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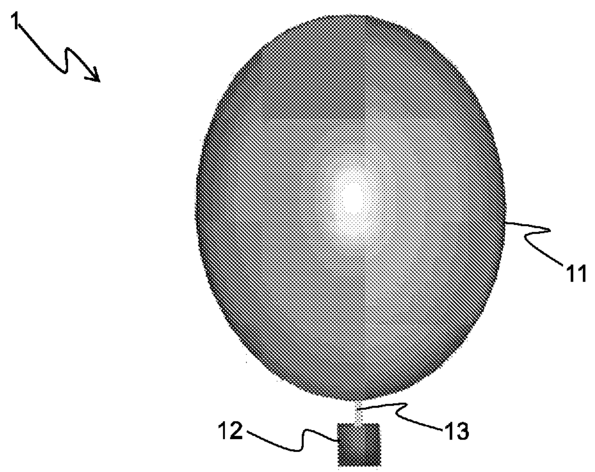

Fig. 1

(57) **Abstract:** The invention consists of a radio probe (1) for detecting air movements (fluctuations) within a cloud and a method of using it, wherein said radio probe (1) comprises a balloon (11) that can be filled with a gas having a lower density than an air mass around it, a container (12) attached to said balloon (11), measurement means (145) positioned in said container (12) and configured for detecting at least one atmospheric datum that represents at least one property of the air mass around said radio probe 1, and transmission means (142) configured for transmitting a signal (SM) in which said at least one atmospheric datum is encoded, and wherein said balloon (11) can generate a hydrostatic thrust having an orientation opposite to, and with substantially the same intensity as, a weight force generated by said radio probe (1), when said radio probe (1) is at an operating height.

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TITLE: "LAGRANGIAN SWARM OF MINI RADIO PROBES FOR ATMOSPHERIC AND ENVIRONMENTAL MONITORING, AND METHOD OF OPERATION THEREOF"

DESCRIPTION:

The present invention relates to an atmospheric radio probe, in particular a radio probe capable of detecting motion fluctuations of small air masses and water vapour within an atmospheric or anthropic cloud. Furthermore, the present invention also relates to a measurement system comprising a plurality (cluster) of said radio probes.

As is known, global warming is one of the most important problems that nations will have to face in the years to come. In order to tackle this problem, it is necessary to know the behaviour of air masses and cloud formations in the atmosphere on both a global level and a mesoscale level. Above all, it is of the utmost importance to understand how the process of nucleation and growth/degrowth of water droplets takes place, in connection with the intense turbulent transport occurring within clouds. These fundamental processes, which produce the various forms of atmospheric precipitation concurring in the global water distribution cycle on Earth, have not yet been fully understood. For this reason, clouds are considered, by the Intergovernmental Panel on Climate Change (IPCC), to pose scientific problems that require urgent attention.

In order to increase the level of cloud knowledge, it is necessary to enhance the level of knowledge of the turbulence of the microphysical processes occurring on a small scale and of the dynamic processes developing on the specific turbulent integral scale of the cloud formation (which scale has a typical extension in the range of ten kilometres).

Knowledge of turbulence within clouds is currently limited. The literature is still scanty as to the nucleation, evaporation, condensation, collision and fragmentation processes occurring within clouds and within the mixing layers forming at the interface with the surrounding clear air. Moreover, another aspect there is little knowledge of concerns the dissipation of the turbulence’s kinetic energy, about which information can be obtained by means of on-site measurements, e.g. measurements taken within clouds; as a matter of fact, no multipoint observations have been conducted yet, with a time resolution of hours, which can quantify the intermittence dynamics and microphysics of cloud turbulence. Indeed, the formation and dissipation mechanisms, along with their intrinsic non-stationarity, anisotropy, intermittence and spatial inhomogeneity, have not yet been comprehended in a satisfactory manner from numerical models used in climatic numerical simulations on a global, continental and regional level.

This is because the current models have been obtained by means of in-cloud surveys using very invasive methods (aircraft, such as instrument-equipped helicopters). Due to their mass and size, the latter make it impossible to detect air movements on the small scales that are typical of microphysics (e.g. scales of the order of fifty centimetres or less). Indeed, the perturbations triggered in the air can dissolve the clouds (especially lukewarm cumuli) before their natural extinction time.

This makes it difficult, if not impossible, to create reliable models that can, for example, be exploited for generating more reliable weather forecasts and, most importantly, for estimating the risks for the population with higher precision, so that weather alerts will only be issued when really necessary.

The present invention aims at solving these and other problems by providing a radio probe for detecting air movements within a cloud.

Furthermore, the present invention aims at solving these and other problems by providing also a method of using a radio probe for detecting air movements within a cloud.

The basic idea of the present invention is to use a plurality of (small) atmospheric radio probes, wherein each one of them comprises a balloon which can be filled with a gas having a lower density than an air mass around it, and which can generate a hydrostatic thrust having an orientation opposite to, and with substantially the same intensity as, the weight force generated by said radio probe, when said radio probe 1 is at an operating height.

