2.1 ATMOSPHERIC HEATING AS A RESEARCH TOOL

Dr. Bernard J. Eastlund and Lyle M. Jenkins[1]

Abstract—Throughout history, mankind has sought to minimize the impact of the unpredictability and severity of violent storms such as tornadoes. To date, solutions have focused on early warning and on development of fortified buildings made to withstand the strong forces that are the hallmark of these atmospheric events. Sophisticated prediction methods have been developed to warn populations of potential storm danger. These "warn and seek shelter" mechanisms have clearly reduced the loss of life and, to a lesser extent, property damage associated with these natural events. However, despite our best efforts, loss of life and costly property damage are still strongly associated with severe weather phenomenon. This paper describes concepts that use either ground or space based platforms for generating beams of microwave radiation to provide localized thermal heating or ionization of the atmosphere. It is further suggested that these heating techniques could initially be used as research tools for improving computer simulations of atmospheric phenomena. The ultimate goal is to utilize such tools for prevention of severe storm produced tornadoes

The experimental techniques include a) heating of rain droplets with microwaves between 26 and 35 Ghz, b) Heating of atmospheric oxygen with microwave frequencies of about 54 Ghz and c) creation of artificial ionization plasma patterns in the atmosphere which can be heated with microwaves. These plasma zones may interact with electrical phenomena by adjustments in atmospheric electrical conductivity. New experimental techniques similar to "ink drop" experiments to determine the diffusion of chemicals in a liquid can be applied to the atmosphere to study heat transport and electrical properties.

The microwave heating technologies provide methods for rapidly heating well-defined regions of a weather system. Ground or satellite based microwave phased arrays, focused on specific locations in the atmosphere, will be used to heat the atmosphere and to create useful artificial ionized plasma patterns. Initial experiments would correlate heating in a specific region of a weather system with computer simulations. Weather research concepts are proposed to improve definition of conditions in a storm.

Weather modification of storms is also described. One such application is to prevent concentration of rotational energy in a mesocyclone by heating the cold rainy downdrafts. The anticipated result is to prevent the precise rotation geometry that can produce a tornado and thus interrupt tornado formation. The selective heating approach may be applied to steering hurricanes and typhoons.

Development of Space-Based Solar Power as a clean, renewable energy source for the world's needs is dependent on an evolutionary approach. Dual use of such systems for weather research and control will increase the economic value of solar power satellites. Understanding the weather and computer simulation of storm systems is necessary before attempting interaction to mitigate storms. When computer simulation can define storm interaction, the initial investment in space-based solar power can save lives and reduce property damage. In the process, the fundamentals of Space-Based Solar Power are demonstrated, leading to development of commercial

1———————————
[1] Jenkins Enterprises
151 Ravenhead
Houston, TX 77034
713-946-0819
jenkins1166@sbcglobal.net

energy systems. This clean, renewable energy source can potentially reduce green house gases and consequently global warming.

1. Introduction

With violent storms such as tornadoes, solutions have focused early warning and on development of fortified buildings to withstand the strong forces that are the hallmark of these atmospheric events. Sophisticated prediction methods have been developed to warn populations of potential storm danger. These "warn and seek shelter" mechanisms have clearly reduced the loss of life and, to a lesser extent, property damage associated with these natural events. However, despite our best efforts, loss of life and costly property damage are still strongly associated with severe weather phenomenon.

Concepts are described that use ground or space based platforms for generating beams of microwave radiation to provide localized thermal heating or ionization of the atmosphere. These heating techniques could be used as a research tool for improving computer simulations of atmospheric phenomena. The ultimate goal is to utilize such tools for prevention of tornadoes.

The experimental techniques include heating of rain droplets with microwaves between 26 and 35 Ghz, heating of oxygen with microwave frequencies of about 55.2 Ghz and focusing microwave radiation between 2.45 Ghz and 35 Ghz at various altitudes to create an artificial ionized plasma pattern in the atmosphere.

The ability to create artificial ionized patterns can lead to direct measurement of electrical parameters, such as the electrical conductivity. Such experiments would help determine the importance of electrodynamic forces in severe storm development.

