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**United States Patent**  
**Chen****5,984,239**  
**November 16, 1999**

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Weather modification by artificial satellites

**Abstract**

A Satellite Weather Modification System (SWMS) uses earth satellites to harness solar energy to modify the thermodynamics and composition of the earth's atmosphere. SWMS has three subsystems: The first subsystem includes a network of earth satellites called Satellite Engines (SEs) used to reflect solar energy and/or transform solar energy into other forms of energy beams discharged at specified locations. The media at these locations and the media through which the energy beams pass absorb these energies and change them into heat. The second subsystem includes a large network of Remote Sensing Devices (RSDs). These sensors are used to measure local media compositions, dynamic parameters and thermodynamic properties. Sensor measurements are fed back to the third subsystem, which includes a network of Ground Control Stations (GCSs). GCSs provide energy beam guidance by estimating each beam's characteristics and its aim point trajectory as functions of time. Integration of these three subsystems establishes a sensor feedback energy beam guidance and control loop. SWMS's weather modification applications include alteration of precipitation, reclaiming of wasteland, reducing damage by bad weather, and improving environment. Its non-weather related applications include supplying concentrated energy to electricity generating stations (solar, wind and hydro), high latitude greenhouse farms, and solar powered airplanes.

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**Related U.S. Patent Documents**

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In addition, the following publications are of interest:

Astronautical Guidance

by R. H. Battin, McGraw-Hill Book Co. 1964

Introduction to Radar Systems

by M. I. Skolnik, McGraw-Hill Book Co. 1962

and

Radar and the Atmosphere

by A. J. Bogush, Jr., Artech House 1989.

In contrast to much of the prior art, this invention employs only solar energy, earth satellites, remote sensing devices and ground control computers. No dispensing of chemicals is needed. The Satellite Weather Modification System (SWMS) is a local as well as a global weather modification tool. For example, SWMS can simultaneously bring rain to dry regions in southern California and drought regions in southern Ethiopia within in a few orbital periods of the Satellite Engines. Most remarkable of all is that these and many other tasks can all be accomplished by switching between some computer codes.

This invention is based on the realization that natural weather patterns always leave opportunities to permit regional weather modifications which are within the capabilities of the proposed Satellite Weather Modification System (SWMS). A fully developed SWMS has the potential to provide the following benefits.

1. Modify cooling, warming, or precipitations of selected regions of earth, thus modifying local and/or global weather patterns.
2. Create and maintain grass or forest lands to balance the rise of carbon dioxide contained in the earth's atmosphere, thus reducing the threat of global warming.
3. Transform some wasteland into productive farmland.
4. Increase farm, fishery and forestry productions at higher latitudes.
5. Increase electricity production on land directly from concentrated solar energy.
6. Increase hydroelectricity production by inducing precipitation in regions upstream of hydroelectric dams.
7. Reduce home and industry energy cost.

8. Reduce environmental damage by harsh weather.
9. Reduce damage to the environment due to the use of fossil fuel and nuclear fuel.
10. Create a unique self-supporting business based on SWMS, which can provide both weather-related and non-weather related services.

SWMS can be implemented employing components which are currently available, including means for reflecting solar rays or discharging infrared radiation or laser beams or incandescent lights.

SWMS improvements can be augmented gradually, still using conventional components, to include discharging frequency agile and or intensity agile energy beams or pulse trains from Satellite Engines (SEs). Each frequency agile energy pulse is designed to penetrate a specified air mass layer of specified composition. For example, these energy pulses can be used to modify a specified air mass inside a thick cloud.

## SUMMARY OF THE INVENTION

This invention is an aerospace system designed to harness solar energy to modify the earth's weather. This system is called Satellite Weather Modification System (SWMS). This invention disclosure covers three areas. A first area involves the design and/or integration of three SWMS key subsystems. A second area involves specifying basic SWMS weather modification techniques. A third area involves the design of unique SWMS applications into self supporting businesses.

The first area of this invention disclosure covers the three SWMS key subsystems. They are:

### 1. Satellite Engines (SEs)

The basic function of an SE is to reflect solar energy or to transform solar energy into another form of energy before discharging it to a specified location. Each SE is a specially designed earth satellite. In a mature SWMS, many millions of SEs will be operating in a coordinated manner. As a minimum capability, each SE will be designed to reflect solar energy and simultaneously convert solar energy into electricity via solar cells. Advanced SE models will be capable of transforming solar energy into energy beams of different frequencies before discharging them. These advanced SEs can simultaneously discharge solar energy, frequency agile and intensity agile MMW (millimeter wave) or RF or microwave pulse trains, infrared radiations, laser light and incandescent light as the mission may require. All physical characteristics of each energy beam (solar or otherwise) are adaptively estimated by Ground Control Stations (GCSs). GCS also estimates each energy beam's guidance by defining its desired aim point trajectory. The criteria used to select and to guide each energy beam are based on an estimated specific thermodynamic change taking place in a specific air mass that satisfies some required weather condition changes.

Each SE will have gimbals panels (i.e., panels mounted on gimbals) on its outer surfaces. Each gimbals panel has a reflector on one side and solar cells on the other side. Also, gimbals-mounted antennae and lamps are attached to the SE structure frame. The SE controls the direction of each energy beam by controlling each panel's two gimbals orientations with respect to the SE structure frame. By using flywheels (or other methods), each SE also controls its structure frame orientation with respect to inertial space.

A minimum SWMS configuration requires that all SEs be placed in two non-coplanar orbits. These orbits are slightly inclined with respect to each other. One orbit will always be higher than the other orbit. Each SE structure frame will maintain an average angular rate of one revolution per year with respect to inertial space. During each orbit around the earth an SE will experience two different operating modes, depending on whether the SE is inside or outside earth's shadow. These modes are described below:

When SEs are outside earth's shadow, SEs in the higher orbit will rotate their solar cell panels (on one SE side) facing the general direction of the sun. At the same time SEs will rotate their reflector panels (on the other side of the SE) facing away from the sun. SEs in the lower orbits will have their reflector panels (on one SE side) facing the general direction of the sun and their solar cell panels (on the other side of the SE) facing away from the sun. This arrangement allows the solar rays first reflecting from the lower orbit SEs' reflectors to the reflectors on the higher orbit SEs, before finally re-reflecting these solar rays to earth (in FIG. 3 see incoming solar rays 3a, rays 3b reflected from the lower orbit to the higher orbit, and rays 3c reflected from the higher orbit into the earth's atmosphere).