This allows the radio probes to float (passive transport) within a cloud, so that multiple measurements can be taken within clouds (endoscopic observations) without, advantageously, modifying their structure (unlike when using instrument-equipped aircraft and helicopters, in which case combustion and/or friction heat is injected due to the sliding action of solid surfaces in relative motion with the clouds), i.e. without altering their natural non-linear and multiscale space-time evolution (ultrawide spectrum of wavelengths and frequencies). Each radio probe of the cluster follows the fluctuating motion of an air mass along an isopycnic surface, i.e. a surface having constant density in the atmosphere, which means that said radio probes move while remaining at a nearly constant height within the cloud. Moreover, their low inertia allows them to track atmospheric movements almost passively even on a dimensional scale that is sufficiently small to allow for microphysics observations (wavelengths of the order of a few decimetres).

The goal of the multi radio probe system is to provide Lagrangian statistics as to the intense turbulence existing within lukewarm clouds and the lower intensity turbulence which is typical of the surrounding air within the Earth’s boundary layer. In more detail, each probe consists of an electronic board (a transceiving printed circuit board preferably comprising pressure, humidity and temperature sensors, accelerometers, magnetometers, and GNSS), connected to a non-expansible biodegradable balloon filled with a mixture of helium and air. The probe system can fluctuate within clouds for a time interval of 1-2 hours, and can preferably measure temperature, pressure, humidity, position, velocity vectors, acceleration and magnetic field fluctuations along the trajectories followed by the probes. The Lagrangian dataset thus generated will advantageously permit the determination of space-time correlations among the physical quantities detected along the radio probes' Lagrangian trajectory.

It must be pointed out that knowing such correlations is of fundamental importance for understanding the dynamics and microphysics of clouds (multiphase systems composed of air, water vapour and liquid water) and also of the boundary limit where they reside, so that numerical models can be improved.

Lagrangian correlation coefficients can be defined for the properties of the fluid particles as detected by the radio probes passing through the Eulerian positions x at the instants t0, and travelling along the Lagrangian trajectories to arrive at the positions x + r(t) at the instants t0 + t. The displacement vector r(t0 + t) is a random variable describing the positions of the particles, at the instants t0 + t, in the mediated set with respect to the initial positions x and the instants t0, which are different for each radio probe. However, r and t are not varied independently. For Lagrangian correlation coefficients, r is a function of t. Such Lagrangian correlation coefficients can be obtained by means of the following formula:

$$R_{L1}(\boldsymbol{x},\tau) = \langle u_i(\boldsymbol{x},t_0)\, u_j(\boldsymbol{x}+\boldsymbol{r}(t_0+\tau))\rangle / \left(\sqrt{\langle u_i^2(\boldsymbol{x},t_0)\rangle}\sqrt{\langle u_j^2(\boldsymbol{x}+\boldsymbol{r}(t_0+\tau))\rangle}\right).$$

According to the state of the art, these quantities have been deduced from studies based on numerical simulations only, i.e. not based on in-field measurements/observations. As to numerical simulations, see "*WALLACE, James M., Space-time correlations in turbulent flow: A review. Theoretical and Applied Mechanics Letters, 2014, 4.2: 022003*".

Further advantageous features of the present invention are set out in the appended claims.

These features as well as further advantages of the present invention will become more apparent in the light of the following description of a preferred embodiment thereof as shown in the annexed drawings, which are provided herein merely by way of non-limiting example, wherein:

- Fig. 1 shows a diagram of a radio probe according to the invention;
- Fig. 2 shows a system for detecting air movements, comprising a plurality of radio probes like the one shown in Fig. 1;
- Fig. 3 shows an electronic board comprising measurement means included in the radio probe of Fig. 1.

In this description, any reference to "an embodiment" will indicate that a particular configuration, structure or feature is comprised in at least one embodiment of the invention. Therefore, expressions such as "in an embodiment" and the like, which may be found in different parts of this description, will not necessarily refer to the same embodiment. Moreover, any particular configuration, structure or feature may be combined as deemed appropriate in one or more embodiments. The references below are therefore used only for simplicity's sake, and shall not limit the protection scope or extension of the various embodiments.

With reference to Fig. 1, the following will describe a radio probe 1 according to the invention; said radio probe 1 can detect air movements within a cloud without, advantageously, modifying the latter's internal dynamics and microphysics.

The radio probe 1 preferably comprises the following parts:

- a balloon 11 which can be filled with a gas having a lower density than an air mass around it, and which can generate a hydrostatic thrust having an orientation opposite to, and with substantially the same intensity as, a weight force generated by said radio probe 1, when said radio probe 1 is at an operating height;

- a container 12 (hereafter also referred to as "nacelle") attached to said balloon 11;
- measurement means configured for detecting at least one atmospheric datum that represents at least one property of the air mass around said radio probe 1, wherein said measurement means are positioned in said container 12;
- transmission means (e.g. a LoRa™ long-range communication interface) configured for transmitting, preferably via radio, a signal SM in which said at least one atmospheric datum is encoded.

This allows the radio probe to float within a cloud. The radio probe 1 can thus track the motion of an air flow along an isopycnic surface.

