1954; Goyer et al., 1960; Abbott, 1975; Dayan and Gallily, 1975; Smith, 1972; Smith, 1976; Ochs and Czys, 1987; Czys and Ochs, 1988), and theoretical/modeling (Sartor, 1960; Lindblad and Semonin, 1963; Plumlee and Semonin, 1965; Paluch, 1970; Schlamp et al., 1976; Tag, 1976; Tag, 1977; Freire et al., 1979; Khain et al., 2004).

[0015] The effect of electric charges on small droplets is similar to the hygroscopic effect of salts. Like droplets of salt solutions, droplets charged to a certain degree require a lower super-saturation to grow by condensation (Harrison and Ambaum, 2008). The electric field of sufficiently charged droplets which are super-cooled may directly facilitate their freezing. As water molecules possess their own electric dipole moment, they tend to align with the electric field, which favors the freezing of super-cooled water at higher temperatures. This effect of direct electrical freezing, although not yet studied in detail, was demonstrated in experiments by Wei et al. (2008).

[0016] The idea to develop cloud modification methods which are based on charging cloud particles is not new. Such methods would be environmentally friendly alternatives to chemical cloud seeding. Another advantage of electrical methods is that charging cloud particles may augment multiple precipitation formation mechanisms at once, while a particular seeding method, targeting a certain mechanism, is implemented for a specific medium to be seeded in cloudy air within a certain range of number concentrations. For example, an increase in precipitation would be achieved in a

warm cloud by an electrically enhanced-hygroscopic effect on droplets and electrically enhanced coalescence. In mixed clouds, i.e. clouds with cold tops and warm bottoms, enhanced ice production via droplet electro-freezing in the upper cloud areas would also contribute to the effect. Additionally, descending ice particles may act as efficient coalescence collectors in warm cloud areas, the so-called seeder-feeder effect.

[0017] To be effective, augmenting a particular process of cloud development requires a certain minimum charge per electrically active cloud particle. For example, enhancing coalescence collision efficiency requires at least a few hundred elementary (electronic) charges on droplets with a radius of 10-20 μm (Khain et al., 2004). Charges per particle of the same order of magnitude are required for effective electro-freezing (Tinsley et al., 2000) and augmenting hygroscopic properties of small droplets (Harrison and Ambaum, 2008). Cloud particles charged sufficiently to significantly modify cloud development processes are referred to hereinafter as supercharged particles.

[0018] The first approach to supercharging cloud particles has been focused on direct charging by generated ions of predominantly the same sign (i.e. unipolar). A number of designs for devices, typically comprising a unipolar ionizer such as a direct current (DC) corona discharge, referred to hereinafter as corona discharge, and other elements enclosed in a body, have been proposed in the previous art. In such devices, particles to be charged which are taken from a cloud or artificially produced in such a form as water droplets, pass in the vicinity of the emitter electrode of corona discharge (EECD) and thus acquire electric charges by ion attachment. Alternatively, in some embodiments, particles acquire an electric charge through contact with a charged electrode. The produced charged particles are then introduced (seeded) into a cloud. Such methods are described, for example, in the patent application of Khain at al. (2003). In practice, however, implementing methods of direct supercharging cloud particles in a large volume of cloudy air would meet with severe engineering difficulties.

[0019] The average charge on a particle which can be achieved by ion attachment is proportional to the logarithm of the so-called unipolarity factor, which is the ratio of the number concentration of dominant sign ions to the concentration of opposite sign ions (Clement et al., 1991). In order to supercharge cloud particles, especially small ones, the corresponding unipolarity factor should also be sufficiently high. As ions of the sign opposite to that of corona ions are always present in the air, the required unipolarity can be maintained only within a limited charging zone around the emitter electrode.

[0020] Other factors limiting the productivity of the charging device are the time required for particle charging and a strong electric field of the produced space charge which may reduce the ion productivity of corona discharge (Smith, 1972; Loveland et al., 1972). Contact supercharging of particles with an electrode is also problematic as in practice it can be achieved only for a small fraction of these particles.

[0021] Once removed from a charging zone, a particle remains supercharged for only a short time due to its non-equilibrium charge decay, the rate of which is proportional to the particle charge. This poses the challenging problem of distributing such particles over a large volume of cloudy air within a limited time. As orographic seeding of clouds with short-lived supercharged particles is unlikely to be efficient, such an unstable seeding medium should be produced and seeded at cloud altitudes, which would require the costly deployment of a number of airborne carriers such as aircrafts or drones. The deployment of chimney-like conduits to deliver supercharged particles into clouds, proposed in the previous art, would also meet with engineering difficulties and high costs.

[0022] Methods based on the direct supercharging of cloud particles by technical means proposed in the previous art are apparently difficult to implement in practice and therefore may not compete with existing cloud seeding methods.

[0023] It is therefore an object of the present application to provide an improved apparatus for weather modification which overcomes the above-mentioned drawbacks of the prior art. It is a further object of the present invention to provide an improved method of increasing the amount of precipitation in a target region, which avoids the drawbacks of the prior art, which is more efficient and less costly. It is a further object of the present invention to provide a method of increasing the amount of precipitation in a target region which is easy to control and which provides an increased rate of success. These objects are achieved by the features of the independent claims. The dependent claims describe preferred embodiments of the present invention.

[0024] The present invention provides an apparatus for weather modification. The apparatus comprises an emitter electrode, means for providing the emitter electrode with an electric charge, electrically coupled to the emitter electrode, an insulating support for supporting the emitter electrode at a predetermined height, and means for earthing the apparatus. The emitter electrode comprises a Malter film. The Malter film preferably comprises a thin film of one or more electrically non-conducting materials. Particularly preferred materials for the Malter film are one or a combination of the following materials: Al_2O_3, Zn_2SiO_3, SiO_2, ZrO_2, $CaCO_3$, Ta_2O_5.

[0025] In a preferred embodiment the emitter electrode is a capacitor with a conductive surface. The capacitor is preferably substantially spherical. A "substantially spherical" capacitor is to be understood as a capacitor with a somewhat spherical shape. Said shape may, e.g., comprise several planes or planar structures which are arranged in a polygon, which is similar to a spherical shape. For example, several pentagons and hexagons may be arranged as on a soccer ball.

[0026] According to a preferred embodiment of the apparatus of the present invention, the emitter electrode comprises one or more emitter electrode assemblies of corona discharge, which are mechanically and/or electrically coupled to each other.

[0027] The support of the apparatus preferably has a height between 6 m and 30 m, particularly preferred between 8 m and 15 m. It is further preferred that the support comprises an insulating layer. Alternatively, the support may be made of an insulating material. The support may further comprise a rigid structure. For example, the emitter electrode can be supported by a frame of a planar polygonal shape having a surface.

[0028] In one embodiment, the emitter electrode comprises two or more electrically coupled parallel wire segments traversing the surface of the frame and separated by a distance.

[0029] The means for providing the emitter electrode with an electric charge can be any means which is suitable to provide a large charge density and/or a large voltage. One preferred example for the means is a charging engine of a Van der Graaf generator.

[0030] According to a preferred embodiment the emitter electrode comprises two or more Malter electrodes, preferably in the shape of a solid or tubular wire, preferably further comprising one or more initiating corona discharge wires. The diameter of the Malter electrodes is preferably larger than the diameter of the initiating corona discharge wires. The initiation corona discharge wires are preferably positioned in the vicinity of and coupled mechanically and/or electrically to the Malter electrodes. According to one embodiment, the mater electrodes are arranged in parallel segments traversing the surface of the frame and separated by a distance.

[0031] In an alternative embodiment the emitter electrode comprises two or more Malter electrodes in the shape of foil strips. The emitter electrode may further comprise a mesh of wire. Alternatively or in addition, the emitter electrode may comprise a mesh of Malter electrodes.

[0032] According to a further embodiment, the apparatus comprises a generator of high frequency electromagnetic waves, which are suitable for contactless heating of the wire loops of the emitter electrode.

[0033] It is further preferred that the apparatus comprises one or more earthed electrodes, wherein the earthed electrodes are located beneath the one or more emitter electrode assemblies and electrically coupled to the means for earthing. The apparatus may further comprise one or more collector electrodes.

[0034] According to a preferred embodiment of the present invention, the apparatus further comprises a reservoir containing a conductive electrolyte solution. Furthermore, an aerosol generator may be provided, which preferably comprises one or more devices for percolating an electrolyte solution.

[0035] In another preferred embodiment, the apparatus further comprises one or more means for generating an updraft. This means can, e.g., comprise a heat source. One simple example for such a heat source is a black substance absorbing solar radiation, which is arranged below or around the apparatus.

[0036] According to another aspect of the present invention an apparatus for weather modification is provided, which comprises a lighter-than-air craft suitable for carrying an emitter electrode, means for providing the emitter electrode with an electric charge, electrically coupled to the emitter electrode, and means for earthing the apparatus. While the height of operation of the apparatus according to the first aspect of the present invention is limited by the height of the insulating support, the operating height of the apparatus according to the second aspect of the present invention is basically unlimited, since the emitter electrode may be transported to any operating height by the lighter-than-air craft. Accordingly, the apparatus according to the present invention may be elevated to a predetermined height depending on a specific application of the apparatus. For example, the height of the apparatus according to the present invention may be regulated in dependence of the height of the clouds present in the target region. Thereby, the effectiveness and rate of success of the apparatus according to the present invention can be dramatically increased in comparison to the prior art.

[0037] Preferably, the lighter-than-air craft is connected to the means for providing the emitter electrode with electric charge via a tether. According to a preferred embodiment the lighter-than-air craft is a light-than-air capacitor having a surface. In other words, the lighter-than-air craft forms a capacitor or is essentially made of components which may also be utilized as a capacitor. Preferably, multiple emitter electrode assemblies are arranged around and uniformly fixed to the surface of the lighter-than-air capacitor, e.g., by means of multiple support rods of variable length. The support rods may have feet contacting the surface of the capacitor which provide a stress-bearing mechanism.

[0038] According to an alternative embodiment, the emitter electrode comprises a hollow capacitor which a spherical or quasi-spherical surface, wherein the lighter-than-air craft is arranged inside the capacitor. Preferably, one or more emitter electrode assemblies are arranged around and electrically coupled to the capacitor. It is further preferred, that the emitter electrode assembly is a wire mesh surrounding the surface of the lighter-than-air craft. In a preferred example, the emitter electrode assembly is supported by spheres placed between the surface of the lighter-than-air craft and the mesh, wherein the spheres are uniformly arranged around the lighter-than-air craft.