When SEs are inside earth's shadow, SEs will rotate their reflector panels to face the reflector panels in the other orbit. This arrangement allows the solar rays to travel between the two orbits inside earth's shadow before discharge to earth (see rays 3z in FIG. 3).

## 2. Remote Sensing Devices (RSDs)

The basic functions of RSDs are to continuously measure the actual atmospheric conditions of each specified weather cell. Ideally, there will be billions of RSDs of every kind distributed over the globe. These RSDs are used to continuously monitor the actual thermodynamics, dynamics, compositions and other physical conditions of the atmosphere, land and water surfaces, subsurfaces, sun and Satellite Engines. There will be different kinds of RSDs measuring different parameters. Some RSDs will be stationary on earth. Other RSDs may be located on Solar Powered Satellite Airplanes (SPSAs), on balloons or on SEs. All RSD measurements are time and location tagged before transmitting to their respective local Ground Control Stations (GCSs) for data correlation and analysis. Some measurements are sent directly to or measured directly by SEs.

## 3. Ground Control Stations (GCSs)

The basic function of GCSs is to provide guidance to each SE. This includes defining the characteristic of each energy beam and its aim point trajectory as functions of time. Each GCS includes a network of supercomputers, special algorithms, mathematical models, monitors, control panels, data storage devices, electronic libraries, data transmitters and data receivers. The main tasks of each GCS are: To maintain detailed information about local weather conditions, to integrate raw local RSDs measurements with filtered information about weather conditions of other locations (received from other GCSs), to extrapolate weather conditions to future time points, to monitor assigned Satellite Engines' (SEs') status, to evaluate assigned SEs' performances, to identify potential local weather patterns which can be modified by SWMS, to estimate potential weather modification options, to evaluate desired weather condition requests, to select optimal SEs groupings, to estimate SEs weather modification tasks options, to coordinate all SEs tasks, to assign and transmit detailed weather modification tasks to each assigned SE (i.e., specify energy beam's characteristic and its aim point trajectory as functions of time), to maintain communication between GCSs, RSDs and SEs, and, finally, to accept human inputs and controls.

The second area of this invention disclosure involves specifying SWMS weather modification techniques. This includes: Cooling the earth by reflecting solar rays back into deep space, warming local regions by redirecting solar rays to local areas, creating clouds by warming local wet surfaces and modifying local air mass velocity components by controlled heating of specific air masses to create pressure differentials.

The third area of this invention disclosure involves organizing SWMS unique services into self supporting business ventures. The SWMS services include: Weather modifications (cooling, warming, altering precipitations, altering air mass velocity components), supply of energy (direct solar power, indirect wind or hydroelectric power or solar powered airplane) and environment improvements (reclaiming wasteland, creating greenhouse farms, reducing bad weather damages, reducing fossil and nuclear fuels usage). Included in SWMS applications is an invention of a Solar Powered Satellite Airplane (SPSA). SPSA comprises a hinged zero lift solar cell disk supported by two wings as shown in FIG. 4. These SPSAs can serve as global communication platforms.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 Satellite Weather Modification System (SWMS) key subsystems Functional Flow Overview.

FIG. 2. External Features of A Typical Satellite Engine (SE). FIG. 2 consists of FIG. 2A (top view), FIG. 2B (right side view), FIG. 2C (front view), and FIG. 2D, showing a typical panel or antenna gimbal rings arrangement.

FIG. 3. Satellite Engines (SEs) Orbital Operations Overview.

FIG. 4. Solar Powered Satellite Airplane (SPSA) Design. FIG. 4 consists of FIG. 4A, which is a sectional view taken along any of the section lines 4A--4A in FIG. 4C and looking in the direction of the arrows; 4B, which is a front view; 4C, which is a top view; and 4D, which is a side view.

FIG. 5. Overview Of A Ground Control Station (GCS) Functions.

FIG. 6. Techniques To Modify Air Mass Velocity Component.

FIG. 7. Some Satellite Weather Modification System (SWMS) Applications.

Detailed descriptions of these figures are presented below. Important items in each figure are identified in the text by a bold faced number representing the figure number. It is then followed by a fold faced lower case letter to identify the item in the figure. Example: 4d identifies item labeled 4d in FIG. 4.

## DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

While there are shown and described the preferred embodiments of the invention, it is to be distinctly understood that the invention is not limited thereto, but may be otherwise variously embodied and practiced within the scope of the appended claims.

To facilitate an understanding of the invention, a number of features are identified herein by letter(s) and a number inside a bold square bracket, as: [letters/number] or [letter-number/number]. Letter(s) or letter-number before a/0 identify major features of the invention. Each non-zero number following the / represents a feature that, while important, is less important than the major features. The major features are:

\_\_\_\_\_ [SWMS/O] = Features relating to Satellite Weather Modification System (SWMS) designs.



In an SWMS the energy and information flow between sun 1a, earth 1b, RSDs 1c, GCSs 1d and SEs 1e, as represented in FIG. 1, are identified and listed below:

\_\_\_\_\_ 1f Solar energy from the sun to the SEs. 1g Solar energy from the sun to earth. 1h Solar activities, such as sun spots, which can affect earth's weather and which are measurable by instruments. 1i Reflected solar energy beams and/or frequency agile energy beams discharged from SEs to earth surface or into the atmosphere or to deep space or to Solar Powered Satellite Airplanes. 1j Coded solar or frequency agile energy beams reflected back to SEs instruments or to RSDs instruments. 1s Solar energy beams or frequency agile energy beams from one SE to another SE. 1k Solar energy or frequency agile energy reflected back to SEs' reflector panels or the SEs' solar cell panels. 1l Energy or signals from earth or from atmosphere received by passive RSDs. 1m Signals transmitted and received by active RSDs. 1n Time and space tagged measurement data transmitted from RSDs to GCSs at regular intervals. 1p Command and control messages from GCSs to RSDs. 1q Status reports from SEs to GCSs at regular intervals. 1r Time tagged detailed assignments (each energy beam's characteristics and its AAP (Adjusted Aim Point) trajectory) for each SE from GCSs at regular intervals. 1t Desired local and global weather condition requests. 1x Data and status display to off-line devices. 1y Off-line analysis to update GCS math models, algorithms, operations and library data base. 1z Data flow between GCSs. Each GCS takes its turn to coordinate the activities of all GCSs. 1u Human (manual) controls. \_\_\_\_\_

## V.2 [SE/#]: Features Relating to Satellite Engine (SE) Design

A major feature [SE/0] is covered in this section. Six additional features [SE/1], . . . , [SE/6] are covered in separate paragraphs.