When the radio probe 1 is in an operating condition, and once it has been positioned within a cloud (as will be further clarified hereinafter), the radio probe 1 is pushed by the air flows in said cloud; at the same time, it collects atmospheric data through its measurement means and transmits to ground, via the transmission means, a signal in which said atmospheric data are encoded.

Also with reference to Fig. 2, the following will describe an atmospheric detection system S; such a system S comprises a plurality of radio probes 1 and one or more ground stations GS.

Each ground station GS comprises the following elements:

- reception means (e.g. a LoRa™ long-range communication interface) configured for receiving the signal SM emitted by one of said radio probes 1;
- memory means, into which data can be stored;
- computing means configured for executing at least the following steps:
    - decoding said at least one atmospheric datum contained in the signal SM;

- o storing said at least one atmospheric datum into the memory means.

More in detail, a method of using a plurality of radio probes 1 for detecting air movements within a cloud according to the invention comprises the following phases:

- a release phase, in which the radio probes 1 are released within or near said cloud, e.g. by a remotely controlled and/or autonomous aircraft that, preferably, transports the radio probe up to the base of the cloud, or up to the desired height in the vicinity of or within said cloud;
- an acquisition phase, in which said radio probe 1 acquires, via measurement means, at least one property of an air mass around said radio probe 1;
- a transmission phase, in which said radio probe 1 transmits, via transmission means, a signal SM encoding said at least one atmospheric datum to at least one of said ground stations GS.

This makes it possible to acquire data as the radio probes are floating within a cloud, tracking the motion of an air flow along an isopycnic surface. This leads to knowing the air flows that are present within a cloud with a high level of spatial resolution, i.e. on the small scale in the turbulence spectrum (wavelengths shorter than a few decimetres).

As aforementioned, during the release phase a remotely controlled and/or autonomous aircraft (e.g. an electric quadcopter) preferably releases said radio probes at the base or at the top of a cloud.

This offers the advantage that the radio probe is placed in the regions with lukewarm cumuli, where supersaturation can be observed along with the resulting water droplet nucleation and the effects on the density of the water vapour phase caused by droplet evaporation, condensation and collision-coalescence, and also in the subsaturated neighbouring regions. It must be pointed out that the regions of transit between the oversaturated cloud and the subsaturated ambient air are of great importance, since these are the regions where an intense acceleration occurs in the dynamics of droplet populations and, potentially, where droplets can reach such dimensions that may lead to precipitations. Advantageously, this makes it possible to improve the knowledge of what happens within a cloud, with a spatial resolution level that can highlight the processes of transport through the boundaries between the clouds and the surrounding subsaturated air.

The release phase may also be conducted on the ground, e.g. by releasing the radio probe 1 directly from the terrestrial surface and letting it go up until it enters a lukewarm cloud.

More in detail, the balloon 11 is designed to have a constant volume, i.e. to prevent said balloon 11 from expanding during the initial rise. This provides control over the hydrostatic thrust received by the balloon 1, so that the operating height of the radio probe 1 can be selected very accurately to have it float within a cloud. In this way, the radio probe 1 will be allowed to follow the motion of an air flow along an isopycnic surface, and hence to passively track atmospheric movements even on a dimensional scale which is sufficiently small to permit microphysics observations.

In order to better control the point of release of the radio probe 1, it is also possible to attach the radio probe 1 to a string through a remote release device (e.g. a snaplink comprising a servo mechanism configured to open or close said snaplink) which can be actuated from the ground (e.g. by means of a remote control or the like). In this manner, the flight of the radio probe can be controlled very easily until it reaches the base of a cloud, where said radio probe 1 can be released to subsequently carry out the acquisition and transmission phases in a fully autonomous way. This solution may be useful when the radio probe 1 is to be released at a height of a few hundreds of metres in a particular location, which may be the base of a cloud, or above a location of particular interest (e.g. a chimney, a cooling tower, e chemical plant, or the like), where measurements of at least one property of the air mass above said point of interest need to be taken.

In addition to the above, the radio probe 1 has an operating height in the range of 1,000 to 2,000 metres above sea level. At such a height, the radio probe 1 can be used for studying clouds causing violent thunderstorms or hailstorms.

Moreover, at such a height the air in which said radio probe 1 must float has such a density that the diameter of the balloon 11 can be kept below fifty centimetres.

The radio probe can thus float within a cloud, so that the radio probe 1 can follow the motion of an air flow along an isopycnic surface, and hence passively track atmospheric movements even on a dimensional scale which is sufficiently small to permit microphysics observations.

As an alternative to or in combination with the above, the balloon 11 has a substantially spherical shape and a diameter equal to or smaller than thirty centimetres. This will allow it to maintain its inertia at such a level as to be able to pick up the energy of the air flows on a much smaller scale than would be possible with prior-art radio probes, resulting in a more reliable tracking of an isopycnic surface of an air flow.

This results in improved air flow detection on a dimensional scale of decimetres.

As an alternative to or in combination with the above, the radio probe 1 has a mass equal to or smaller than twenty grams. This contributes to allowing the radio probe 1 to track an isopycnic surface of an air flow in an even more accurate manner.