[0039] The skilled person will understand that the preferred features described with respect to the apparatus according to the first aspect (mounted on a support) may also be utilized in order to improve the apparatus according to the second aspect (lighter-than-air craft).

[0040] According to still a further aspect of the present invention, a method of increasing the amount of precipitation in a target region is provided. The method comprises the steps of providing an emitter electrode, analyzing the meteorological situation in and/or close to the target region, and providing the emitter electrode with an electric charge in response to the meteorological analysis, thereby causing the emitter electrode to ionize the vicinity of the emitter electrode.

[0041] According to a preferred embodiment, the method further comprises the step of elevating the emitter electrode to a predetermined height. According to a first alternative, the predetermined height is between 6 m and 30 m, preferably between 8 m and 15 m. According to a second aspect of the present invention, the predetermined height is greater than 100 m, preferably greater than 500 m.

[0042] It is in general preferred that the predetermined height is determined on the basis of the meteorological situation in and/or close to the target region. It is in particular preferred that the predetermined height is determined on the basis of the altitude of the clouds in and/or close to the target region. According to a preferred embodiment of the method, the predetermined height is at least 50%, preferably at least 65% of the altitude of the clouds in and/or close to the target region.

[0043] According to the first aspect, it is preferred that the step of providing an emitter electrode comprises mounting the emitter electrode on an insulating support. According to the second aspect, the step of providing an emitter electrode comprises preferably the step of elevating the emitter electrode by means of a lighter-than-air craft.

[0044] It is furthermore preferred that the emitter electrode comprises a Malter film. The Malter film comprises a thin film of one or more electrically non-conducting materials, preferably of one or a combination of the following materials: Al_2O_3, Zn_2SiO_3, SiO_2, ZrO_2, $CaCO_3$, Ta_2O_5.

[0045] According to a further preferred embodiment, the inventive method comprises the step of moisturizing the soil beneath the emitter electrode with water or a water-based conductive electrolyte solution.

[0046] Preferably, one or more collector electrodes comprising sheets of metal or wire mesh are arranged on the

surface of the earth beneath the emitter electrode and are electrically coupled to one or more earthed electrodes. In general, the inventive method may comprise the step of providing one or more earthed electrodes. Furthermore, a heat source may be placed beneath the emitter electrode. The heat source may be achieved by a substrate absorbing solar radiation, which is distributed beneath the emitter electrode.

[0047] According to a specific embodiment, a reservoir containing a conductive electrolyte solution may be provided, wherein the reservoir is placed on the surface of the earth beneath the emitter electrode and electrically coupled to one or more earthed electrodes. Furthermore, a layer of conductive carbon granules may be provided on the surface of the earth, wherein the layer is beneath the emitter electrode and electrically coupled to one or more earthed electrodes.

[0048] According to a preferred embodiment of the inventive method, several emitter electrodes are provided and arranged in an emitter electrode assembly. Preferably, several emitter electrode assemblies are provided. The several emitter electrode assemblies are preferably supported by a frame of, e.g., planar shape. Preferably, the emitter electrode assemblies are electrically coupled to each other and mechanically coupled with flexible joints to each other and to the sides of the frame. The frame is preferably positioned at an angle to the surface of the earth. Said angle is preferably between about 20 and about 70 degrees.

[0049] In a preferred embodiment, the emitter electrode comprises two or more electrically coupled parallel wire segments traversing the surface of the frame and separated by a distance. In a preferred example, the frame is triangular and both wire segment ends are held in place by a number of flexible supports fixed in pairs to each of the two sides of the frame wherein flexible supports provide a stress bearing mechanism on the wire segments. Preferably, the frame is triangular and the wire is wound around the frame in one strand through notches on two sides of the frame wherein the notches are provided in pairs on each of the sides of the frame.

[0050] The emitter electrode assemblies are preferably of isosceles triangular shape and are arranged into one or more pyramids. The bases of the pyramids preferably do not contain an emitter electrode and are arranged parallel to the surface of the earth. Preferably, the apices of adjacent pyramids point in different directions.

[0051] The skilled person will understand that the apparatus according to the first and second aspects of the present invention may be utilized in order to perform the method described above. According to a particular preferred embodiment of the inventive method two or more apparatuses may be arranged in a row, particularly in the same direction as the prevailing wind. Thus, the effect to be achieved by the method according to the present invention may be increased or even multiplied. Additionally or alternatively, two or more parallel rows of apparatuses as described above are arranged in a grid. The grid and in particular the distance between adjacent apparatuses is preferably determined on the basis of the meteorological situation in and/or close to the target region.

[0052] According to a further aspect of the present invention the method described above may be utilized in order to achieve a reverse effect. Accordingly, a method for decreasing precipitation in a first target region is provided. The method comprises the steps of selecting a second target region for increasing precipitation, and increasing precipitation in said second target region by the methods described above. Thereby, a decrease of precipitation in said first target region is caused. The skilled person will understand that all preferred features described above with respect to the method of increasing precipitation may also be used for the method for decreasing precipitation.

[0053] It is further to be understood that all features described with respect to the apparatus may also be utilized to improve the method described above and vice versa.

[0054] The method and the apparatus described above may be utilized for several inventive applications. According to a first aspect, the present invention is directed to the use of the apparatus and/or the method described above for dissipating fog in a target region. The skilled person will understand that the increase of precipitation in a target region using the apparatus and/or the method described above will essentially dissipate all fog present in said target region.

[0055] According to a second aspect the present invention is directed to the use of the apparatus and/or method described above for increasing the cloud coverage in a target region. Thereby, the temperature of the surface of the earth in the target region is decreased.

[0056] According to a third aspect, the present invention is directed to the use of the apparatus and/or method described above for decreasing the probability of the formation and the intensity of cyclones at early stages of their development.

[0057] According to a fourth aspect, the present invention is directed to the use of the apparatus and/or method described above for augmenting the inflow of oceanic moisture inland and moisture recycling in terrestrial areas.

[0058] According to a fifth aspect, the present invention is directed to the use of the apparatus and/or method described above for re-forestation in a target region.

[0059] In one embodiment, invention provides an apparatus for weather modification comprising: an emitter electrode; means for providing the emitter electrode with an electric charge, electrically coupled to the emitter electrode; an insulating support for supporting the emitter electrode at a predetermined height; and means for earthing the apparatus; wherein the emitter electrode comprises a Malter film.

[0060] The Malter film can comprise a thin film of one or more electrically non-conducting materials. The Malter film can comprise one or a combination of the following materials: Al_2O_3, Zn_2SiO_3, SiO_2, ZrO_2, $CaCO_3$, Ta_2O_5.

[0061] The emitter electrode can be a capacitor with a conductive surface. The capacitor can be substantially spherical.

[0062] In some embodiments, the emitter electrode can comprise one or more emitter electrode assemblies of corona discharge, which are mechanically and electrically coupled to each other.

[0063] In some embodiments the support can comprise a rigid structure support can have a height between 6 m and 30 m, preferably between 8 m and 15 m. The support can comprise an insulating layer or be made of insulating material.

[0064] In some embodiments, the means for providing the emitter electrode with an electric charge can comprise a charging engine of a Van der Graaf generator.

[0065] The emitter electrode can be support by a frame of a planar polygonal shape having a surface. The emitter electrode can comprise two or more electrically coupled parallel wire segments traversing the surface of the frame and separated by a distance.

[0066] The emitter electrode can comprise two or more Malter electrodes in the shape of a solid or tubular wire further comprising one or more initiating corona discharge wires. The diameter of the Malter electrodes can be larger

than the diameter of the initiating corona discharge wires. The initiating corona discharge wires can be positioned in the vicinity of and coupled mechanically and electrically to the Malter electrodes. The Malter electrodes can be arranged in parallel segments traversing the surface of the frame and separated by a distance.

[0067] The emitter emitter electrode can comprise two or more Malter electrodes in the shape of foil strips. The emitter electrode can comprise a mesh of wire or a mesh of Malter electrodes.

[0068] Some embodiments of the invention further comprises a generator of high frequency electromagnetic waves for contactless heating of wire loops of the emitter electrode.

[0069] Some embodiments of the invention further comprise one or more earthed electrodes wherein the earthed electrodes are located beneath the one or more emitter electrode assemblies and electrically coupled to the means for earthing.

[0070] Some embodiments of the invention further comprise one or more collector electrodes.

[0071] Some embodiments of the invention further comprise a reservoir containing a conductive electrolyte solution.

[0072] Some embodiments of the invention further comprise an aerosol generator. The aerosol generator can comprise one or more devices percolating an electrolyte solution.

[0073] Some embodiments of the invention further comprise one or more means of generating an updraft.

[0074] Some embodiments of the invention further comprise a heat source. The heat source can comprise a black substance absorbing solar radiation.

[0075] An embodiment of the invention provides: an apparatus for weather modification comprising: a lighter-than-air craft suitable for carrying an emitter electrode; an emitter electrode; means for providing the emitter electrode with an electric charge, electrically coupled to the emitter electrode; and means for earthing the apparatus.

[0076] The lighter-than-air craft can connected to the means for providing the emitter electrode with an electric charge via a tether.

[0077] The lighter-than-air craft can be a lighter-than-air capacitor having a surface. Multiple emitter electrode assemblies can be arranged around and uniformly fixed to the surface of the lighter-than-air capacitor with multiple support rods of variable length. The support rods can have feet contacting the surface of the capacitor which provide a stress-bearing mechanism.

[0078] The emitter electrode can comprise a hollow capacitor with a spherical or quasi-spherical surface and the lighter-than-air craft can be arranged inside the capacitor.

[0079] The one or more emitter electrode assemblies can be arranged around and electrically coupled to the capacitor. The emitter electrode assembly can be a wire mesh surrounding the surface of the lighter-than-air craft. The emitter electrode assembly can be supported by spheres placed between the surface of the lighter-than-air craft and the mesh and the spheres can be uniformly arranged around the lighter-than-air craft.