Methods are proposed for creating atmospheric ionized plasma patches with ground based microwave phased arrays. These are focused on specific locations in the atmosphere. These plasma patches can be used for obtaining time dependent diagnostics of temperature and thermal transport as a function of time. The electrical conductivity of the patches can lead to new diagnostics of localized electrical properties in severe storms. Microwave heating of localized regions of the atmosphere can provide temperature perturbations that spread via radiative or conductive transport. Diagnostics of this temperature transport process, with radiometry or other means, can provide valuable validation of the assumptions and results of computer simulations. The experimental technique is similar to "ink drop" experiments to determine the diffusion of chemicals in a liquid. This can be applied to the atmosphere to study heat transport and electrical properties.

Creation of artificial ionization plasma patterns in the atmosphere can permit experimental study of the influence of electrical phenomena on storm systems and contribute to new computer simulations including electrodynamic forces. Such plasma patterns can also be heated with microwaves to provide a unique new experimental tool that can artificially generate acoustic and gravitational waves in the atmosphere.

Advanced computer simulations of severe weather systems, such as the Advanced Regional Prediction System (ARPS) code, require accurate boundary condition information for application to real storms. Wind profiles as a function of altitude are an essential input. Another potential application is hurricane simulation. Steering winds are crucial to the development and track of hurricanes. Microwave heating can produce localized high temperature regions and aid the measurement of the wind velocity in those regions.

Initially, inexpensive ground based microwave phased arrays focused on specific locations in the atmosphere, will be used to create the plasma patch and to heat the atmosphere. Initial experiments would correlate heating in a specific region of a weather system with computer simulations of the weather system. Eventual applications include the dual use of solar power satellites to provide a green energy source for mankind while being capable of applying microwaves to generate plasma patches and potentially control severe weather.

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One concept is to prevent concentration of rotational energy in a meso-cyclone by heating the cold rainy downdrafts within the storm. [Ref. 4]. If applied at the right zone with the appropriate intensity, the convective shears will be disrupted. The anticipated result is to eliminate the death and destruction from tornadoes.

2. Safety and Experimental Guidelines

Experimentation with microwave beams in the atmosphere could lead to concerns about safety. The microwave flux required for useful heating experiments, or for weather modification can be accomplished with local microwave flux on the order of 5 milliwatts/ cm^2 [Ref. 6] which is within the guidelines for home microwave oven emission. Nevertheless, because of public safety concerns, we would follow the recommendations of the National Academy of

Science. The National Academy of Science [Ref. 5] has published some guidelines for the conduct of severe weather mitigation research:

-Theoretical modeling and simulation analysis of the physics, chemistry and biology of the relevant geophysical, geochemical climate and ecological systems

-Study of potential for instability and chaos

-Small–scale mitigation experiments to determine physical, chemical and biological properties where they are known

-Detailed design, development and cost analysis of deployment systems

-Study of related natural events to understand their relevant properties, including the statistics of their occurrence.

-Study of possible ecological, geophysical, geochemical and atmospheric side effects, including consideration of reversibility.

3. Weather Research Concepts

Artificial Ionized Plasma Patterns in the Atmosphere as Experimental Tool

Electrical conductivity modification by creation of artificial ionization plasma patterns in the atmosphere can, for the first time, permit experimental study of electrical phenomena and contribute to new computer simulations of electrical activity in severe weather systems. Such plasma patterns can also be heated with microwaves to provide a unique new experimental tool that can artificially generate acoustic and gravitational waves in the atmosphere.

Artificial Ionospheric Mirrors have been studied since the 1980's. The principal objective was to enable over the horizon communication. The power levels (10^9watts) to generate the fields were considered prohibitively expensive. Consequently, no artificial Ionospheric mirrors have been produced in any portion of the atmosphere. Recently an approach has been patented by Eastlund that takes advantage of the Sun's cosmic rays to aid in producing the plasma pattern [Ref. 3]. The cosmic particles can reduce the electrical breakdown field of the atmosphere by up to a factor of 40. This in turn will reduce the power required by a factor of 1600. It is expected that the artificial ionized plasma patterns can be created using inexpensive magnetron power beaming. An example of such a plasma pattern is shown in Figure 1.