This results in improved air flow detection on a dimensional scale of decimetres.

As an alternative to or in combination with the above, the balloon 11 is made, at least partly, of biodegradable material, such as, for example, Mater-Bi™ produced by Novamont®. This makes it possible to use a large number of radio probes 1 (even simultaneously) without polluting the environment.

It is thus possible to improve the knowledge of the air flows within clouds on a dimensional scale of decimetres.

Also with reference to Fig. 3, the following will describe an electronic board 14 comprised in the preferred embodiment of the radio probe 1.

The electronic board 14 preferably comprises the following components:

- processing means 141, e.g. a microcontroller, preferably of the 8-bit, 16-bit or 32-bit type;
- the transmission means 142, e.g. a long-range (LoRa™) communication interface;
- positioning means 143, which preferably comprise a receiver of positioning signals emitted by a global navigation satellite system (GNSS), i.e. a receiver capable of determining its own position on the basis of received positioning signals, wherein said signals are emitted from satellites in low orbit around the Earth;
- inertial means 144 (e.g. an accelerometer and/or a gyroscope and/or a MEMS compass) capable of detecting an acceleration to which said electronic board 14 is subjected and/or an orientation of said electronic board 14. This makes it possible to establish the accelerations undergone by said radio probe 1 and/or the orientation of said radio probe 1;
- the measurement means 145 configured for detecting at least one property of said air mass, preferably consisting of a humidity and/or temperature and/or pressure sensor (e.g. the MS8607 sensor available from TE Connectivity®);
- a communication antenna 146 connected to the transmission means 142 and, preferably, configured to operate on one or more frequency bands centred at a frequency of, respectively,

ca. 433 MHz, 868 MHz and 915 MHz;

- a positioning antenna 147 connected to the positioning means 143 and, preferably, configured to operate in one or more of the L1 (1575.42MHz) and L2 (1227.60MHz) bands;
- a reset button 148 connected to the processing means 141, which are configured to return into an initial (predefined) state whenever said reset button is pressed.

It must be pointed out that the board 14 is preferably located inside the container 12, and that said container 12 has one or more apertures allowing air to enter said container 12, so that the measurement means 145 can detect at least one property of said air.

As aforementioned, the radio probe 1 preferably comprises also the inertial means 144 configured for detecting at least one dynamic datum that represents an acceleration and/or an orientation of said radio probe 1, and said transmission means are also configured for transmitting a second signal in which said at least one dynamic datum is encoded.

Thus, further properties of the isopycnic surface of an air flow along which the radio probe moves can be known; in fact, in addition to the properties of the air mass (such as pressure, temperature and humidity), it is also possible to reconstruct the direction of the air flow, based on the orientation of the radio probe 1, and/or the velocity of said air flow, based on the accelerations undergone by said radio probe. This will improve the knowledge of what happens within a cloud, with a spatial resolution level of the order of decimetres.

In order to reconstruct the direction and/or the velocity of the air flow in a more accurate manner, the container 12 is attached to said balloon 11 by means of a string. This will reduce the inertia of the balloon 11 and of the container 12, so that, when the air flow changes direction and/or velocity, the balloon 11 and/or the container 12 will be able to follow more accurately the isopycnic surface of the air flow, thereby allowing the inertial means 144 to collect data of higher quality (i.e. data showing less difference from the actual quantities) and, most importantly, having a higher spatial resolution than would be attainable with the balloon 11 rigidly constrained to the container 12. It will thus be possible to improve the knowledge of what happens within a cloud, with a spatial resolution level of the order of decimetres.

In addition to the above, the inertial means 144 (Inertial Measurement Unit - IMU) may also be positioned inside the balloon 11 or on the outer surface of said balloon 11 (e.g. on a second electronic board, whether a rigid or flexible one), thereby making it possible to reconstruct three-dimensional speed, acceleration and magnetic-field fluctuations; in fact, such inertial means 144 comprise, preferably, three accelerometers, three gyroscopes and three magnetometers with NED (North, East, Down) reference. This fluctuation reconstruction will allow for an even more accurate calculation of the direction and/or velocity of the air flow, because the balloon has a surface area per mass unit ratio which is much smaller than that of the container 12, and will therefore tend to follow the isopycnic surface of the air flow even more accurately. This will further improve the quality of the information collected by the inertial means 144.

It will thus be possible to improve the knowledge of what happens within a cloud, with a spatial resolution level of the order of decimetres.

As aforementioned, each one of the radio probes 1 of the system S preferably comprises also the positioning means 143, which are coupled to a positioning antenna 147 and which are configured for determining at least one position datum on the basis of received positioning signals, wherein said position datum represents a position of said radio probe, and wherein said transmission means are also configured for transmitting a third signal in which said at least one position datum is encoded.

This makes it possible to know, through an absolute positioning system, the extension and evolution of the Lagrangian trajectories of the air masses within the clouds. It will thus be possible to improve the knowledge of what happens within a cloud, with a spatial resolution level of the order of fifty centimetres.