[0080] Another embodiment of the invention provides: a method of increasing the amount of precipitation in a target region, comprising the following steps:

[0081] a) providing an emitter electrode;

[0082] b) analyzing the meteorological situation in and/or close to the target region; and

[0083] c) providing the emitter electrode with an electric charge in response to the meteorological analysis, thereby causing the emitter electrode to ionize the vicinity of the emitter electrode.

[0084] The method can further comprise the step of elevating the emitter electrode to a predetermined height. The predetermined height can be between 6 m and 30 m, preferably between 8 m and 15 m. The predetermined height can be greater than 100 m, preferably greater than 500 m. The predetermined height can be determined on the basis of the altitude of the clouds in the target region. The predetermined height is at least 50%, preferably at least 65% of the altitude of the clouds in the target region.

[0085] The method can comprise the step of providing an emitter electrode comprises mounting the emitter electrode on an insulating support.

[0086] The step of providing an emitter electrode can comprise elevating the emitter electrode by means of a lighter-than-air craft.

[0087] In the method the emitter electrode can comprise a Malter film. The Malter film can comprise a thin film of one or more electrically non-conducting materials. The Malter film can comprise one or a combination of the following materials: Al_2O_3, Zn_2SiO_3, SiO_2, ZrO_2, $CaCO_3$, Ta_2O_5.

[0088] The method can further comprise the step of moisturizing the soil beneath the emitter electrode with water or a water-based conductive electrolyte solution.

[0089] The one or more collector electrodes comprising sheets of metal or wire mesh can be arranged on the surface of the earth beneath the emitter electrode and electrically coupled to one or more earthed electrodes.

[0090] The method can further comprise the step of providing one or more earthed electrodes.

[0091] In the method a heat source can be placed beneath the emitter electrode.

[0092] The method can further comprise the step of providing a reservoir containing a conductive electrolyte solution, wherein the reservoir is placed on the surface of the earth beneath the emitter electrode and electrically coupled to one or more earthed electrodes.

[0093] The method can further comprise the step of providing a layer of conductive carbon granules on the surface of the earth, wherein the layer is beneath the emitter electrode and electrically coupled to one or more earthed electrodes.

[0094] The method can further comprise the step of providing an aerosol generator, wherein the aerosol generator is placed beneath the emitter electrode.

[0095] Several emitter electrodes can be provided and arranged in an emitter electrode assembly. Several emitter electrode assemblies can be provided.

[0096] The several emitter electrode assemblies can be supported by a frame of planar shape. The emitter electrode assemblies can be electrically coupled to each other and mechanically coupled with flexible joints to each other and to the sides of the frame.

[0097] The frame can be positioned at an angle to the surface of the earth. The angle can be between about 20 and about 70 degrees.

[0098] In the above method, the emitter electrode can comprise two or more electrically coupled parallel wire segments traversing the surface of the frame and separated by a distance. The frame can be triangular and both wire segment ends can be held in place by a number of flexible supports fixed in pairs to each of the two sides of the frame wherein

flexible supports provide a stress-bearing mechanism on the wire segment ends. The frame can be triangular and the wire wound around the frame in one strand through notches on two sides of the frame wherein the notches are provided in pairs on each of the two sides of the frame.

[0099] In the above method, the emitter electrode assemblies can be of isosceles triangular shape and arranged into one or more pyramids with bases containing no emitter electrodes and being parallel to the surface of the earth. The apices of adjacent pyramids can point in different directions.

[0100] In another embodiment of the invention, two or more apparatuses according to the invention can be arranged in a row in the same direction as the prevailing wind. Two or more parallel rows of apparatuses according to the invention can be arranged in a grid.

[0101] In another embodiment of the invention there is provided a method for decreasing precipitation in a first target region comprising the following steps: selecting a second target region for increasing precipitation; and increasing precipitation in said second target region by a method described herein, thereby causing a decrease of precipitation in said first target region.

[0102] The apparatus and/or the methods of the invention can be used for dissipating fog in a target region, or for increasing the cloud coverage and decreasing the temperature of the surface of the Earth in a target region, or for decreasing the probability of the formation and the intensity of cyclones at early stages of their development, or for augmenting the inflow of oceanic moisture inland and moisture recycling in terrestrial areas, or for re-forestation in a target region.

BRIEF DESCRIPTION OF THE DRAWINGS

[0103] In the following preferred embodiments of the invention are described with reference to the drawings, in which:

[0104] FIG. **1** shows a sketch of a preferred embodiment of the apparatus according to the present invention.

[0105] FIG. **2** shows a sketch of another preferred embodiment of the apparatus according to the present invention.

[0106] FIG. **3** shows a further preferred embodiment of the apparatus of the present invention.

[0107] FIG. **4** shows a further preferred embodiment of the apparatus according of the present invention.

[0108] FIG. **5** shows the arrangement of several emitter electrode assemblies on a pyramidal frame according to a preferred embodiment.

[0109] FIGS. **6***a* to **6***d* show details of the arrangement shown in FIG. **5**.

[0110] FIGS. **7***a* and **7***b* show triangular embodiments of elementary emitter electrode assemblies according to the present invention.

[0111] FIG. **8** shows an alternative embodiment of a triangular elementary emitter electrode assembly.

[0112] FIG. **9** shows a further embodiment of a triangular elementary emitter electrode assembly.

[0113] FIG. **10** shows a preferred embodiment of the apparatus according to the present invention.

[0114] FIG. **11** shows an example of the quasi-spherical capacitor according to the present invention.

[0115] FIG. **12** shows an example of a lighter-than-air craft used for the present invention.

[0116] FIG. **13** shows a Malter electrode according to the present invention.

[0117] FIGS. **14** and **15** show a Malter mesh according to the present invention.

[0118] FIG. **16** shows a Malter foil strip according to the present invention.

[0119] FIG. **17** illustrates the trajectory of a water molecule during its collision with an ion.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[0120] In the general method and its implementations described herein, artificial cloud charging is achieved indirectly and remotely with ground-based devices, wherein no techniques for seeding clouds with electrically unstable supercharged droplets are required. The basis of the method is to controllably augment a natural process of cloud charging with engineered means rather than to attempt engineering as an alternative to it. Certain specific, non-limiting embodiments deal primarily with the increasing of precipitation in target areas. Increasing precipitation at a ground area is performed, in various embodiments, by introducing an additional charge on cloud particles in a target region of the atmosphere that is in meteorological relation to the target ground area, which subsequently induces precipitation onto the latter.

[0121] In nature, all clouds are charged, i.e. they contain charged particles, to a certain degree. In thunderstorm clouds, multiple mechanisms of intense internal charging are related to the formation of precipitation, especially ice production, thus creating a positive feedback between cloud electrification and precipitation (MacGorman and Rust, 1988). Global thunderstorm activity is believed to be the dominant charge separator in the model of the global electric circuit (Wilson, 1929), where an electric potential of about 250-300 kV is maintained between the negatively charged Earth and the positively charged ionosphere. Pairs of air ions of opposite polarity (bipolar ionization) are constantly produced in atmospheric air by natural energetic particles, mostly cosmic rays. In fair weather regions, these ions are driven by the so-called fair-weather electric field, the gradient of ionosphere-to-Earth potential, thus forming a leakage electric current, known as fair-weather or ambient current, flowing through the atmospheric column with a density of about 1-4 pA m^{-2}.

[0122] Non-thunderstorm layer clouds, in which internal charging is absent or relatively weak, produce a large proportion of the total precipitation on the Earth. Such clouds are sensitive to external charging by the fair-weather electric current because the electrical conductivity of cloudy air is typically many times less than that of clear air at the same altitude, mainly due to the attachment of ions, the carriers of fair-weather current, to cloud particles (Zhou and Tinsley, 2007). When an approximately downward fair-weather current flows through clear-to-cloudy air interfaces with a high gradient of electrical conductivity, electric charges accumulate on particles of cloud boundaries—positive on the top and negative on the bottom.

[0123] Charge separation in external cloud charging occurs in the following way. The initial charge separation on a microscopic scale occurs when ion pairs are created by energetic particles. Then, due to electric forces in the fair-weather electric field, ions of opposite polarities are dragged apart in opposite directions, positive downward and negative upward. Eventually, some of these ions attach to cloud particles thus charging the latter, positively on the top and negatively on the bottom of cloud boundaries. Any charge separation requires

an energy input. The initial energy input to create ion pairs is provided by energetic particles. The energy input required to separate opposite sign ions to macroscopic distances is provided by the global electric circuit which in this process acts as an electric power generator.

[0124] The average electric charge achieved on cloud particles by external charging is proportional to the fair-weather current density and typically close to the supercharging threshold (Zhou and Tinsley, 2007; Harrison and Ambaum, 2008), which suggests that the supercharged fraction of cloud particles may affect cloud development. On the other hand, observations have provided a large body of evidence that weather variables are strongly correlated with the fair-weather current. Cyclical and irregular variations in solar activity modulate atmospheric ionization and hence the fair-weather current in the lower atmosphere. Recent studies, based on the observed sensitivity of weather variables to solar activity, strongly indicate that the input of cosmic rays is not negligible (Tinsley, 2000; Carslaw at al., 2002; Tinsley and Yu, 2002; Palle et al., 2004; Harrison and Ambaum, 2008). Evidence of the statistical relationship between precipitation and cosmic ray flux was first presented by Kniveton and Todd (2001) and later by Zhao et al. (2004). A comparative analysis of heavy rainfall correlations with cosmic rays, varying with different locations around the Mediterranean basin, was provided by Mavrakis and Lykoudis (2006).

[0125] In principle, weather modification can be achieved by controlling the density of the fair-weather electric current, to which the external charging of non-thunderstorm clouds is sensitive. As producing artificial bipolar ionization in a large volume of atmospheric air is technically difficult, if at all possible, increasing the fair-weather electric field at cloud altitudes is an option. This can be achieved locally by the accumulation of an electric charge on an object situated below the clouds which acts as a charge capacitor. Negative charge is preferable as the direction of the electric field of this capacitor is the same (downwards) as that of the fair-weather electric field. The higher the elevation of the capacitor above the ground, the higher the electric field strength at cloud altitudes. This is also because the electric field of the opposite sign image charge induced by the ground, which is conductive in this context, reduces at cloud altitudes with elevation of the capacitor.