[SE/1]

SEs can have any shape. In this description it is assumed that the basic structure frame of each Satellite Engine (SE) has an outer contour resembling a flat rectangular box of dimension  $L$  (Length).times. $W$  (Width).times. $H$  (Height), where  $H$  is the smallest dimension. All six outside surfaces of this flat box are either fully or partially covered with reflecting materials.

[SE/2]

On top of each  $L$ .times. $W$  surface is an array of  $n$ .times. $m$  panels.

[SE/3]

one side of each  $n$ .times. $m$  panel is made of a reflecting material. It is used to reflect solar rays or laser lights. The other side of each  $n$ .times. $m$  panel is made of solar cells. They are used to convert solar energy into electrical currents.

[SE/4]

Each  $n$ .times. $m$  panel is independently mounted on gimbals on top of each  $L$ .times. $W$  surface. The construction is in such a way that each one of the  $n$ .times. $m$  panels has at least two independent degrees of attitude freedom,  $2p$  and  $2r$ , with respect to the SE structure frame  $2f$ .

[SE/5]

FIG. 2 illustrates  $n \times m$  panels on each  $L \times W$  side of a Satellite Engine structure frame. Gimbals rings on SE's  $L \times H$  and  $W \times H$  sides 2a 2b 2c 2d are designed to provide independent attitude controls of antennae or lamps or any direction pointing devices. Some antennae are used to discharge frequency agile and intensity agile energy beams to earth. Some antennae are used to transmit or receive frequency agile energy beams between SEs. Other antennae are used for communication purposes. Lamps are used to discharge to earth infrared radiations, laser lights or incandescent lights. The number of side gimbals antennae or devices are not limited to only four 2a 2b 2c 2d as illustrated in FIG. 2.

[SE/6]

Additional features displayed in FIG. 2 are identified as follows:

\_\_\_\_\_ 2f SE structure frame. The  $L \times W \times H$  box. 2h A typical set of gimbals rings which measure and control each reflector/solar-cell panel's attitudes 2r 2p with respect to SE structure frame 2f. 2p One of the two degrees of attitude freedom of each panel with respect to SE structure frame. 2r One of the two degrees of attitude freedom of each panel with respect to SE structure frame. 2q Reflector/solar-cell panel's possible third degree of attitude freedom with respect to SE structure frame. This will require larger spacing between panels. 2a Frequency agile and intensity agile RF or MMW or Microwave energy pulse train transmitting antennae. 2b Reflector/solar-cell panels. 2c Gimbals mounted infrared lamps or incandescent light lamps or laser antenna 2d Reflector/solar-cell panels.

In addition, each SE has a number of subsystems residing in its structure frame 2f. They are not shown in FIG. 2, but they are identified below as:

\_\_\_\_\_ 2w Momentum wheels or other means are used to control and maintain attitude stabilization of SE structure frame 2f with respect to inertial space (see feature (C/#] below) 2n Navigation subsystem. 2p Energy transformation subsystem: Transform dc current from solar cells into infrared, frequency agile and intensity agile energy pulses (see features [F/#]). 2c Computer subsystem. 2z Communication subsystem. 2i Retractable receiver designed to receive energy beams from other SEs. 2y Power regulator. 2e Energy storage devices are used to store solar energy collected when SE is outside earth's shadow. This energy can be used when SE is inside earth's shadow. 2u Optical camera package (optional or as part of RSDs). 2v Synthetic Aperture Radar package and antenna (optional or as part of RSDs). 2w Thermal imaging camera package (optional or as part of RSDs). 2x Infrared camera package (optional or as part of \_\_\_\_\_ RSDs).

### V.3 [OP/#]: Features Relating to SEs Orbital Operations

A major feature [OP/1] is covered in this section. Ten additional features [OP/1], . . . , [OP/10] are covered in separate paragraphs.

[OP/1]

As a minimum SWMS configuration, all orbiting SEs are placed in a pair of non-coplanar orbits. These orbits are inclined slightly with respect to each other. In this case, all SEs are apportioned about equally to and distributed uniformly along these two orbits. If both orbits are rotated into a single plane, one orbit will always be slightly higher than the other orbit. The orbits are thus nonintersecting and preferably

noncoplanar. Unless otherwise specified, the following descriptions will be for SEs operations on a pair of nonintersecting-noncoplanar orbits.

[OP/2]

At the center of each SE will be the origin of two coordinate systems both moving with the SE along its orbit. One set of solar-fixed axes has one axis that constantly points at the center of the sun. These coordinate axes have an average angular rate of one revolution per year with respect to inertial space. Another set of axes are fixed with respect to the SE structure frame. During normal operations that set will continuously tilt slightly with respect to the solar-fixed axes as required by the mission.

A third set of completely inertial coordinate axes is needed to relate vectors from one set of solar-fixed axes to another.

[OP/3]

In a typical SWMS operation, each SE  $3n$  in the lower orbit maintains its  $n \times m$  solar reflector panels (on one  $L \times W$  surface) facing the general direction of the sun. Simultaneously, each lower orbit SE's other  $L \times W$  surface will have its  $n \times m$  solar cell panels facing away from the sun. At the same time each SE  $3m$  in the higher orbit will have its  $n \times m$  solar cell panels (on one  $L \times W$  surface) facing the general direction of the sun. Its other  $n \times m$  solar reflectors (on its other  $L \times W$  surface) will be facing away from the sun.

Each SE experiences two modes of operation during each orbit around the earth. These two modes are defined according to the position of the SE which is inside or outside the earth's shadow. Consider these two cases:

[OP/4]

First, when SEs are outside earth's shadow: In this case the SEs' reflector/solar-cell panel arrangements are as specified in section [OP/3]. These arrangements allow incoming solar rays  $3a$  from the sun to be reflected as shown at  $3b$  from the lower orbit SEs' reflectors to SEs reflectors on the higher orbit before finally being re-reflected as solar rays  $3c$  to earth.