In order to further improve the quality of the acquired positioning data (i.e. to further increase the spatial resolution), the positioning antenna 147 is preferably arranged inside, or on the outer surface of, the balloon 11 together with the inertial means 144, and the processing means 141 are also configured for executing the following steps:

- acquiring, via the inertial means 144, said at least one dynamic datum that represents the orientation of said balloon 11,
- acquiring, via the positioning means 143, said at least one position datum (only) when said at least one dynamic datum indicates that the positioning antenna 147 is oriented in such a way as to receive signals coming from the sky vault directly, i.e. with no reflection.

This increases the signal-to-noise ratio of the signals used by the positioning means 143 for determining the position of the radio probe 1, thereby advantageously reducing the positioning error. It will thus be possible to improve the knowledge of what happens within a cloud, with a spatial resolution level of the order of decimetres.

In addition to the above, each one of the radio probes 1 preferably comprises also dust detection means (e.g. the GP2Y1010AU0F sensor available from Sharp®, the PMS5003 sensor available from Homotix®, or the like) configured for detecting at least one dust concentration datum that represents a mass value in volume units of (thin) atmospheric dusts that are present in the air mass around said radio probe 1, e.g. dusts having a size in the range of 0.3 μm to 1 μm and/or 1 μm to 2.5 μm and/or 2.5 μm to 10 μm, and said transmission means are also configured for transmitting a fourth signal in which said at least one concentration datum is encoded. This feature is very interesting, in that it permits using the radio probes 1 for environmental monitoring purposes on metropolitan areas and industrial, agricultural, forestal, etc. sites.

This makes it possible to study how the condensation phenomenon occurring within a cloud is conditioned by the presence of thin dusts that may act as condensation nuclei. It will thus be possible to improve the knowledge of what happens within a cloud, with a spatial resolution level of the order of decimetres.

In addition to the above, the radio probe 1 preferably comprises also organic compound detection means (e.g. the CCS811 sensor available from Cambridge CMOSSensors™) configured for detecting at least one volatile organic compound concentration datum that represents a mass value in volume units of volatile organic compounds (such as, for example, carbon dioxide or the like) that are present in the air mass around said radio probe 1, and wherein said transmission means are also configured for transmitting a fifth signal in which said at least one volatile organic compound concentration datum is encoded.

This makes it possible to study how the condensation phenomenon occurring within a cloud is conditioned by the presence of volatile organic compounds that may increase the temperature by absorbing the infrared radiation emitted by the Earth's surface. It will thus be possible to improve the knowledge of what happens within a cloud, with a spatial resolution level of the order of decimetres.

It must be pointed out that two or more radio probes 1 as described above can be used to advantage in order to conduct in-field experiments. For the purpose of making a scattering analysis, preferably through the use of an algorithm using at least ten distances between neighbours in a graph (distance-neighbour graph algorithm), a number of radio probes in excess of ten, preferably 100 radio probes, can be used.

In more detail, the algorithm using information about distances between neighbours in a graph (distance-neighbour graph algorithm) is employed in order to study the scattering, the diffusion and the fluctuations of physical parameters (such as, for example, the pressure, temperature and/or humidity of the air around the radio probe 1, and/or the position, velocity and/or acceleration of said radio probe 1) from multiple points in the surrounding environment at the same time. For this algorithm to be applied effectively, the radio probes must be within the same volume (e.g. within a neighbourhood defined by a sphere having a radius of 2-3 metres) prior to their release. In this manner, the radio probes 1 will share the same initial conditions (e.g. pressure, temperature, humidity, position) in relation to the surrounding environment. After having been released, the radio probes 1 will move from the initial volume and will provide periodic readings of their instantaneous positions. The received dataset will then be analysed by an electronic computer (e.g. a server) comprising processing means, preferably high-performance ones (e.g. CPUs, GPUs, FPGAs, CPLDs or the like), configured for executing a post-processing activity aimed at extrapolating regression models concerning the clouds’ turbulent scattering, diffusion and microphysics.

In other words, a method for detecting movements of the multiphase flow within a cloud by means of a plurality of radio probes 1, wherein each one of said radio probes 1 comprises the positioning means 143, comprises the following phases:

- a release phase, in which said plurality of radio probes 1 are released within a neighbourhood around a point located within or near the cloud, and wherein said neighbourhood preferably has the shape of a sphere having a diameter in the range of two to three metres;

- a reception phase, in which a plurality of signals are received, via reception means, which comprise position data transmitted by said plurality of radio probes 1 within a (predefined) time interval;
- a processing phase, in which processing means determine, on the basis of said plurality of position data, at least one space-time relationship between said air movements within said cloud, e.g. by configuring the processing means for executing a set of instructions implementing an algorithm that uses at least one distance between neighbours in a graph (distance-neighbour graph algorithm).

A larger amount of data can thus be acquired per analysed cloud. It will thus be possible to improve the knowledge of what happens within a cloud, with a spatial resolution level of the order of decimetres.