[0126] If the capacitor in the above configuration is a sphere with a conductive surface of radius R, which is a common type of charge capacitor, elevated to height h above the ground and maintained at the potential U relative to the ground, the electric field E at cloud altitude H is given by the following expression:

$$E(H) = 4RU\frac{Hh}{(H^2 - h^2)^2} \tag{1}$$

[0127] Expression (1), which takes account of the above-mentioned effect of image charge, allows one to assess practical requirements for the parameters R, U, and h. To achieve E=120 V/m at cloud base H=600 m, a reasonable enhancement of electric field for clouds at this altitude, which would lead to a several-fold increase in the cloud charging current, a spherical capacitor with R=3 m at h=300 m should be set at a voltage of about U=3.5 MeV.

[0128] As a non-limiting example, the requirements for achieving values of the above parameters by an order of magnitude can be technically met with a Van der Graaf generator (VDGG), the charging engine of which is earthed and the spherical capacitor of which, electrically coupled with the charging engine, is elevated to the required height above the surface of the Earth by a lighter-than-air craft.

[0129] A practical solution is to have a spherical lighter-than-air craft acting as the VDGG capacitor by making its surface electrically conductive, e.g. covering the surface with a metallic foil or a conductive paint. In the embodiment shown in FIG. **1**, this lighter-than-air capacitor **11** can be anchored to the surface of the Earth **12** with a tethering rope **13**, the length of which and thus the capacitor's elevation can be controlled via a reel **14**. The wire **15**, located in the vicinity of the rope by supports **16**, e.g. loops attached to the rope, and wound together with the rope on the reel, electrically couples the capacitor, via another wire **17**, to the (negative) electrode **18** of the VDGG charging engine **19**, the (positive) base of which **110** is electrically coupled to the earthing point **111**. Such a support comprising a lighter-than-air craft and a tethering rope anchored to the surface of the Earth is referred to hereinafter as a tethered support.

[0130] As the electric field of the system fades with distance from the capacitor and only the vertical component of the field is of concern, clouds passing over the latter will be charged during a limited time. The time required for fully charging a cloud can be estimated as follows. Assuming that the cloud is charged, i.e. the electric charge distribution is finally established, the conservation law for the density of space charge p and the vector of fair-weather current density J reduces as follows:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot J = \nabla \cdot J = 0 \tag{2}$$

[0131] It is further assumed that Ohm's law is valid, therefore J and electric field strength E are related via the electrical conductivity of the air σ as:

$$E = \frac{1}{\sigma}J \tag{3}$$

[0132] The Poisson equation which relates E and ρ is

$$\nabla \cdot E = \frac{\rho}{\varepsilon} \tag{4}$$

[0133] In this equation, ∈ is the dielectric permittivity of the air that is approximately equal to that in a vacuum, $\in \sim \in_0 = 8.85\times10^{-12}$ F M^{-1}. The following expression arises by substituting the expression (3) into (4) and taking into account the expression (2):

$$\rho = -\varepsilon J \cdot \nabla\left(\frac{1}{\sigma}\right) \tag{5}$$

[0134] Assuming that the gradient of electrical resistivity 1/σ in (5) is perpendicular to the boundary between clear and cloudy air and the axis of coordinate x is selected along this

gradient, the following expression for the absolute value of the density of space charge can be obtained from (5):

$$|\rho| = \varepsilon J_n \left| \frac{d}{dx}\left(\frac{1}{\sigma}\right) \right| \approx \varepsilon J_n \left| \frac{\Delta(1/\sigma)}{\Delta x} \right| = \frac{\varepsilon J_n}{\Delta x}\left(\frac{1}{\sigma_{cld}} - \frac{1}{\sigma_{air}}\right) = \frac{\varepsilon J_n}{\sigma_{air}} \frac{\gamma - 1}{\Delta x} \quad (5)$$

[0135] Here J_n is the normal (relative to the boundary surface) component of atmospheric current density, Δx is the width of the interface between clear and cloudy air, σ_{cld} is the conductivity of cloudy air, and $\sigma_{air}=\gamma\sigma_{cld}$ is the conductivity of clear air ($\gamma>1$). In many cases it can be approximated that the boundary is flat and parallel to the surface of the Earth, therefore J_n is the vertical component of atmospheric current density. The estimation of time τ required for charge accumulation can be obtained as the ratio of the surface charge on cloud boundary $|\rho|\Delta x$ and current density J_n. As follows from (5), $\tau=\in(\gamma-1)/\sigma_{air}$. For typical values $\sigma_{air}\sim10^{-13}\ \Omega^{-1}\ m^{-1}$ and $\gamma\sim10$, this time $\tau\sim900$ s, or 15 min. Depending on their horizontal velocity, clouds may pass a distance of kilometers during that time; therefore, multiple elevated capacitors should be provided along the direction of cloud motion at a distance between them that assures a reasonably continuous electric field and hence atmospheric current enhancement for the passing clouds. A distance between capacitors in the line, not exceeding twice the distance between the cloud base and capacitors, is a guide.

[0136] In practice, a unit comprising a two-dimensional grid (a cluster) of elevated capacitors (elements) may be required to achieve a sufficient width of cloud charging area. Each capacitor may be at a fixed location or may be mobile, e.g. on a truck or boat. Depending on atmospheric conditions and the achieved degree of influence, the effect may be observed over a period from the beginning of influence ranging from 20-30 minutes to 1-2 hours. Therefore, to achieve the effect in a specified target area under the varying speed and direction of cloud motion and other atmospheric conditions, a network of multiple units, which are selectively operated, is generally required.

[0137] Another approach is based on creating an airborne space charge in an area of atmosphere below the cloud base, which can be achieved from ground-based facilities at elevations lower than those required for the discussed airborne capacitors. Space charge in a volume of air is defined as the sum of charges, taking into account their signs, of all particles (including ions and charged aerosols) contained in this volume. The produced plume of space charge, acting as an airborne charged capacitor, is then elevated by natural and/or artificial updrafts. In contrast to ions, the lifetime of space charge accumulated by aerosols is much longer, typically up to about 20-40 min, which allows the space charge plume to be elevated, depending on the updraft, to altitudes of up to a few kilometers.

[0138] During an operational session, the space charge, preferably negative, should be continuously produced by charging natural or artificial aerosols in a certain location, at a sufficient rate, and at a sufficient height above the ground, which determines the initial plume elevation. In contrast to the discussed case of a charged solid capacitor, clouds may be electrified not necessarily directly above the device, but above the produced space charge plume, which propagates in the atmosphere.

[0139] In order to estimate where the effect will take place if achievable, both the area and degree of cloud electrification, dependant on the space charge plume dynamics, can be predicted based on a set of meteorological data and the characteristics of a particular space charge generator. Many models of aerosol plume dynamics, based on the Gaussian dispersion model and developed over the last few decades for different atmospheric conditions, can be applied to a plume of charged aerosol particles, the motion of which, due to low electrical mobility, is mostly governed by air motions. The basic set of input parameters for a plume model includes the generator's charging rate (i.e. the charge acquired by aerosols per unit of time), the initial plume elevation, the wind speed and direction as well as vertical and horizontal standard deviations of the space charge distribution, which depend on the atmospheric stability class (i.e. a measure of the atmospheric turbulence). Some models developed for certain atmospheric conditions require additional meteorological parameters.

[0140] The method of forecasting artificial cloud electrification is as follows. If atmospheric conditions are favorable, including the presence of suitable clouds, meteorological data including cloud base, cloud cover, and those relevant to the plume modeling parameters are continuously collected and the parameter values are obtained. The data should be collected over a large area of the possible plume propagation, typically over tens of kilometers.

[0141] As the space charge generator's charging rate may depend on atmospheric conditions, which will be discussed later, this rate is also measured and/or modeled based on meteorological data. Next, a model that is most suitable for prevailing atmospheric conditions is selected and run. Having obtained the modeled density profile of the space charge, a two-dimensional profile for the vertical component of the plume's electric field and thus for the associated atmospheric electric current (AEC) near the cloud base at a known altitude can be obtained from the space charge profile by a numerical integration over the volume of plume. In turn, other profiles such as those for the induced space charge densities on cloud boundaries, electric field in the cloud, and charge distribution on cloud particles (provided that their spectra are measured, e.g. with a radiometer) can be obtained, for example, based on the approach of Zhou and Tinsley (2007).

[0142] In weather modification, forecasting models for the results of the applied influence (in this case electrical), which could predict, in particular, the onset and amount of precipitation with an acceptable degree of accuracy, are not available at the current state of the art. It is unlikely that such models will be available in the near future because of the high variability and large number of processes and parameters involved, as well as the current availability of computing power for multi-channel processing with a high resolution.

[0143] The previously described method for cloud electrification modeling could be further extended to achieve some quantitive estimations of the precipitation to be induced, provided that the following method is implemented. At this stage, only statistical approaches can provide a certain degree of confidence that there is a good chance that an applied influence, which is parameterized in a certain way, will produce an effect, which should also be properly parameterized. Correlations between the influence parameters and the effect parameters under similar atmospheric conditions can be statistically quantified based on historical data of weather modification in a particular area using expert systems of artificial intelligence, such as industry standard Hugin or a custom developed implementation. In this method, similarity of atmospheric conditions should also be parameterized, and a

degree of similarity for each parameter, i.e. the maximum acceptable difference of values between cases, should be defined. The set of parameters for the similarity of atmospheric conditions includes but may not be limited to parameters of aerological diagrams and cloud parameters such as cloud type, cloud base altitude, spatial profiles of temperature, ice particle and droplet spectra, supersaturation, etc.

[0144] As in the case of elevated solid capacitors, deploying space charge generators to produce or enhance precipitation in a reasonably large target area under varying atmospheric conditions may require a network of clusters of such generators. To be effective for the purpose of weather modification, space charge generator design should be optimized to achieve the highest possible performance. Preferably, the embodiment should be practical, in particular regarding its deployment and mobility. Facilitating the initial vertical transport of space charge may also be advantageous. As the delivery of charged aerosols into clouds is not required in this method, achieving a high space charge production rate, not necessarily supercharging aerosol particles, is important.