[OP/5]

The electricity generated by the higher orbit SEs' solar cell panels is used to supply each SE's internal needs. Excessive electricity is transformed to different forms of energy beams and discharged to earth via antennae or lamps or stored for later use. At the same time, each lower orbit SE's  $3n$  solar cell panels on one of its  $L \times W$  surfaces are facing away from the sun. These solar cells receive solar rays  $3r$  reflected from earth or  $3b$  reflected from other SEs. Electricity generated by these solar cell panels is used to supply each SE's internal needs. Any excess electricity is transformed to different forms of energy beams and discharged to earth via antennae or lamps or to another SE or stored for later use.

[OP/6]

Second, when SEs are inside earth's shadow and when solar or laser rays are required in the shadow: In this case, selected SEs in the shadow and in both orbits  $3m'$  and  $3n'$  have their  $n \times m$  reflector panels facing away from their respective SE structure frames. These SEs are



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[OP/10]

The  $n$ .times. $m$  panels may be arranged in a way slightly different from the one described so far. It is possible to mix the number of solar-cell panels and the number of reflector panels on each  $L$ .times. $W$  side of each SE. This arrangement applies to all SEs in both orbits 3h, 3g as follows: Each  $L$ .times. $W$  side of each SE will have  $(n$ .times. $m-k)$  reflector panels and  $k$  solar-cell panels facing away from its SE structure frame, where  $k=0, 1, \dots, (n$ .times. $m)$ . For each  $L$ .times. $W$  side, the exact  $k$  number is dependent on each SE's internal power consumption need and its mission requirements. This arrangement is especially useful for SEs in geo-synchronous orbit.

#### V.4 [RSD/#]: Features Relating to Remote Sensing Devices (RSDs) Integration

A major feature [RSD/0] is covered in this section. Two additional features [RSD/1] and [RSD/2] are covered in separate paragraphs.

[RSD/1]

Remote Sensing Devices (RSDs) 1c comprise millions of independently operated sensors. These RSDs are located on the ground, on the water, in the air, on SPSAs, or on SEs. RSDs perform independent measurements such as monitoring sunspots, measuring the composition and thermodynamics properties of a particular atmospherical air mass, monitoring the effect of SEs' energy beams, etc.

[RSD/2]

Each sensor continuously makes redundant measurements. Each measurement is time and location tagged and transmitted to a specified Ground Control System (GCS) 1d computers at regular intervals. These data are in standard formats so that they can be quickly correlated, analyzed and accepted by various algorithms and mathematical models in the GCSs 1d computer network.

#### V.5 [GCS/#]: Features Relating to Ground Control Stations (GCSs) Designs

GCSs provide the guidance of each energy beam. This includes the selection of each energy beam's characteristic and its corresponding Adjusted Aim Point (AAP) trajectory. A major feature [GCS/0] is covered in this section. Three additional features are [GCS/1], GCSs subsystem overview; [GCS/2], simplified GCS tasks design; and [GCS/3], a typical matured GCS subsystem tasks design and partition.

[GCS/1] GCS Overview

Each Ground Control Station (GCS) 1d' includes a network of interconnected supercomputers, electronic libraries, data receivers, data storage devices, data transmitters, visual display devices and control consoles. There are hundreds of GCSs 1d in the SWMS. Each GCS monitors weather conditions within a designated region of earth. Each GCS receives designated RSDs measurements 1n', local weather requests 1t' and data from other GCSs 1z. Each GCS also transmits estimated tasks 1r' to a specified group of SEs and receives data from other GCSs 1z. Data generated by each GCS are broadcast to all other GCSs 1z. Therefore, each GCS will have detailed global weather information and status of all SEs at discrete time points. Each GCS will take its turn to be the master GCS, which coordinates the operations of all GCSs in the SWMS.

(NOTE: the notations 1d', 1n', 1r', 1t' represent designated GCSs, selected RSDs' data, specified SEs' tasks and local weather requests respectively. Their corresponding notations without the ' given in FIG. 1 are for all GCSs, all RSDs data, all SEs tasks and all weather requests.)

### [GCS/2] Simplified GCS Tasks Designs

In most SWMS applications, SEs' assignments involve only reflecting solar rays. This is the case for SWMS during its initial stage of development. In this stage of development a GCS's principal task involves defining AAPs (Adjusted Aim Points) trajectories of each energy beam (centerline of each reflected solar ray) in some earth fixed coordinate system.

The available solar energy and the directions of incoming and reflected solar rays to and from each n.times.m reflector panel can be calculated as a function of time. These calculations use measurements of SE structure frame orientations with respect to inertial space, orientation measurements of each reflector panel gimbals with respect to its SE structure frame and orbital mechanics.

On the other hand, the desired aim point of each reflected energy beam and its trajectory are both specified by GCSs. This is done by distributing the aim points over the surface that is to be warmed by the solar rays. These aim points are then adjusted to take into account the atmospheric refraction and absorption of each energy beam and transform desired aim points to a corresponding set of AAPs (Adjusted Aim Points). A set of AAP vectors will be defined in an earth-fixed coordinate system. Each AAP point will be at the tip of its corresponding AAP vector. Next, AAPs trajectories are defined based on the amount of energy and rate of energy that is to be deposited onto the desired space. These estimated AAPs trajectories are transmitted to their corresponding SEs.

An LOS vector is defined as a vector from the center of any reflector panel to its corresponding AAP. Both this LOS vector and its corresponding reflecting solar ray vector are expressed in the same coordinate system, based for example on the SE structure frame fixed axes. Then the vector difference between these two vectors at a given time defines an error vector. This error vector specifies the required change of available energy beam's direction at that time.

The unit vector of each desired direction will be transformed to SE structure frame fixed coordinate axes. Assuming the SE structure frame follows a predetermined orientation schedule with respect to inertial space, then the desired gimbals angles of each reflector panel can be calculated from its unit desired direction vector. Also, each desired direction vector must satisfy the solar rays' availability constraints.

These computations must be repeated continuously many times a minute. This will provide the required error signal to the stepping motors to torque each gimbals ring. This scheme will control each reflected solar ray to follow its AAP trajectory in a timely fashion.