Furthermore, in addition to the raw measurements provided by the radio probe, derived quantities such as kinetic energy are also used in order to analyse the physical characteristics of the cloud under examination. To calculate kinetic energy from raw measurements, raw data are acquired from the sensors installed on the radio probe 1 with a predefined frequency, preferably greater than or equal to 1 Hz. The datasets of multiple radio probes permit, advantageously, the detection of kinetic energy fluctuation levels from various points of the cloud. This information can then be used for studying the intermittent behaviour and microphysics within clouds.

In other words, during the reception phase a plurality of second signals are received, which comprise a plurality of atmospheric data, each one representing at least one property of an air mass around one of said radio probes 1 at a time instant, and during the processing phase said at least one relationship is determined also on the basis of said plurality of atmospheric data.

An even larger amount of data can thus be acquired per analysed cloud. It will thus be possible to improve the knowledge of what happens within a cloud, with a spatial resolution level of the order of decimetres.

In combination with the above, the space-time relationship preferably comprises Lagrangian correlation coefficients, and during the processing phase said Lagrangian correlation coefficients are determined.

This leads to obtaining simulation models that are much more accurate than prior-art ones. It will thus be possible to improve the knowledge of what happens within a cloud, with a spatial resolution level of the order of decimetres.

Of course, the example described so far may be subject to many variations.

Some of the possible variants of the invention have been described above, but it will be clear to those skilled in the art that other embodiments may also be implemented in practice, wherein several elements may be replaced with other technically equivalent elements. The present invention is not, therefore, limited to the above-described illustrative examples, but may be subject to various modifications, improvements, or replacements of equivalent parts and elements without however departing from the basic inventive idea, as specified in the following claims.

CLAIMS

1. Radio probe (1) for detecting air movements within a cloud, comprising

- a balloon (11), which can be filled with a gas having a lower density than an air mass around it,
- a container (12) attached to said balloon (11),
- measurement means (145) positioned in said container (12) and configured for detecting at least one atmospheric datum that represents at least one property of the air mass around said radio probe 1, and
- transmission means (15) configured for transmitting a signal (SM) in which said at least one atmospheric datum is encoded,

characterized in that

said balloon (11) is capable of generating a hydrostatic thrust having an orientation opposite to, and with substantially the same intensity as, a weight force generated by said radio probe (1), when said radio probe (1) is at an operating height.

2. Radio probe (1) according to claim 1, wherein said balloon (11) has a constant volume.

3. Radio probe (1) according to claim 2, wherein said operating height is comprised between 1,000 and 2,000 metres above sea level.

4. Radio probe (1) according to claims 2 or 3, wherein the balloon (11) has a substantially spherical shape and a diameter equal to or smaller than thirty centimetres.

5. Radio probe (1) according to any one of claims 1 to 4, wherein the radio probe (1) has a mass equal to or smaller than twenty grams.

6. Radio probe (1) according to any one of claims 1 to 5, further comprising inertial means (144) configured for detecting at least one dynamic datum that represents an acceleration and/or an orientation of said radio probe (1), and wherein said transmission means are also configured for transmitting a second signal in which said at least one dynamic datum is encoded.

7. Radio probe (1) according to claim 6, wherein the inertial means (144) are positioned either within the balloon (11) or on an outer surface of said balloon (11).

8. Radio probe (1) according to claims 6 or 7, comprising a string, and wherein the container (12) is attached to said balloon (11) by means of said string.

9. Radio probe (1) according to any one of claims 1 to 8, further comprising

- a positioning antenna (147) for receiving positioning signals, and
- positioning means (143) coupled to said positioning antenna (147) and configured for determining at least one position datum on the basis of said positioning signals,

wherein said position datum represents a position of said radio probe, and wherein said transmission means are also configured for transmitting a third signal in which said at least one position datum is encoded.

10. Radio probe (1) according to claim 9, wherein the positioning antenna (147) is positioned either within the balloon (11) or on the outer surface thereof, and wherein the processing means (141) are also configured for executing the following steps:

- acquiring, via the inertial means (144), said at least one dynamic datum that represents the orientation of said balloon (11),

– acquiring, via the positioning means (143), said at least one position datum when said at least one dynamic datum indicates that the positioning antenna (147) is oriented in such a way as to directly receive signals coming from the sky vault.

11. Radio probe (1) according to any one of claims 1 to 10, further comprising dust detection means configured for detecting at least one dust concentration datum that represents a mass value in volume units of atmospheric dusts that are present in the air mass around said radio probe (1), and wherein said transmission means (142) are also configured for transmitting a fourth signal in which said at least one concentration datum is encoded.

12. Radio probe (1) according to any one of claims 1 to 11, further comprising organic compound detection means configured for detecting at least one volatile organic compound concentration datum that represents a mass value in volume units of volatile organic compounds that are present in the air mass around said radio probe (1), and wherein said transmission means (142) are also configured for transmitting a fifth signal in which said at least one volatile organic compound concentration datum is encoded.

13. Radio probe (1) according to any one of claims 1 to 12, wherein the balloon (11) is made, at least partly, of biodegradable material.