[0145] The concept of a cost-effective space charge generator based on charging natural atmospheric aerosols by corona discharge (unipolar) ions in an open air environment was first introduced by Vonnegut (1962). To test the apparatus outlined in his patent and a hypothesis regarding convective charging by the delivery of natural space charge into clouds, Vonnegut and Moore (1958) deployed a simple EECD comprising a straight **7** km long wire of about 0.25 mm in diameter. In this embodiment, the wire was supported along its length at about 10 m above the ground on 80 metallic antenna masts and connected to the negative electrode of a commercial DC source operating at a voltage of 25 kV. The positive electrode of the DC source was earthed, with the ground acting as the collector electrode of corona discharge.

[0146] Using a thin wire as the emitter electrode is more practical than using needle-type electrodes with sharp tips because the latter become blunt due to electrochemical corrosion, while the corrosion of wire occurs more slowly and nearly uniformly along its length. Thin wire also minimizes the release of hazardous gases such as ozone and nitrogen oxides under an electric field of excessive strength on the surface of the emitter electrode, which can occur when using sharp tips. In contrast, high ion output can be achieved without the discharge of hazardous gases by using a corona discharge under a moderate electric field on a large surface area of wires.

[0147] The basic design of Vonnegut and Moore, however, is impractical in respect of deployment, upsizing, relocation, and maintenance of thin fragile wires. Moreover, supports (masts) may introduce a significant leakage current flowing through them. In a high-voltage environment, any support structure with a conductivity that cannot be absolute zero may introduce a leakage current. Wetting a support structure in moist conditions may increase its conductivity. Due to the leakage current, the ground, which has a finite conductivity, may no longer be considered as conductive, especially at large distances between the earthing electrode (earthing point) of the DC source and the support, which leads to a performance degradation of the emitter electrode caused by reduced voltage on the latter and, possibly, overloading of the DC source.

[0148] A significant improvement to the basic design, as shown in FIG. **2**, is to compact the wire or electrically coupled wire segments into an emitter electrode assembly (EEA) **21**, which is elevated by preferably a single support **22** to a height above the ground and electrically coupled, for example with a suitable wire **23**, to the negative electrode **24** of DC source **25**, the positive electrode of which is electrically coupled with the earthing point **26**. Such a design was proposed in the Russian patent of Rostopchin at al. (2001).

[0149] By definition, an EEA comprises one or more electrically coupled emitter electrodes and a structure which supports them, referred to hereinafter as the emitter electrode frame or simply electrode frame. According to the design of Rostopchin at al., the frame of the EEA is in the shape of an isosceles pyramid, and the wire is wound around the pyramid's sides in a single strand. A single EEA is mounted on a support by means of holders and a bracket (not shown in FIG. **2**). A high-voltage insulator (not shown in FIG. **2**) is positioned between the support and the bracket.

[0150] The ratio of the ion production rate, called the ionic current, to the leakage current is an important performance characteristic of a corona discharge embodiment. Attempts should be made to achieve the highest possible value of the ionic current-to-leakage ratio, which, among other factors, depends on the support quality. The latter is determined by both the support's insulating properties and its ability to carry an EEA with the highest possible ionic current output and therefore having a large mechanical load, i.e. weight and momentum which are mostly contributed by the electrode frame.

[0151] Accordingly, the first improvement to the design of Rostopchin at al. is to exclude the insulator and construct a seamless support from a suitable insulating material. Such measures may reduce the weight and improve both the mechanical strength and the electrical resistivity of the support. In this case, where the support is a rigid vertical structure with two ends, the first of which is fixed to the ground and the second to an EEA, referred to hereinafter as the ground support, a non-limiting example of a suitable support is a telescopic mast made of hollow fiberglass segments and stabilized by three or more tethering ropes fixed to the ground. Such a mast, which is readily transportable in parts and allows easy maintenance of the load, is widely used to support antennas.

[0152] In another improved embodiment proposed herein, a tethering support for an EEA elevated by a lighter-than-air craft is alternatively used, which is especially advantageous if the elevation height needs to be readily varied, e.g. for maintenance purposes, or the required height is difficult to achieve with a ground support, which, as will be discussed later, is often the case.

[0153] A non-limiting example demonstrating the concept of a tethered support is an embodiment shown in FIG. **3**. A lighter-than-air craft **31** is mechanically coupled with a rope or a pivot joint **32** to the first end of a support rod **33**, carrying an EEA **34** (i.e. fixed to its frame). The upper end of the tethering support rope **35**, the length of which is controlled by the reel **36**, is fixed to the support rod. The wire **37**, located in the vicinity of the rope by supports **38**, e.g. loops attached to the rope, and wound together with the rope on the reel, is electrically coupled with another wire **39** to the first (negative) electrode **310** of a DC source **311**, e.g. the charging engine of a VDGG, the second (positive) electrode of which **312** is electrically coupled to the earthing point **313**.

[0154] Regardless of the support type, it is recommended that support parts, e.g. mast and ropes, are covered with a film of an insulating fat-like water repellent substance to prevent

the accumulation of continuous conductive water film on those parts under wet conditions.

[0155] Even if the leakage current is minimized, achieving a high ionic current may introduce the abovementioned problem of the loss of voltage on the emitter electrode due to the finite conductivity of the ground. A further improvement to the embodiment (see FIG. **2**) is to introduce one or more earthing points **27** in the vicinity of corona discharge, electrically coupled, for example with a suitable wire **28**, with the earthing point of a DC source. The number of earthing points required depends on the consumption current, type of ground, and the ground area beneath an EEA towards which most of the generated ions move. For negative corona discharge, this area is referred to hereinafter as the anode area. In order to charge aerosols in a larger volume of air, a larger anode area is preferred. As a guide, the radius of anode area should be at least equal to the EEA's elevation height. Type of ground and consumption current define the density of earthing points in the anode area required to maintain a sufficient conductivity of the latter. For example, if the ground is wet soil and the consumption current is about 100-200 and a single earthing point is introduced beneath an EEA operating under a voltage of 70 kV, the anode area would have a radius up to 5-8 m. If the soil is dry, a grid of earthing points covering the anode area which are electrically coupled to each other and to the earthing point of a DC source is required. In this case, the distance between neighboring earthing points arranged in a grid should be 1-2 m. Earthing points, which are typically earthed rods made of conductive material, e.g. a metal, should be deep and preferably reach soil layers which are wetter than the surface, if any. For average soil, the minimum recommended depth of an earthed rod is about 0.5 m. For dry soil, the minimum depth should be greater.

[0156] Alternatively or additionally to deploying a larger number of earthing points, the conductivity of the soil in the anode area may be increased by moisturizing (watering) during operations of the space charge generator. Preferably, the soil is moisturized with an environmentally friendly electrolyte such as a water solution with a common mineral that suppresses vegetation growth under the ion generator, i.e. salt water, in order to minimize the positive corona discharge on vegetation tips.

[0157] Additionally or alternatively, especially in cases where moisturizing is inefficient or impractical, e.g. if the installation surface is the roof of a building or rocky terrain, other types of collector electrode of corona discharge rather than the ground may be introduced to replace or augment the soil in the anode area. Accordingly, in some embodiments (see FIG. **2**), a highly conductive collector electrode **29**, such as one or more sheets of metal or wire mesh, may be positioned on the ground and electrically coupled, for example with a suitable wire, directly to the grounded electrode of the DC source.

[0158] In yet other embodiments, as shown in FIG. **4**, a reservoir **41** filled with a conductive electrolyte solution, such as salt water, may be electrically coupled to the local earthing point **42** and to the earthing point **43** of the DC source **44** with a wire **45**, and may be placed under the EEA **46**, which is elevated by a ground support **47**, acting as the collector electrode of corona discharge. In this case, percolating the electrolyte solution, for example with streams of air, may generate artificial aerosols **48** from residues of evaporating electrolyte drops released by bursting bubbles in addition to improving soil conductivity.

[0159] Techniques for improving the effectiveness of the surface of the Earth as a collector electrode and/or for introducing other collector electrodes as discussed are also applicable to embodiments with the tethering support. For example, the performance of the embodiment shown in FIG. **3** may be improved, as previously discussed, by introducing additional earthing points **314** and additional collector electrodes of corona discharge (not shown) coupled to the earthing point **313** of a DC source **311**.

[0160] According to the design of Rostopchin at al., pyramid surfaces traversed by wire segments are arranged at an angle to the surface of the Earth. Two advantages of such an embodiment of the EEA are that the produced space charge is removed and fresh atmospheric aerosols are supplied for charging by horizontal winds, and the number of passes of the same air parcels containing space charge through the wires, which reduces their ion generation performance, is minimized. The optimal value of this angle ranges between about 20-70 degrees under common atmospheric conditions.

[0161] In the EEA embodiment of Rostopchin at al., a higher ionic current can be achieved by using a thinner wire, increasing wiring density, using a larger frame, or by a combination of these. Certain limitations, however, apply to the latter due to the limited mechanical performance of the frame.

[0162] The separation distance between wire segments determines the density of wiring. This density cannot be increased indefinitely. For a particular segment, the electric field from other segments affects the production of ions. For given values of voltage and wire thickness, there is a certain limit for the separation distance after which adding new wire segments on a frame will not lead to a significant increase in ion productivity. For a voltage of 50-70 kV and a wire with 0.1-0.2 mm diameter, this separation distance is about 1.5-3 cm. Under a given voltage, increasing the maximum efficient density of wiring requires using a thinner wire.

[0163] The thinner the wire is, the more sensitive it is to degradation by corrosion and the higher the requirements for its corrosion resistance. A non-limiting example of commercially available wire suitable for this purpose is one with a diameter of 0.1-0.2 mm made of monel, a highly corrosion resistant Ni+Co+Cu-based alloy.

[0164] The thinner the wire is, the stiffer (i.e. more dimensionally stable) the frame should be to support it. If using thinner wire and/or increasing the frame size, thicker and heavier planks or rods should be used, which defeats the purpose of achieving the highest possible length of wiring and hence ion output at a given weight of an EEA.

[0165] One solution to the problem is to use a number of smaller EEAs instead of one large EEA, in this case using a pyramidal frame. A non-limiting example of such an embodiment **50** is shown in FIG. **5** where six EEAs in the shape of a triangular pyramid are deployed. By way of a non-limiting example, the apexes **51***a* and **52***a* of adjacent EEAs **51** and **52** point alternatively upward and downward respectively. This design enables optimal ventilation by horizontal winds and reduces the number of passes of the same air parcels containing space charge through the EEAs **51** and **52**. For extra stability, the apexes of upward oriented pyramids are connected by rods **53** which do not carry a strong load and therefore can be lightweight. In turn, these rods are connected with rods or support ropes **54** to a plate **55** attached to the top of the mast **56**. In a similar way, the apexes of downward

oriented pyramids are connected by rods **57** which, in turn, are connected with rods or support ropes **58** to the bracket **59** attached to the mast.