There are several potential applications of these artificially ionized plasma patterns. They may aid in telecommunications to increase the function of mobile phones or to enable over the horizon communications. The atmospheric heating capability may be applied to specific regions. Modifying electrical conductivity may be accomplished in a controlled manner

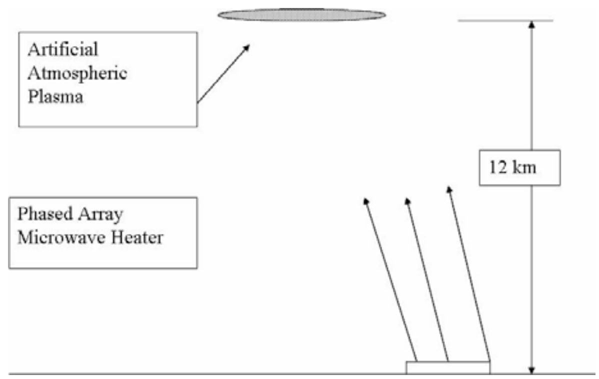

Figure 1 Schematic Drawing of Artificial Atmospheric Plasma Production System

Artificial atmospheric plasmas can be produced by focusing microwaves from phased array antennas on localized regions of the atmosphere. [Ref. 3] These plasma patterns can be heated with microwaves at frequencies comparable to the plasma frequency in the patch. The electrical conductivity of the plasma patterns can lead to experiments in manipulating the electrical properties of weather systems through adjustments in atmospheric electrical conductivity. Figure 2 is a schematic of an artificial atmospheric plasma pattern produced in the interior of a mesocyclone.

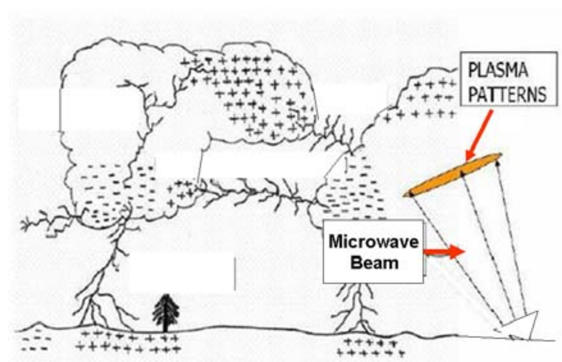

Figure 2. Plasma pattern inserted in mesocyclone.

These capabilities open opportunities for interactive weather research. Selective heating may modify steering winds. Electrical conductivity has a role in understanding lightning. The ability to interactively generate plasma patterns from 10 to 100 km altitudes in a range of sizes provides a valuable experimental tool.

4. WEATHER MODIFICATION-TORNADOES

Computer simulation of severe storms has been characterized by the Advanced Regional Prediction System (ARPS) code developed by the Center for Analysis and Prediction of Storms (CAPS) at the University of Oklahoma[Ref.8]. It includes conservation equations for momentum, heat(potential temperature), mass(pressure), water substance(water vapor, liquid and ice), subgrid scale turbulent kinetic energy and the equation of state of moist air. Initial conditions include a clear day in the Midwest, a cylindrical column of air heated about 10 degrees K and a wind shear structure as a function of altitude defined by balloon measurements. The code predicts the development of a mesocyclone as illustrated in Figure 3. The code is limited in the consideration of raindrop size, acoustic and gravitational wave phenomena. The latter interaction with storm systems is a recent theory.

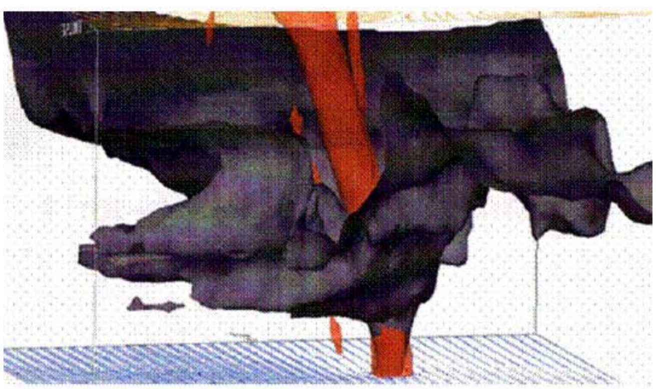

Figure 3 ARPS Simulation of Mesocyclone with Tornado

Simulation of Heating of Rain Drops in a Mesocyclone Using Microwaves at 26 Ghz.