14. Method of using a radio probe (1) according to any one of claims 1 to 13 for detecting air movements within a cloud, comprising

- a release phase, in which said radio probe (1) is released within or near said cloud,
- an acquisition phase, in which said radio probe (1) acquires, via measurement means, at least one property of an air mass around itself,
- a transmission phase, in which said radio probe (1) transmits, via transmission means, a signal (SM) encoding said at least one atmospheric datum to at least one ground station (GS).

15. Method according to claim 14, wherein, during the release phase, a remotely controlled and/or autonomous aircraft releases said radio probe (1) at the base or at the top of a cloud.

16. Method of using a plurality of radio probes (1) according to any one of claims 9 to 10 for detecting air movements within a cloud, comprising

- a release phase, in which said plurality of radio probes (1) are released around a point located within or near said cloud,
- a reception phase, in which a plurality of signals are received, via reception means, which comprise position data transmitted by said plurality of radio probes (1) within a time interval,
- a processing phase, in which processing means determine, on the basis of said plurality of position data, at least one space-time relationship between said air movements within said cloud.

17. Method according to claim 16, wherein, during the reception phase, a plurality of second signals are received which comprise a plurality of atmospheric data, each one representing at least one property of an air mass around one of said plurality of radio probes (1) at a time instant, and

wherein, during the processing phase, said at least one relationship is determined also on the basis of said plurality of atmospheric data.

18. Method according to claims 16 and 17, wherein said at least one relationship comprises Lagrangian correlation coefficients, and wherein, during the processing phase, said Lagrangian correlation coefficients are determined.