[0166] A non-limiting example of a practical implementation of this design is shown in FIG. **6***a* where the bases of upward oriented pyramids **61***a* and the bases of downward oriented pyramids **62***a* are arranged in different planes **63***a* and **64***a* respectively. The edges of pyramid bases in different planes are mechanically coupled with supports **61***b* in FIG. **6***b*, preferably allowing a certain degree of flexibility. In each plane, as shown in FIG. **6***c*, the edges of the corresponding pyramids **61***c* are fixed to the support plate **62***c* with bolts and nuts **63***c*. As shown in FIG. **6***d*, the support plate **62***d* of each plane, to which the edges of the pyramid bases **61***d* are fixed with bolts and nuts **63***d*, is fixed at a certain position along the mast **66***d* with top and bottom brackets **64***d* and **65***d* respectively.

[0167] A pyramidal shape, however, is not the only one optimal for an EEA. A large variety of EEAs can be implemented in a modular design where frames of a planar shape, the surfaces of which are traversed by at least two parallel segments and preferably arranged at an angle to the surface of the Earth, are mechanically and electrically coupled to each other. Such an EEA module comprising a planar frame and the supported wire segments of an EECD arranged parallel to each other with a separation distance between them is referred to hereinafter as an elementary EEA (EEEA).

[0168] In general, the shape of an EEEA frame can be polygonal, but mechanically the most stable shape is triangular. Because of their planar shape, pre-assembled EEEAs can be easily transported in large quantities and EEAs can be assembled from and disassembled into EEEAs at an installation site.

[0169] As a non-limiting example, an EEA of pyramidal shape can be assembled from three or more EEEAs with the same size and shape of isosceles triangles. Compared to a pyramidal EEA where the wire segments form a continuous wire, that is, a wire that is wound around the whole frame in one strand, this embodiment is more robust as breaking the wire, e.g. by a bird, will disrupt a smaller fraction of wiring.

[0170] The sides of an EEEA frame, which can be rods or planks, for example, can be made of conductive or non-conductive materials. If a metal frame is used, e.g. made of hollow tubes, care should be taken to prevent the wire from coming into immediate contact in the open air with the frame made of a different metal. Otherwise, wire segments may be quickly destroyed at contact points in the electrochemically corrosive environment and thus fall apart.

[0171] By way of a non-limiting example, in one triangular embodiment of EEEA **70***a* shown in FIG. **7***a*, a number of wire segment supports **71***a*, for example in a hook-like shape, are fixed in pairs to each of two sides **72***a* and **73***a* of the frame along their length, each holding the corresponding end of wire segment **74***a* (inset). The wire segments may form a continuous wire or be wound around the supports in more than one strand. The ends of these strands (in this case a single strand is shown) are fixed at points **75***a* and **76***a*, via which this EEEA is electrically coupled to other EEEAs, which may be electrically coupled to make this EEEA less prone to wire breakage. Using non-metallic supports or those made of the same metal as the wire which are flexible to a certain degree, is preferable, as this may reduce stress on the wire if the sides of the frame are slightly bent under variable external forces. The vertical post of supports may also be made in the form of a spring. A spring-based support **71***b* on the inward side of the frame is shown in FIG. **7***b* (inset).

[0172] In preferred embodiments, a solution proposed herein is to separate the weight bearing frame structure from the wire supporting frame structures, but to have them flexibly coupled. In this configuration, a number of smaller EEEAs with lightweight frames which are stiff enough to support denser wiring with thinner wire are coupled with flexible joints to each other and to a weight bearing (external) planar frame. If the wiring of an EEEA is broken, this EEEA can be quickly replaced without the need for re-wiring it onsite. As a non-limiting example, a flexible joint can be a spring or a zigzag shaped piece of a suitable wire acting as a spring. As in the case of elementary frames, larger EEA structures can be assembled from external frames supporting EEEAs.

[0173] FIG. **8** illustrates a non-limiting example of how a triangular EEEA **80** can accommodate a larger total length of thinner wire **81** by making the frame **82** external for a number of smaller EEEAs **83** connected with flexible joints **84**.

[0174] By way of a non-limiting example, another triangular embodiment of an EEEA **90** to be supported by an external frame is shown in FIG. **9**. Frame **91**, made of flat planks of an insulating material, for example painted wood, has notches **92** on each of two sides of the frame along their length, through which the wire **93** is wound around the frame as shown, forming parallel segments between notches on the opposite sides of the frame (wire on the opposite side of the frame is shown as a dashed line). The ends of the wire strand are fixed at points **94** and **95**, via which this EEEA is electrically coupled to other EEEAs, and can be optionally electrically coupled.

[0175] Alternatively or additionally to using external frames which support smaller EEEAs with flexible joints, a wire mesh can be used as an emitter electrode instead of parallel wire segments. By using such a mesh in EEEAs, which is self-supporting to a certain degree, larger frames can be used as mesh is much less sensitive to frame deformations than wires. Attaching mesh to the frame may be achieved in different ways without the need for multiple supports or notches in the case of wire segments. Compared to the latter, conductive mesh is more robust against breaks both mechanically and electrically. Replacing broken or corroded mesh is also easier.

[0176] Rostopchin at al. noted that operating an EEA at sub-zero temperatures causes the accumulation of frost on the wire, which reduces its performance as the emitter electrode. To combat this problem, they suggested using an electric heater and fan, blowing warm air towards the EEA. Rostopchin at al. recognized that this technique does not work satisfactorily in the presence of a strong wind, which removes the stream of warm air before it reaches the EEA.

[0177] A practical solution to the problem would be to make the wire self-heating by passing a low-voltage current through it. Arranging a low-voltage circuit with a conventional source of electricity such as a transformer is problematic as the electrical separation of high-voltage and low-voltage circuits can be technically difficult and a leakage current may be introduced. The solution proposed herein is to deploy a source of electromagnetic emission, such as a microwave generator with a suitable antenna, to heat the emitter electrode remotely without direct electrical contact. In this case, an electric current is induced in closed wire circuits, such as a

wire mesh segment or a wire strand with electrically coupled ends which are parts of the emitter electrode, causing the latter to warm.

[0178] The elevation height of an EEA above the ground is an important parameter, which determines aerosol charging efficiency. Ions produced by an EEA tend to flow towards the collector electrode of corona discharge, i.e. downward. Their motion is mostly governed by a strong electric field close to the emitter electrode and, at larger distances from the latter, both by wind and the electric field. As a large proportion of atmospheric aerosols become charged between the EEA and the surface of the Earth, the elevation of the EEA should be preferably high enough to ensure that most of the produced ions are attached to aerosols before they are wasted by recombination when reaching the surface of the Earth.

[0179] In still air, this optimal elevation height depends on the spectrum and especially on the number concentration of aerosol particles in atmospheric air, which determine the lifetime of ions in the relatively aerosol-rich terrestrial air where ion recombination can be negligible. Under most conditions, this time usually ranges between 3 and 8 minutes.

[0180] Therefore, the optimal elevation height in still air can be estimated as the distance to which ions can travel between the EEA and the surface of the Earth during their lifetime. In practice, this distance for a particular EEA embodiment can be found experimentally by measuring the spatial electric field profile beneath the EEA and the subsequent numerical calculation of the charged particle trajectory (and thus its vertical path) during the ion lifetime, which can also be measured using existing techniques.

[0181] Alternatively, the optimal elevation height can be found experimentally by measuring the concentration of negative ions at increasing elevation heights of the EEA. A substantial reduction in ion concentration after a certain elevation would indicate that the optimal elevation has been reached.

[0182] In practice, the optimal elevation height, according to experimental studies by Jones and Hutchinson (1975) on producing space charge plumes using a basic point-to-ground corona discharge unit in the presence of wind, should be at least about 9 m. Deploying more advanced embodiments of EEAs such as those proposed herein would probably require even higher elevations. If achieving the optimal height is difficult with a ground support, more space charge generators and/or generator(s) with tethered supports should be deployed.

[0183] If deploying more space charge generators to compensate for their performance degradation due to a lower than optimal elevation height, the height should be at least 6 m.

[0184] In this regard, embodiments with a tethered support may be preferred. The higher the elevation of an EEA, the higher operating voltage required to achieve the same ionic current. In this regard, using a VDGG as an alternative to commercial DC sources can be advantageous. In this case, a lighter-than-air spherical capacitor of a VDGG can be used as a lighter-than-air craft. In embodiments of this kind shown in FIG. **10**, the frame **101** of an EEA can be positioned around the surface of the lighter-than-air spherical capacitor (craft) **102** with multiple support rods **103** and feet **104**, uniformly distributed over the surface. The tethering rope **105** fixed to the lighter-than-air spherical capacitor (craft) and the wire **106** electrically coupled to the EEA are connected to other components of this embodiment (not enumerated) in the same fashion as in FIG. **3**. As the craft may be inflatable and its radius may vary, support rods should be of variable length and provide a stress-bearing mechanism on their feet, e.g. by incorporating a spring.

[0185] Alternatively, as shown in FIG. **11**, the frame **111** of an EEA is fixed by non-flexible support rods **112** around the surface of the spherical or quazi-spherical capacitor, which is not a lighter-than-air craft. As a non-limiting example, a quazi-spherical capacitor can be assembled from lightweight sheets **113** with conductive external surfaces, e.g. made of plastic and covered with a conductive paint, electrically coupled and joined mechanically. As a non-limiting example, such sheets can be cut and arranged like swatches on a soccer ball surface. An initially deflated balloon is placed inside the capacitor and then inflated with a lighter-than-air gas, e.g. helium, until it occupies the volume of the capacitor, making the latter buoyant.