### [GCS/3] Typical Matured GCS Tasks Designs and Partitions

FIG. 5 graphically illustrates typical SEs' assignments (energy beams' characteristic and their AAPs trajectories) estimation process designed for a more matured SWMS. Key functions are identified by blocks and connected by high speed data busses (dashed lines). The main processing sequence is: 5b 5d 5e 5f 5e 5k 5m 5n 5b. Other functions of FIG. 5 are identified below:

5a A GCS library. This includes individual mathematical models 5q, Integrated global-weather/SWMS (Satellite Weather Modification System) model 5p, Historical weather statistics 5i, Encyclopedia of energy beam transmission, refraction, absorption, and reflection

characteristics in all kinds of weather conditions 5t, Encyclopedia of meteorology 5s, past SEs weather modification performance data 5v, Catalogued encyclopedia of SWMS Satellite Engines performance 5f permitting rapid search for SEs task assignments that will satisfy the new weather modification constraints specified by 5e.

5q Individual models include: Sun, sunspots, solar radiation, lunar orbital motion, solar wind intensity distribution, earth orbital motion, earth's gravitational model, atmospherical layer models, ocean current models, earth surface and subsurface models, natural and man-made discharges, absorption, refraction models, etc. Satellite Engines model, SE system performance models, interactions between atmosphere models and all other models, etc.

5i Historical global and local weather data statistics, including such data as annual rainfall distributions, annual temperature distributions, seasonal weather conditions, etc.

5t Encyclopedia of the interaction of energy beams with atmosphere, land mass and sea surfaces.

5f Encyclopedia of SEs performance data classified according to: energy types and characteristics, guidance law employed (AAPs' trajectories), initial atmospherical conditions, required atmospherical conditions changes, Satellite Engines sub-groupings. These data are continuously updated by off-line simulations 1y and by data from actual SEs past performances 5v. Data 5f output back to 5e will include SEs groupings, each energy beam characteristics and AAPs' trajectories, all expressed as functions of time.

5l Estimate the desired weather conditions in next (Tb,Tc) interval based on past weather condition statistics. Desired weather is expressed in terms of weather characteristic vectors for each affected weather cell.

5g Special desired weather condition requests. All requests are expressed in terms of weather characteristic vectors sequences for each weather cell. Both weather cells and weather characteristic vectors are defined in 5d.

5b Update integrated mathematical model using designated RSDs 1n', designated SEs' status reports 1q', and updated data from other GCSs 1z. The results of these updates yield an up-to-date integrated global weather math model with Satellite Engines' math models integrated in the total model. The resultant model is to be used for further extrapolations 5d, for storage in local GCS library 5a and for broadcasting to all other GCSs 1z.

5c Estimations of selected SEs' task assignments for the next (Tb,Tc) interval based on anticipated requirements from 5l and 5g. These estimates are passed on to 5d.

5v Off-line evaluation of SEs performances in the previous (Tb,Tc) interval using actual RSDs measurements 1n' and previous cycle SEs' assignments 1r' adjusted by actual SEs status reports 1q'. Results of SEs performance evaluations are used to update GCS library data 5t, 5f and 5q.

5d Forward extrapolation of integrated mathematical model 5b, from  $t=T_a$  to  $t=T_c$ , in equal  $dT$  increments, where  $dT=(T_c-T_a)/N$  and  $N=a$  large even integer. If the actual RSDs measurements for the (Ta,Tb) interval are in agreement with previously estimated weather parameters, then this extrapolation process can be reduced to only the (Tb,Tc) interval.

The atmosphere is subdivided into weather cells. The average thermodynamics, dynamics and air composition parameters inside each weather cell are represented by a vector called the weather characteristic vector. Each weather cell is represented by its weather characteristic vector for a fixed time duration.

5e First, find the required weather changes by taking the differences between the extrapolated weather conditions from 5d and the corresponding desired weather conditions from 5h. This is done by manipulating the corresponding weather characteristic vectors.

Next, initialize a search in 5f for the SEs' task assignments during the (T<sub>b</sub>,T<sub>c</sub>) interval. SE task assignments from 5f will include parameters which define each energy beam's characteristics and its Adjusted Aim Point (AAP) trajectory. This search uses the initial weather conditions from 5d, required weather changes from 5d and 5h. However, a sequence of desired weather conditions from 5h is selected at reduced constraint levels. This will ensure that at least one set of the answers found from 5f will later satisfy the criteria in 5k.

Found in 5f are SE's task assignments which include each one of its energy beam's characteristics as a function of time and their corresponding Adjusted Aim Point (AAP) trajectories.

Each SE assignment parameter is found by matching stored 5f energy absorption patterns or thermodynamic changes patterns with their corresponding required change patterns 5e.

5k The SEs' tasks assignments found in 5f are evaluated by performing parallel simulations. The results of these simulations should determine which set of SEs assignments best satisfies the desired weather conditions imposed on the SEs by 5h. All calculations are done in terms of weather characteristic vectors at the weather cells' levels 5d.

5m Define detailed Satellite Engines' task time lines based on optimal selection from 5k. These assignments are transmitted to the corresponding SEs 1r'. A second set of these assignments is sent to 5c for the next computation cycle. A third set of these data is sent to the GCS library data bus to be broadcast as indicated at 1z to all GCSs in the SWMS. This last step is necessary to take care of conditions when a GCS is reassigned to manage a different set of SEs in the next computation cycle.

5n Initialize the next computation cycle. The current (T<sub>b</sub>,T<sub>c</sub>) interval is shifted down to become the next (T<sub>a</sub>,T<sub>b</sub>) interval, and a new (T<sub>b</sub>,T<sub>c</sub>) interval is selected with the old T<sub>c</sub> set to equal to the next T<sub>b</sub>. The next computation cycle repeats at 5b.

The descriptions set out above outline a typical process to define SEs grouping, each energy beam type, each energy beam's physical characteristics and its Adjusted Aim Point (AAP) trajectory. These parameters are transmitted to their corresponding SEs 1r'.

NOTE: 1x, 1y, 1z, 1r', 1q' and 1n' refer to the same items identified in FIG. 1. The prime ' denotes that these data belong to only a subgroup of SEs or subgroup of RSDs.

## V.6 [C/#]: Features Relating to Control Energy Beam Directions

One major feature [C/0] is covered in this section. Two additional features [C/1] and [C/2] are covered in separate paragraphs.

### [C/1] Overview

Each SE shall release its energy beams in a timely fashion following its AAP trajectory as specified by its GCS 5m. SE's control subsystem aims each energy beam at its AAP (Adjusted Aim Point) and makes each energy beam follow its AAP trajectory in a timely fashion.