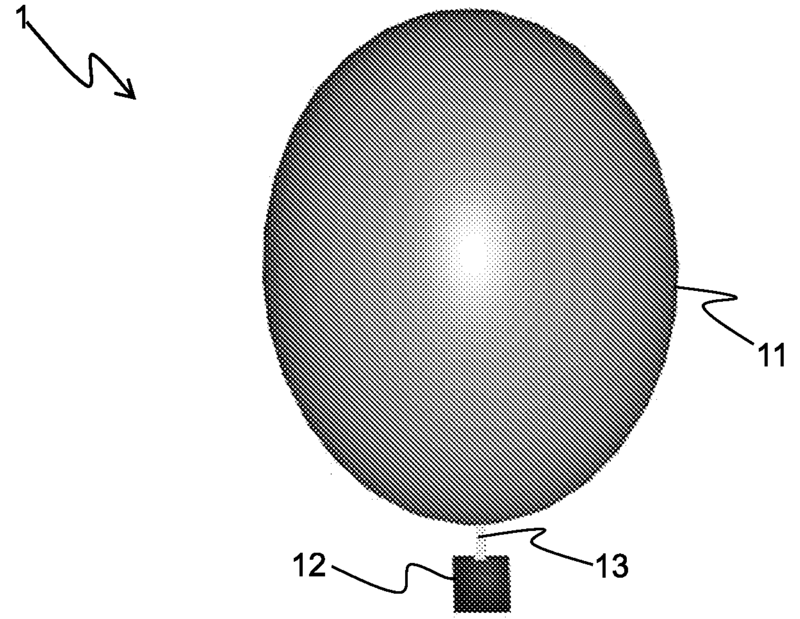

Fig. 1

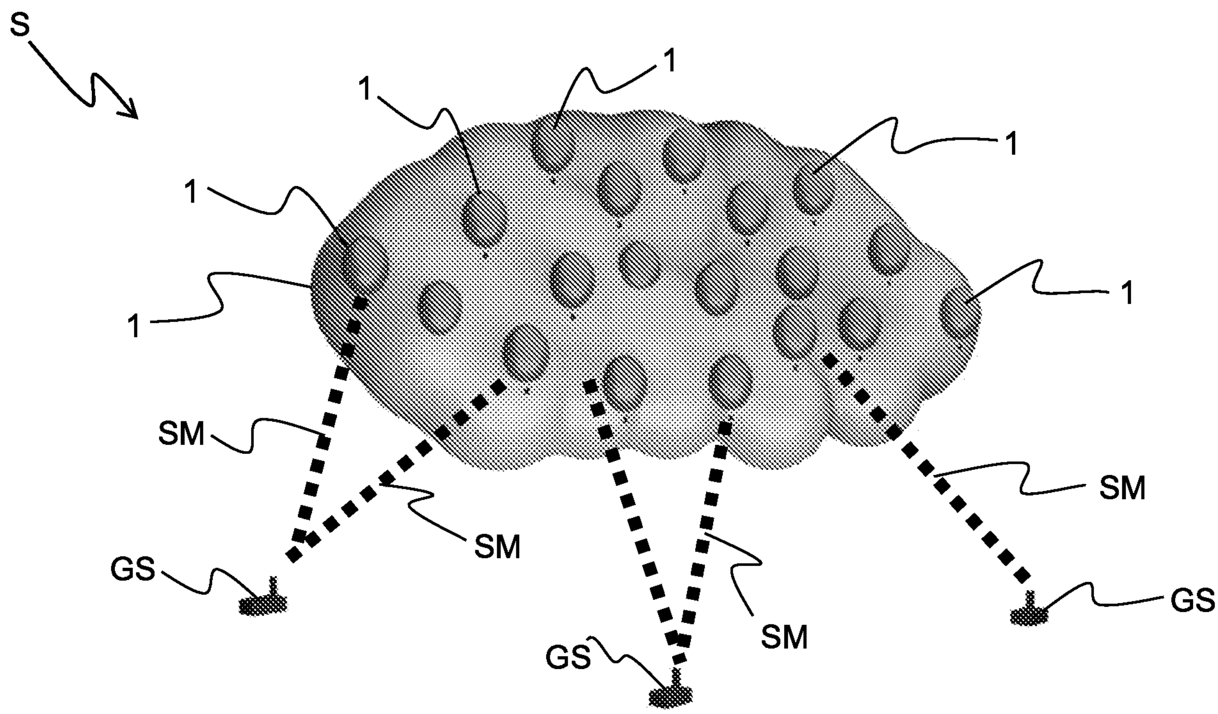

Fig. 2

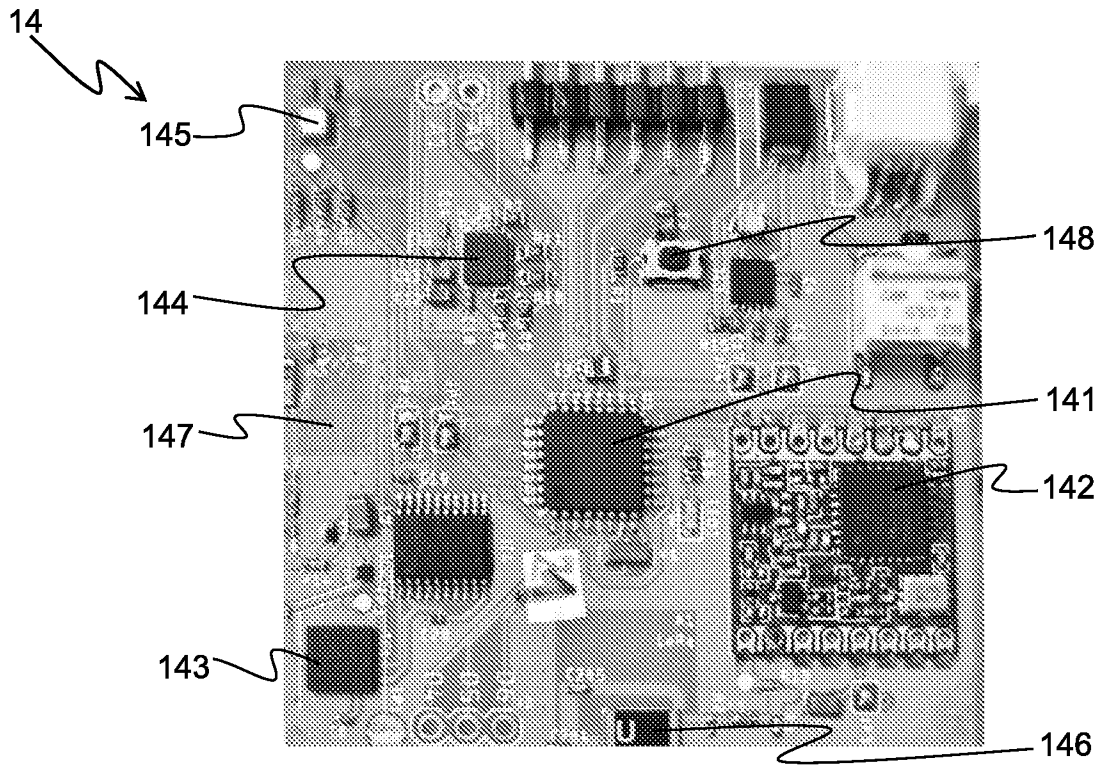

Fig. 3

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2023/055125

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01W1/08
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G01W

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4 899 583 A (BOOKER D RAY [US]) 13 February 1990 (1990-02-13) abstract column 1, line 51 - column 2, line 8 column 2, line 8 - column 3, line 2 column 4, lines 41-47 column 7, lines 55-61 figure 12 -----	1-5,7,8, 10-18
X	WO 2021/099688 A1 (HURRICANE UNWINDER OY AB [FI]) 27 May 2021 (2021-05-27) abstract page 1, lines 4-8 page 2, line 16 - page 10, line 30 figures 1-27 ----- -/--	1-3,5-7, 9-18

[x] Further documents are listed in the continuation of Box C.

[x] See patent family annex.

* Special categories of cited documents :

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"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance;; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
15 August 2023	23/08/2023

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Bagnera, Carlo

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Form PCT/ISA/210 (second sheet) (April 2005)

International application No
PCT/IB2023/055125

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 10 689 084 B2 (SPACE DATA CORP [US]) 23 June 2020 (2020-06-23) abstract figures 1,2,2A column 1, lines 22-58 -----	1-3,5,7, 9-18
A	KR 102 006 934 B1 (SJ MNC [KR]) 2 August 2019 (2019-08-02) abstract paragraph [0084] -----	1-18

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/IB2023/055125

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			WO	2021099688	A1	27-05-2021
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			US	2019002074	A1	03-01-2019
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