The ARPS model was modified to study effects on a "standard storm" of electromagnetic radiation beamed from a "Thunderstorm Solar Power Satellite." The details results of this study indicated significant effects on the simulated storm from the microwave beam[Ref. 6].

These original simulations with the ARPS code by Eastlund [Ref. 6] attempted to determine the effect of microwave heating and included several key parameters. The code was modified to include microwave heating functions applied as a function of rain droplet density. Power levels ranged from 5x 10^9 to 10^{12} watts, (The projected power from a large solar power satellite is estimated at about 1 x 10^{10} watts.) Volume of the storm that was heated ranged from 0.5 km^3 to 100 km^3. The microwave energy heated rainfall above a specified intensity in the storm, rather than focusing only on the cold rainy downdraft. The simulation resulted in the elimination of the hook echo region of the storm as shown in Figure 4 A and 4 B. Figure 5 A shows the velocity profile over a 64 x 64 km grid, demonstrating formation of a "hook-echo" indicating positions of possible tornadoes. Figure 5 B shows the effect of heating the denser rain areas at a rate of 0.05 $^{o}K/s\text{-}m^3$ Note that the hook-echo has been eliminated, indicating the possible elimination of tornadoes[Ref. 9].

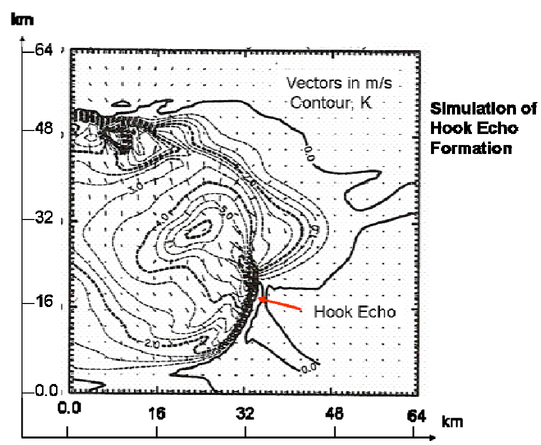

Figure 4 A Formation of Hook Echo

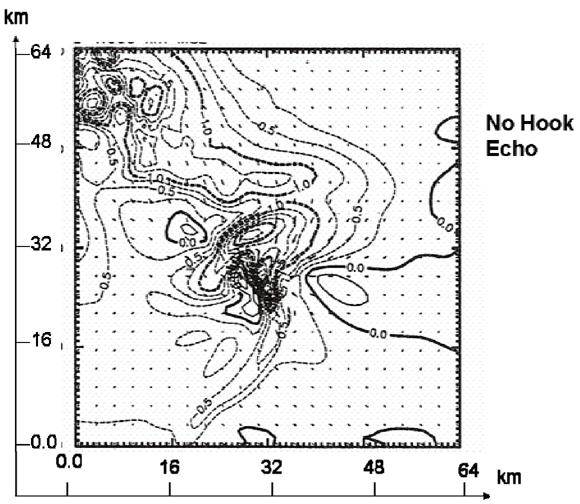

Figure 4B Elimination of Hook Echo by Heating of rain drops in mesocyclone

The ARPS code has been improved to show tornadogenesis [Ref. 10], but there has not been a recent evaluation of the effect of microwave heating. Based on the earlier simulation, the potential interaction with the storm is indicated. The refinement of the analysis should define the critical parameters. These are beam intensity, duration of heating and location in the storm that will disrupt those convective shears creating tornadoes.

One of the short-comings of the ARPS simulation is the definition of initial storm conditions in near real time. There may be techniques to integrate Doppler radar with analysis of Global Positioning System measurements. By measuring the bend and signal delay relative to the unaffected radio waves, scientists are able to get readings on atmospheric temperature, humidity, pressure and electron density[Ref. 11]. The measurements are far more accurate than atmospheric readings taken from weather balloons or other space-based instruments.