[0186] Another proposed lighter-than-air embodiment **120** is shown in FIG. **12**. Sections of wire mesh or EEEAs with either mesh or parallel wire segments **121** are electrically coupled and joined mechanically, forming an EEA of a quazi-spherical shape. If framed EEEAs are used, using flexible joints connecting the sides of the frames is preferred as previously discussed. Inflated spheres **122** are uniformly distributed over and attached, e.g. by small loops, to the inward side of the surface of the mesh. If framed EEEAs are used in this embodiment, the spheres are attached to pairs of joined-frame sides. A balloon **123** is placed inside the EEA and then inflated with a lighter-than-air gas until the spheres provide a stress-bearing support for the EEA. In this configuration, a sufficiently large EEA with a diameter of several meters may act as both the emitter electrode and the capacitor as in this case the system possesses its own (significant) capacity.

[0187] At EEA elevation heights achievable with a tethered support which can reach hundreds of meters, the ionic current flowing out of the EEA in other than downward directions may not be negligible. This is because the electric field of the positive charge left on the ground which, along with the electric field of the produced space charge governs the downward ion flow, decreases with elevation height. Therefore, a uniform distribution of the surface of an EEA around the lighter-than-air craft or capacitor, where most of the ions depart from the EEA and initially propagate in all directions, is recommended.

[0188] A significant enhancement of the produced ionic current can be achieved by introducing the Malter effect in the above embodiments. Malter (1936) observed that when a thin film of some non-conducting substances such as Al_2O_3, Zn_2SiO_3, SiO_2, ZrO_2, $CaCO_3$, Ta_2O_5 and a few other oxides is applied to a cathode which is subject to bombardment by electrons, secondary electron emission occurs from the surface of film. Such an electrode is referred to hereinafter as a Malter electrode. Secondary electron emission leaves a net positive charge on the surface of the film of the Malter electrode, referred to hereinafter as Malter film, causing a strong electric field across the Malter film layer. As the Malter film is not conductive, the positive charge does not neutralize as fast as it builds up, causing the film layer to act as a dielectric medium of a capacitor, the "plates" of which are oppositely charged film and cathode surfaces. Electrons emitted on the cathode surface in the highly intensive electric field are further tunneled through the Malter film and released into the air, ultimately forming negatively charged molecular clusters, i.e. negative ions. For the Malter effect to occur there must be an initiating source of particles or ionizing radiation (e.g. high

energy electrons, ions, X-rays, ultraviolet radiation) capable of removing electrons from the film surface. Also, the electron emission rate of the cathode must be greater than the rate of removal of the positive charge from the film surface. If the Malter electrode is bombarded by electrons, the ionic current emitted by this electrode, depending upon conditions, may be up to several thousand times greater than the primary bombarding current (Hawkes, 1992).

[0189] As a non-limiting example, a higher ionic current produced by an EEEA can be achieved, as illustrated in FIG. **13**, by the introduction of additional Malter electrodes **131** in the form of segments of a thicker wire coated with a Malter film, which are parallel and electrically coupled, for example by soldering points **132** on film-free areas **133** to thin wire segments **134**. The latter act primarily as initiating sources for the adjacent Malter electrode, which also can be based on a hollow wire (tube) instead of a solid wire to minimize weight. For simplicity, tubular wire is referred to hereinafter as wire. Such a wire couple **130** substitutes ordinary wires in the discussed embodiments. The diameter of Malter wires should be large enough and thin wires should be close enough to Malter wires to assure the effective bombardment of the latter by the emitted electrons and ions. As the electric field strength on the surface of a wire is inversely proportional to the diameter of the latter, the bombarding electrons and negative ions, decelerated by the electric field of the Malter wire, can reach the surface of this wire and provide the impact required for the secondary emission if the diameter of Malter wire is sufficiently large. Moreover, wires with a larger diameter provide a higher ionization output per unit length as their emitting surface is larger. More than one corona initiating wire per Malter wire can be used.

[0190] A similar approach of introducing the Malter effect can be taken if the emitter electrode is a mesh as shown in FIG. **14** where the segment of a Malter mesh **140** is shown above (left picture) and below (right picture) the surface of the mesh. Thin wires **141** are positioned as discussed above and soldered at points **142** to the first set of parallel wires **143** of a thick wire mesh covered with a Malter film. In the same way, thin wires **144** are also positioned below and soldered at points **145** to the second set of parallel mesh wires **146**, which are perpendicular to wires **142** of the first set. If the second set of mesh wires is above the first one (e.g. wires of the upper set are welded to wires of the lower set), another arrangement of thin wire is given in FIG. **15** where the segment of a Malter mesh **150** is shown above (left picture) and below (right picture) the surface of the mesh. On the left picture, thin wires **151** are positioned above the wires **152** of the first (bottom) set by soldering at points **153** to the wires **154** of the second (top) set of Malter mesh wires. On the right picture, thin wires **155** are positioned below the wires of the second set by soldering at points **156** to the wires of the first set of Malter mesh wires.

[0191] Alternatively, the Malter electrode can be a metal foil, one or both surfaces of which are coated with a Malter film. Such a Malter electrode is referred to hereinafter as Malter foil. In this configuration, thin "igniting" corona wires are located in the vicinity and fixed to one or both surfaces of Malter foil as previously discussed in the case of Malter wire. A non-limiting example of such a configuration where the Malter foil is a strip is shown in FIG. **16**. One or more thin wires **161** are positioned above and fixed to one or both surfaces **162** of the Malter electrode at points **163**. As in the case of a pair of ordinary and Malter wires, such an electrode substitutes wires in the discussed EEEAs. Accordingly, a wire mesh can be substituted by a mesh made of strips of Malter foil with corona wires fixed preferably to both active surfaces of the foil.

[0192] For the embodiment illustrated in FIG. **12**, another alternative is to substitute the whole surface of wire mesh or wire segments in EEEAs by a Malter foil with corona wires on its outer surface.

[0193] If the concentration of aerosols in the atmosphere is low, some embodiments may comprise a generator of artificial aerosols, such as, for example, manufactured by TSI Incorporated, of Shoreview, Minn., USA, to increase the amount of aerosols in the air surrounding and especially below the EEA. Preferably, the aerosol generator is located below the EEA of the space charge generator. A reservoir with a percolated solute, used as an alternative or additional collector electrode as previously discussed, may also be used.

[0194] Air motions, such as horizontal wind and vertical updrafts, increase the efficiency of aerosol charging by removing air parcels containing charged aerosols and supplying air parcels with fresh aerosols. Also, the optimal elevation height may be decreased due to air motions. In this regard, creating artificial air motions is advantageous, especially updrafts which increase the initial elevation of the space charge plume.

[0195] Accordingly, in some embodiments, a fan or a heat source may be placed below the EEA. Burners of various types, which can also act as aerosol generators, can be deployed as heat sources. If a wire mesh is used as an additional or alternative collector electrode of corona discharge, it can be made a heat source by elevating it to a short distance from the ground and passing a low-voltage strong electric current, e.g. from a transformer, through it. Heating with solar radiation can be achieved by providing a "heat island" around the space charge generator, i.e. a black surface, of a conductive material which can also act as a collector electrode of corona discharge. A practical solution is to coat the ground with black and conductive granules of a carbon substance, e.g. natural coal.

[0196] In addition to charging atmospheric aerosols leading to RCC via augmenting the fair-weather current, a corona discharge generating a sufficiently high AEC of unipolar ions may produce another effect which is the modification of the relative humidity profile in the atmosphere. As a result, a vertical motion of moistened air parcels facilitating the elevation of space charge plume may be produced and atmospheric instability may be locally produced or augmented. The latter, under favorable atmospheric conditions, may lead to facilitating cloud formation.

[0197] The physical mechanism of separation of atmospheric moisture (water vapor) from other air components leading to the re-distribution of the vapor and referred to hereinafter as selective moisture transport (SMT), is as follows. Collisions between a moving ion and air molecules cause a momentum transfer from the former to the latter, which, per unit of time, appears as a viscosity force acting on the ion. In the absence of an electric field, this process is random (Brownian) and the average macroscopic momentum transfer is zero. In DC corona discharge, however, most of the generated ions are of the same (negative) charge and therefore most of them move in the same direction. As the motion of ions is organized in this way, the momentum transfer from ions to air molecules appears on a macroscopic scale as a force exerted on the air and causing it to flow as "ionic wind" in the prevailing direction of ion motion. In prior studies,

however, it had escaped attention that the generated "ion wind" accelerates water vapor to a degree significantly higher compared to other air components, causing the vapor to move ahead of other components in the air flow.

[0198] In contrast to molecules of other air components, a molecule of water (H_2O) possesses its own electrical dipole moment. Due to an attractive charge-to-dipole electric force between ion and water molecules, the latter may collide with the ion and thus gain momentum transferred from the latter, while collisions of other air molecules with the ion may not be geometrically possible.

[0199] Trajectories of water vs. non-water molecules are shown in FIG. **17**, illustrating the effect of the increased collision cross-section for a water molecule with a trajectory **171**, moving parallel to axis X at a distance r from it (collision distance) towards an air ion **172** of radius R. Non-water molecules moving parallel to the axis X at a distance r from it can collide with the ion only if $r<R$. In contrast, due to the attractive charge-to-dipole electric force, those water molecules with a collision distance $R<r<\rho$, where ρ is their maximum collision distance, can also collide with the ion. In this regard, water molecules behave differently to other air molecules while colliding with atmospheric ions and this difference is described in terms of the collision cross-section, determined in this case by maximum collision distance. As $\rho>R$, the collision cross-section of water molecules is larger than that of non-water molecules.

[0200] The collision cross-section ratio of water to non-water molecules, called the enhancement factor, has been estimated by Nadykto et al., (2003). For typical air ions with diameters of 0.6 nm, the enhancement factor was found to be about 7. For water molecular clusters with dipole moments larger than those of the water molecule H_2O, such as water dimer $(H_2O)_2$ and others $((H_2O)_n, n>2)$ which appear in higher concentrations when vapor is closer to saturation, the enhancement factor values were found to be even higher. The larger the ion-to-molecule collision cross-section, the larger the number of ion-to-molecule collisions and thus the greater the momentum transferred to molecules in a volume of air per unit of time, i.e. the macroscopic force exerted on this volume of air. Accordingly, this average force per molecule is larger for water molecules, i.e. they gain a higher acceleration. This process of SMT may lead to increasing relative humidity in some areas of air at the expense of dehydration in others areas from which the moisture is taken, i.e. parcels of moistened and dehydrated air are initially formed.