#### [C/2] Direction Controls

This energy beam directional control task is partitioned into two sub-tasks. First, control the orientation of SE's structure-frame axes with respect to inertial space. This is done by using inertial flywheels or other means. Second, control the orientation of solar-reflector/solar-cell panels, antenna dishes, or lamp axes with respect to the SE's structure-frame axes. This is done by measuring the actual gimbals angle settings and torquing each gimbals ring to its desired orientation. Each energy beam's desired orientation at a given time is defined by its unit vector from reflector (or antenna or lamp) center to its AAP at that time. Using, for example, the directional cosine technique, these desired unit vectors can be transformed into desired gimbals angles. A more detailed description on how this is done has been presented above at [GCS/2].

#### V.7 [F/#]: Features Relating to Energy Beam Frequency and Intensity Selections

A major feature [F/0] is covered in this section. Seven additional features [F/1], . . . , [F/7] are covered in separate paragraphs.

Solar rays will be the primary energy beams discharged by the SEs. However there are times when other types of energy beams are required to penetrate a cloud layer, or to heat up a specified air mass of specific composition. In these cases, frequency agile and intensity agile energy beams are used. The frequency of an energy beam determines its ability to penetrate a layer of atmosphere of a specified composition. It also determines the degree of absorption of a given frequency energy beam by an air mass of a particular composition. Weather cells air mass compositions are estimated by Remote Sensing Devices (RSDs).

#### [F/1]

A specific energy beam's frequency and intensity will be selected to satisfy a given depth of atmospheric penetration and to yield a specified energy absorption contour or temperature elevation contour.

#### [F/2]

The change of energy into heat is monitored by RSDs, such as infrared sensors or thermal imagery cameras. Or it can be estimated from specially designed ground receivers. These receivers measure the presence of frequency agile energy beams which are frequency, amplitude or phase modulated. These RSDs data are used by GCS or by SEs directly, thus enabling adaptive adjustments of energy beams' frequencies and intensities.

#### [F/3]

Energy intensity at a given location is also controlled by energy beam guidance laws which specify each energy beam Adjusted Aim Point's (AAP's) trajectory, the speed AAP moves along its trajectory, dwell times, locations on an AAP trajectory and the shape of an AAP trajectory.



([W1/0], . . . , [W4/0]).

#### V.8.1 [W1/#]: Features Relating to Modifying Global Weather Conditions

This technique employs a very large number of Satellite Engines (SEs) to modify global weather conditions by blocking or redirecting solar rays. One major feature [W1/0] is covered in this entire section. Six additional features [W1/1], . . . , [W1/6] are covered in separate paragraphs.

[W1/1]

This method involves using millions (or even billions) of Satellite Engines (SEs) to block or redirect solar rays. Typically, this requires a large number of low inclination and non-coplanar orbits near the equatorial plane. When the earth requires cooling, the Ground Control Stations (GCSs) simultaneously command all SEs to rotate their  $n \cdot (m-k)$  ( $k=0, 1, \dots, <<m$ ) reflector panels (on one  $L \cdot W$  side) to face the general direction of the sun and away from earth. These SEs block part of the solar energy from reaching the earth by reflecting the solar energy away from earth and thus assist the earth's cooling process.

Each SE will reserve  $k$  solar cell panels (along with  $n \cdot (m-k)$  reflector panels) to face the sun. These solar cell panels are used to generate electricity for the SE's internal use. The value of  $k$  is such that  $k=0, 1, 2, \dots, <<m$ . The  $k=0$  case implies that solar cells located on the back side of each reflector panel or on its other  $L \cdot W$  surface can generate sufficient electricity for the SE's internal use.

[W1/2]

The reflected solar rays' guidance is done by specifying the Adjusted Aim Points (AAPs) of each reflected solar energy beam and trajectories of these AAPs in deep space away from earth. In this case the AAPs can be simply computed as the line-of-sight aim points, because the reflected solar rays will have little or no interference (refraction) by the atmosphere.

[W1/3]

It is to be noted that when the equatorial regions become cooler, the average temperature differences between the polar regions and the equatorial regions are reduced. Therefore this technique may be used to modify global weather patterns or to create favorable local weather conditions which can be further modified by SWMS.

[W1/4]

When controlled cooling is not required, GCSs command some or all SEs to direct their collected solar energy to other SEs or to earth directly. Again, this is done by specifying the AAPs of each energy beam and their trajectories to the desired locations on earth or at specified Satellite Engines' reflector panels or solar cell panels. This process selectively cools certain regions but at the same time heats up other regions. This technique can also be used to supply energy to specific devices. All these tasks are under GCSs control.

[W1/5]

If these temperature differential regions are sufficiently close, an air mass motion is introduced which forces the air mass to move from the high pressure region to the low pressure region. This technique can be used to move an air mass of specific composition from one location to another. This technique can also be used to modify the jet stream path and therefore modify the weather on either side of the jet stream.

[W1/6]

Distributing AAPs over a small wet surface and aiming solar rays at these AAPs will cause evaporation. This will increase the humidity of air above the wet surface. As the humid air rises to higher altitudes clouds will form. These clouds can be used to cool local regions by blocking the sun's rays. They can also cause precipitation.

#### V.8.2 [W2/#]: Features Relating to Modifying Local Weather Conditions

This technique is similar to feature [W1/6] but requires far fewer Satellite Engines (SEs). Also, SEs orbits are paired as specified in feature [OP/0]. One major feature [W2/0] is covered in this entire section. Two additional features [W2/1] and [W2/2] are described in separate paragraphs.

[W2/1]

This technique can be used to warm a local region. This is done by distributing AAPs (of all SEs' reflected energy beams) over the region to be warmed. Each reflected energy beam will be assigned to dwell at a given AAP for a given duration, or each AAP trajectory will be limited to circle within a desired region.

[W2/2]

This technique can be used to create a high humidity air mass or to form clouds. This is similar to feature [W2/1] above, except that the reflected solar rays are aimed at AAPs distributed over a wet surface, such as a lake or a patch of ocean. This process is originated by Ground Control Stations (GCSs) defining the AAP trajectory of each energy beam over the wet surfaces. Satellite Engines (SEs) then reflect solar rays to their respective AAPs. This process is essentially the same as one that occurs in nature, except that both the wet surface area and the timing are selected and controlled by SWMS. Also, the intensity of the solar ray can be made more concentrated than what occurs in nature. This process will increase the moisture content of the air mass above the heated wet surface. As the high humidity air rises to higher altitudes, it begins to cool and form clouds.