[0201] As the number of molecules of all components in a volume of air is constant at a given temperature and pressure and the molar mass of water (18 g/mol) is less than that of dry air (29 g/mol), an increase in humidity reduces the density of the air and vice versa. According to Archimedes' principle, dehydrated air parcels descend while moistened ones ascend. This continuous process appears as upward moisture transport on a larger scale, leading to the formation of an initially elevated air mass with artificially increased humidity. When ascending, artificially moistened air parcels are adiabatically cooled at a lower rate than natural air parcels, and hence have a relatively low adiabatic (temperature) lapse rate. As atmospheric instability results from the difference between the adiabatic lapse rate of an air mass and the ambient lapse rate in the atmosphere, an air mass moistened by the SMT may be less stable than that formed by natural convection. Under certain atmospheric conditions, the effect of the locally increased instability may lead to the condensation of vapor in the moistened air masses, which augments the latter's buoyancy by the release of latent heat and ultimately forms clouds. This process may occur at lower altitudes than in the case of naturally moistened air masses or may occur only in artificially moistened air masses, and its expansion to a larger scale may be possible if the atmosphere is nearly or weakly unstable for natural air masses. The ascent by convergence of neighboring moist air masses towards the area of artificial updraft, which initially may be a small influence, can trigger a change of dynamics of the natural air masses by releasing latent heat. Although achievable only on some occasions, this effect is unique with respect to other existing methods of weather modification.

[0202] The elevation height of an EEA that is optimal for SMT is generally lower than that for optimal aerosol charging as the density of the AEC, not just the concentration of ions, is important. Charging the largest possible amount of natural or artificial aerosols is not desirable in this case as the space charge produced in the path of the AEC flow, unless removed at a high rate, e.g. by a strong wind, reduces the density of the AEC. If the primary purpose of operating a corona discharge embodiment is to achieve the maximum possible SMT, no artificial aerosols should be produced and the recombination of the generated ions on the anode area should be favored by selecting a lower EEA elevation height. To achieve a higher density of the AEC, using a smaller anode area than in the case of aerosol charging is also recommended. For a particular embodiment, the simplest way of selecting the optimal elevation height of the EEA, which governs the balance between the achievable AEC and the air volume where the SMT takes place, is experimental.

[0203] A decrease in precipitation in a target area can be achieved by a planned increase of precipitation in a different area, whereby the area targeted for the decrease of precipitation will be in the precipitation shadow of the area where the precipitation was induced.

[0204] Individual space charge generators may be controlled manually or automatically from a centralized location. Depending on a particular application, the embodiments as described above are placed on all relevant types of conveyances (stationary or mobile) on the ground or in the water. In the latter case, a platform on a body of water provided with an anode area electrically coupled with an earthing electrode submerged into the water is required.

[0205] For other applications of weather modification apart from increasing or decreasing precipitation in a target area, influencing physical processes which are responsible for an effect or effects generally require specific methods and specific parameters for the deployed embodiments, such as the elevation height of a charged capacitor or EEA and the anode area of the latter.

[0206] For the dispersion of fog, which is cloud located on or near the surface of the Earth, one approach is to position the charged capacitor or an EEA of corona discharge above the fog layer with a tethered support to cause the accumulation of space charge on the boundary of the fog layer. To achieve the effect in a reasonably large area, multiple lighter-than-air embodiments should be deployed and/or an embodiment or embodiments should be moved to dissipate different fog areas. In this configuration, the fog layer should be thick enough for the efficient collection of smaller fog particles by larger ones, which may not take place in all cases. The alternative solution is to deploy corona discharge embodiments inside the fog layer operating in an optimal regime for SMT.

In dehydrated air parcels, the fog dissipates by droplet evaporation, while in moistened air parcels the droplets and ice crystals, if any, grow large and sediment by the force of gravity, possibly collecting fog particles as they descend. The updraft caused by the release of latent heat favors the formation of larger particles suspended and grown for a longer time and causes the convergence of the neighboring foggy air to be modified by the SMT. This convergence may be augmented by the ongoing removal of supersaturated vapor by condensation and, if a fog is cold, by growing ice crystals, leading to the reduction of the vapor partial pressure.

[0207] In order to initially disperse fog below an EEA, the aerosol particles of which are charged and thus reduce the AEC, the initial elevation height of an EEA should preferably be low and then gradually increased to an optimal value. Alternatively, corona discharge embodiment or embodiments should start operating before the forecasted occurrence of fog, i.e. in fog prevention mode.

[0208] Another application is the reduction of the temperature of the surface of the Earth. Non-limiting examples of this application are energy savings in populated areas and the reduction of sea surface temperature for a long period over large areas in order to reduce the occurrence and intensity of cyclones as their genesis is dependent on the water temperature. During daytime, cloud cover at low altitudes which reflects solar radiation back into space can be created or augmented at times of favorable atmospheric conditions by operating corona embodiments in the SMT mode. At nighttime, low cloud cover which reduces the emission of infrared radiation into space can be reduced or removed by enhancing precipitation in a target area by deploying charged capacitors or corona discharge embodiments in the aerosol charging mode as discussed. In this application, the effect can still be achieved even if the size of precipitation hydrometeors is small and they cannot reach the surface of the Earth, however cloud dissipation can be achieved. To some degree, the effect still can be achieved if fewer and larger but not precipitating cloud particles are produced by the influence. In this case, cloud transparency for the outgoing infrared radiation may be increased.

[0209] In nature, vegetation cover, especially forests, produces moistened parcels of air due to high evaporation over a large surface of leafs, which may increase atmospheric instability as previously discussed. Near shorelines, large forested areas increase the inflow of sea moisture inland and maintain a healthy hydrological cycle by moisture recycling (precipitation-evaporation-precipitation) over large distances from the shore (Makarieva and Gorshkov, 2007). In this regard, a large array of corona discharge embodiments which operate for a long period in SMT mode aiming to increase atmospheric instability when possible, and in RCC mode aiming to enhance precipitation over land if suitable clouds are present, may substitute the forest cover in deforested areas facilitating their re-forestation, until the cover is restored. To improve the hydrological cycle over large distances inland by augmenting moisture recycling as forests do, a large network of controlled embodiment grids (units) covering un-forested areas up to hundreds of kilometers from the shoreline may be required. The same approach can be taken for accelerated afforestation in forest farming which may provide a number of other benefits such as carbon sequestration, production of renewable bio-fuels and renewable timber which stores the sequestered carbon and, in many cases, can replace other materials that consume a large amount of energy in their production.

[0210] Although the invention herein has been described with reference to particular embodiments, it is to be understood that these embodiments are merely illustrative of the principles and applications of the present invention. It is therefore to be understood that numerous modifications may be made to the illustrative embodiments and that other arrangements may be devised without departing from the spirit and scope of the present invention which is defined by the following claims.

LIST OF ABBREVIATIONS

[0211] AEC Atmospheric Electric Current
[0212] CN Condensation Nuclei
[0213] DC Direct Current
[0214] EEA Emitter Electrode Assembly
[0215] EECD Emitter Electrode of Corona Discharge
[0216] EEEA Elementary Emitter Electrode Assembly
[0217] IN Ice Nuclei
[0218] RCC Remote Cloud Charging
[0219] SMT Selective Moisture Transport
[0220] VDGG Van der Graaf Generator

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1-76. (canceled)

77. A method of increasing the amount of precipitation in a target region, comprising the following steps:

a) providing an emitter electrode at a predetermined height;

b) analyzing the meteorological situation in and/or close to the target region; and

c) providing the emitter electrode with an electric charge in response to the meteorological analysis, thereby causing the emitter electrode to ionize the vicinity of the emitter electrode.

78. The method of claim **77**, wherein the charged emitter electrode acts as a charge capacitor.

79. The method of claim **77**, wherein the fair-weather electric current at cloud altitude is increased by the charged emitter electrode.

80. The method of claim **77**, wherein cloud particles present in the target region are being charged by means of the charged emitter electrode.

81. The method of claim **77**, wherein the predetermined height is determined on the basis of the altitude of the clouds in the target region.

82. The method of claim **77**, wherein the predetermined height is at least 50%, preferably at least 65% of the altitude of the clouds in the target region.

83. The method of claim **77**, wherein the step of providing an emitter electrode at a predetermined height comprises elevating the emitter electrode by means of a lighter-than-air craft to the predetermined height.

84. The method of claim **77**, wherein the emitter electrode comprises a Malter film, which preferably comprises a thin film of one or more electrically non-conducting materials and/or one or a combination of the following materials: Al_2O_3, Zn2SiO3, SiO2, ZrO2, CaCO3, Ta2O5.

85. An apparatus for weather modification comprising:
a lighter-than-air craft suitable for carrying an emitter electrode;
an emitter electrode;
means for providing the emitter electrode with an electric charge, electrically coupled to the emitter electrode; and
means for earthing the apparatus.

86. The apparatus of claim **85**, wherein the charged emitter electrode is adapted to act as a charge capacitor.

87. The apparatus of claim **85**, wherein the charged emitter electrode is adapted to increase the fair-weather electric current at cloud altitude.

88. The apparatus of claim **85**, wherein the lighter-than-air craft is a lighter-than-air capacitor.

89. The apparatus of claim **85**, wherein the emitter electrode is a wire mesh surrounding the surface of the lighter-than-air craft.

90. The apparatus of claim **85**, wherein the emitter electrode comprises a Malter film, which preferably comprises a thin film of one or more electrically non-conducting materials and/or one or a combination of the following materials: Al_2O_3, Zn2SiO3, SiO2, ZrO2, CaCO3, Ta2O5.

91. Use of the apparatus according to claim **85** for at least one of:
dissipating fog in a target region;
increasing the cloud coverage and decreasing the temperature of the surface of the earth in a target region;
decreasing the probability of the formation and the intensity of cyclones at early stages of their development;
augmenting the inflow of oceanic moisture inland and moisture recycling in terrestrial areas;
re-forestation in a target region.

92. Use of a method according to claim **77**, for at least one of:
dissipating fog in a target region;
increasing the cloud coverage and decreasing the temperature of the surface of the earth in a target region;
decreasing the probability of the formation and the intensity of cyclones at early stages of their development;
augmenting the inflow of oceanic moisture inland and moisture recycling in terrestrial areas;
re-forestation in a target region.

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