#### V.8.3 [W3/#]: Features Relating to Moving an Air Mass Upwards

One major feature [W3/0] is covered in this entire section. Two additional features [W3/1] and [W3/2] are covered in separate paragraphs.

[W3/1]

This technique is designed to initiate and/or modify an air mass's upward motion. This is done by adaptively aiming energy beams of specified characteristics at specified AAPs. These AAPs are distributed in a vertical column inside or near the air mass that is to be moved. The type, frequency, intensity and AAP trajectory of each energy beam are adaptively selected based on sensors' feedback measurements

which lead to optimal upward movement of the air mass due to energy absorption. Combinations of energy beam characteristics with guidance law (AAPs trajectories) options are simulated to obtain an optimum combination. One such criterion to judge the optimum combination can be a criterion which determines the rate of climb at which this air mass will rise to higher altitudes.

[W3/2]

Some SEs are located on earth's surface for this purpose. Other SEs may be in the air or move with the rising air column. These ground based or sea based SEs are used to heat the air column from below.

#### V.8.4 [W4/#]: Features Relating to Modifying an Air Mass's Horizontal Velocity Component

One major feature [W4/0] is covered in this entire section. Two additional features [W4/1] and [W4/2] are covered in separate paragraphs.

The best way to transport an air mass of specific composition and thermodynamic properties is to allow it to be carried by wind currents that exist in nature at that time. However, natural wind does not always satisfy weather modification requirements. The following techniques to transport an air mass are presented.

[W4/1]

This technique includes creating a pressure differential on either horizontal side of the air mass to be moved. This technique is similar to the one discussed in section [W1/5], except in this case in air mass size and movement are very localized. This technique requires unequal distribution of energy into two adjacent sides of the air mass to be moved. This is done by unequal concentrations of energies, AAPs, or energy beams' dwell times on either side of an air mass.

[W4/2]

This case involves concentrating AAPs trajectories along a desired direction of air mass motion. FIG. 6 illustrates this concept. Consider the case where an air mass has no initial lateral motion component. The objective is to move the air mass near 6x to points near 6y. First, define this desired direction by an arrow 6v relative to earth 6e, which may be inclined at an angle with respect to the local gravity vector. Next, imagine a large tube 6i enclosing the air mass to be moved and with the desired directional arrow 6v along tube's centerline 6x-6y. Next, define a sequence of AAPs (6a', 6b', 6c', 6d', . . . ), such that the maximum energy absorption of each energy beam will be made to concentrate near the centerline of the tube (at 6a, 6b, 6c, 6d, etc., respectively). All these AAPs are estimated by GCSs and transmitted as assignments to the SEs 6s on orbits 6h or 6g. Note: each 6s point in FIG. 6 can represent many SEs. These SEs will first (at  $t=t_a$ ) concentrate all their energy beams at AAP 6a' near point 6x. This large input of energy will cause the air mass near 6a to absorb the energy and expand rapidly in all directions. Assume a constant temperature contour (resulting from absorption of these energy beams) can be represented by a tear shaped figure labeled 6k. Next (at  $t=t_b$ ), let these SEs shift their common aim point to an adjacent AAP at 6b'. This will result in rapid heating of another air mass centered at 6b. This will cause another tear shaped constant temperature contour labeled by 6l. Continuing this process is like producing a sequence of small "explosions" along the imaginary tube's centerline. The size of each "explosion" is controlled by the number of SEs (or energy beams) shearing the same AAP at a given time. The speed of the induced air mass velocity component along 6v also depends on the spacing and rate of change of these AAPs or energy beams dwell times along their AAP trajectories. When energy focus reaches the end of the tube 6y, this process can be repeated again starting near 6x.

This concept can be explained in another way by considering the rows of small circles in FIG. 6. Each small circle represents the expansion due to absorption of concentrated energy beams at a given location 6a, 6b, 6c, . . . etc. The small arrows radiating out from the center of each small circle in FIG. 6 represents the direction of the local air velocity. As the energy center moves from 6a to 6b to 6c . . . , the velocity components between energy centers cancel each other out. What is left over is only the velocity component in the desired direction 6v. When the energy beams are removed, the surrounding cooler air will rush back into the imaginary tube 6i and push the air in the 6v direction. This technique will always introduce an air mass velocity component in the local vertical direction. This vertical velocity component may not be a bad feature in many applications, as when moving a humid air mass inland and allowing it to condense to rain. The horizontal velocity component will move the air mass inland. The vertical velocity component will allow the air mass to move to a higher and colder altitude. This will delay the air mass's condensation into rain until it has reached its desired location. If the air mass has an initial lateral velocity component 3i, then the final air mass velocity vector 3k is the vector sum of its velocity vector caused by its initial velocity 3i plus the SWMS induced velocity vector 3j.

The best way to use this technique is to first create a rising column of air near 6y using techniques described in section [W3/0]. Next, simultaneously applying the teachings at [W3/0] and [W4/2] will cause the air mass inside the imaginary tube 6i to feed to the rising air column created by [W3/0].

#### [A##/]: Features Relating to Satellite Weather Modification System (SWMS) Applications

There are five major features [A1/0]-[A3/01], [A6/0] respectively covered in separate sections. There are a total of 16 (=0+0+3+0+8+5) additional features respectively covered in separate paragraphs. These additional features are:

[A3/1], . . . , [A3/3],

[A5/1], . . . , [A5/8],

[A6/1], . . . , [a6/5].

Some SWMS applications are designed to employ various combinations of the basic weather modification techniques described in section V.8. Other applications are related to energy supply and solar powered airplanes (FIG. 4). All applications are designed to offer unique and useful services. All applications are selected to have the potential to compete successfully in the real business world. Some of these SWMS applications are illustrated in FIG. 7 and described below.

#### V.9.1 [A##/]: Features Relating to Increasing Precipitation

One major feature [A1/0] is covered in this section.

[A1/0]

High humidity air masses are created by application of techniques specified in sections [W1/6] AND [W2/2] over wet surfaces 7x to cause cloud formation. Cloud temperatures are maintained by techniques covered in sections [F/0], [W3/0] and [W4/2]. The air mass is allowed to







Stock can be issued and offered to the public to raise the necessary funds to finance these ventures. Raised funds will then be used to build prototypes of SWMS subsystems: Satellite Engines (SEs), Ground Control Stations (GCSs), Remote Sensing Devices (RSDs) and Solar Powered Satellite Airplanes (SPSAs).

[A6/3]

Initially a few basic services will be offered to potential customers who can afford to pay for SWMS services. In each orbit each SE can sequentially service many locations below its orbit. Therefore, by simply changing some computer codes these SEs can also service some non-paying customers as a public service.

[A6/4]

Some of the initial services to be offered by SWMS are illustrated in FIG. 7. Satellite Engines (SEs) distributed in the orbits (7h and 7g) are too small to be shown in FIG. 7. Solar rays 7a from the sun are first reflected 7b from the SEs in the lower orbit to SEs in the higher orbit before finally being reflected to earth 7c. Some initial services to be offered by SWMS are described below:

1. Techniques described in section [A4/0] are used to warm local regions during extremely cold winter days. Potential paying customers are orange growers in Florida 7r and California 7r, greenhouse farms 7w, etc. Potential nonpaying customers are small farmers at high latitudes, etc.
2. Solar Powered Satellite Airplanes (SPSAs) 7p (described in section [A5/0]) are used to carry communication relay instruments or weather monitoring equipment 4l over local regions. Potential paying customers are communication companies, news services, etc. Potential non-paying customers are public education services, environmental protection agencies, weather services, local police departments, etc. It is to be noted that when an SPSA flies a closed loop pattern 7t (dashed line racetrack patterns in FIG. 7) above a given land region, it can be used to compete for business with satellites in a geo-synchronized orbit. The advantages of SPSA include that these SPSAs are re-usable and closer to earth and each SPSA carries its own reusable launching system.
3. The technique discussed in section [A1/0] is used to bring rain to dry regions in the world. The Satellite Engines' (SEs') tasks are to warm the ocean surface a few miles off the southern California coast 7x. These tasks must also be timed with the local ocean wind direction, so that the high humidity air mass created by SEs over the ocean can be carried inland by the wind. To support the energy beams' direction guidance laws, a set of AAPs are defined and distributed over an ocean surface area 7x. The trajectories of these AAPs can follow the local water current, be timed in accordance with local wind directions, and avoid local cloud formations. Potential paying customers are southern California water authority 7y, etc. Potential non-paying customers are drought victims of Ethiopia 7z, etc.

[A6/5]

FIG. 7 illustrates some SWMS applications. Items in this figure are identified below:

\_\_\_\_\_ 7a Solar rays from the sun. 7b Solar rays reflected from SEs in lower orbit 7g to SEs in higher orbit 7h. SEs are too small to be shown in these orbits. Each 7b line in FIG. 7 represents solar rays from thousands of reflector panels belonging to many SEs. 7c Solar rays reflected from higher orbit 7h to earth or to SPSA 7p. SEs are too small to be shown in this figure. Each

7c line in FIG. 7 represents solar rays reflected from thousands of reflector panels belonging to many SEs. These solar rays can be aimed at many AAPs on earth or they may be focused on a single AAP at the center of an SPSA disk. 7d Nature generated whirlwinds. 7e Earth. 7g Lower orbit of a nonintersecting-noncoplanar orbital pair. 7h Higher orbit of a nonintersecting-noncoplanar orbital pair. 7i Directions of air mass motions induced by SWMS. This will create a whirlwind which can be used to cancel an existing whirlwind 7d. 7j Direction of air mass motions induced by SWMS. This will create a whirlwind which can be used to increase the strength of an existing whirlwind 7d. 7p Solar Powered Satellite Airplane (SPSA). 7r Local region to be warmed by solar energy. 7t SPSA flight pattern defined by GCS as focal point of thousands of reflecting solar rays. In most cases the SPSA flight path is the same as the common AAP trajectory defined by GCS. 7v Electricity generating stations: direct solar, wind or hydroelectric. 7w Greenhouse farms. 7x Ocean or other wet surfaces to be heated by concentrated solar energy beams. This is done to increase the air mass humidity above 7x. 7y Increased precipitation by SWMS in southern California 7z Increased precipitation by SWMS in northern Ethiopia. \_\_\_\_\_

## APPENDIX: ACRONYMS

AAP Adjusted Aim Point.

GCS Ground Control Station (see FIG. 1).

LOS Line-Of-Sight.

MMW Millimeter Wave.

RSD Remote Sensing Device (see FIG. 1).

SE Satellite Engine (See FIG. 2).

SPSA Solar Powered Satellite Airplane (see FIG. 4).

SWMS Satellite Weather Modification System (see FIG. 1).

\_\_\_\_\_ [SWMS/#] Invention features relating to Satellite Weather Modification System (SWMS) designs (# = 0, 1, . . . ,5). [SE/#] Invention features relating to Satellite Engines (SEs) designs (# = 0, 1, 2, . . . ,6). [OP/#] Invention features relating to SEs orbital OPERations (# =0, 1, 2, . . . ,10). [C/#] Invention features relating to SEs' energy beam direction Controls (# = 0, 1, 2). [RSD/#] Invention features relating to Remote Sensing Devices (RSDs) integration into the SWMS (# = 0, 1, 2). [GCS/#] Invention features relating to Ground Control Stations (GCSs) (SEs guidance) designs (# = 0, 1, 2, 3). [F/#] Invention features relating to Frequency agile energy beams' frequency and intensity selections (# = 0, 1, . . . ,7). [W#/#] Invention features relating to SWMS's basic Weather modification techniques. Four major features are: [W1/0], [W2/0], [W3/O] and [W4/0]. [W1/#] Invention features relating to modifying global weather conditions (# = 0, 1, . . . ,6). [W2/#] Invention features relating to modifying local weather conditions (# = 0, 1, 2). [W3/#] Invention features relating to moving an air mass in a vertical upward direction (# = 0, 1, 2). [W4/#] Invention features relating to modifying air mass velocity horizontal component (# = 0, 1, 2). [A#/#] Invention features relating to SWMS applications. Six major features are: [A1/0], [A2/0], [A3/0], [A4/0], [A5/0] and [A6/0]. [A1/#] Invention features relating to increasing precipitation applications (# = 0). [A3/#] Invention features relating to creating whirlwinds (# = 0, 1, 2, 3). [A4/#] Invention features relating to warming local regions (# = 0). [A5/#] Invention features

relating to SPSA design and applications (# = 0, 1, . . . ,8). [A6/#] Invention features relating to business ventures based on applications of SWMS and SWMS/SPSA services (# = 0, 1, . . . ,5). \_\_\_\_\_

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