6. Thunderstorm Solar Power Satellite

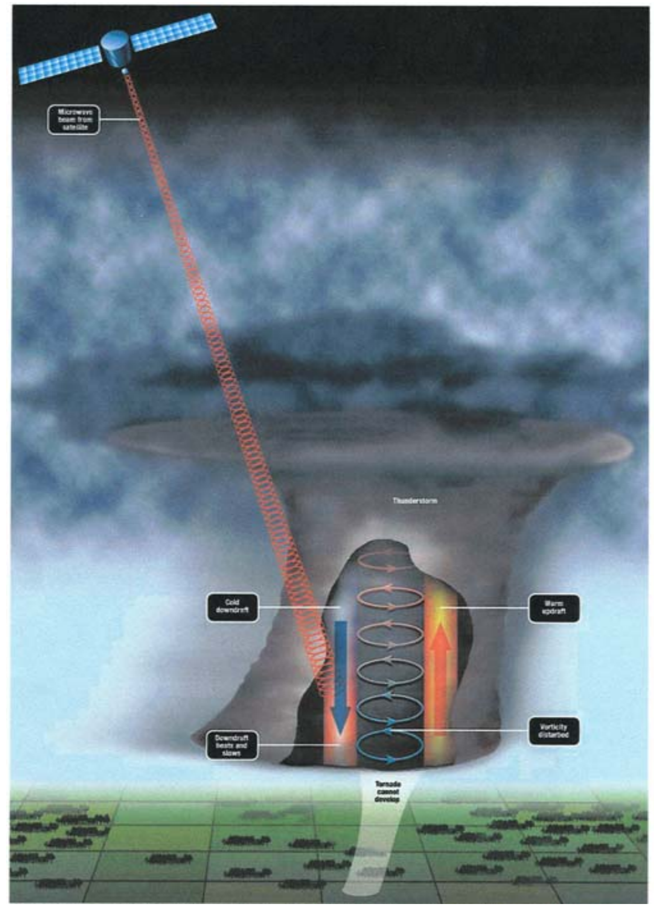

Figure 5-TSPS in action

Figure 5 is an overview graphic from the New Scientist and portrays the elements of interacting with a thunderstorm[Ref. 13]. Eastlund has described the effect of adding heat to the cold rain downdraft in the CAPS(Center for Analysis and Prediction of Storms) computer simulation of a supercell thunderstorm[Ref. 6]. Although it was not an adequate representation of tornadogenesis, the simulation did indicate an interaction with the microwave heating of the cold rain region.

Solar Power Satellites provide the elements to generate and focus energy on a thunderstorm. Space-Based Solar Power systems have been studied by NASA and DOE(Department of Energy) as a clean, renewable power supply for civilization's energy needs[Ref. 12]. The concept consists of orbiting solar collectors that provide electricity to microwave generators. An antenna array of these microwave generators forms a beam to direct the energy to receivers on the surface of the Earth. There the beam is converted back into electricity for use in the commercial power grid. In the TSPS concept this beam is concentrated and directed into the cold rain region of a thunderstorm. Directing this beam of intense energy into the cold rain downdraft of a mesocyclone will heat the raindrops. This is expected to disrupt the tornado formation process if the heating is applied to the right place to destabilize the convective shears.

The TSPS concept is based on adding a little energy to modify the convective shear forces in a thunderstorm[Ref. 9]. By selective heating of the cold rain, it alters the process that concentrates energy in tornadoes. Since most mesocyclones do not produce tornadoes, our objective is to normalize the critical storms.

6. Ground-based Demonstration Concept

Fundamental requirements must be defined by an understanding of the meteorological processes within a thunderstorm. Convective shears act to concentrate the energy in tornadoes. The computer simulations provide the tool for defining TSPS requirements and a basis for system analysis of various implementation options.

Weather modification that is inherent in the TSPS concept represents a significant obstacle to implementing the system. An initial ground-based phase seems essential to provide a basis for flight system decisions. Acquisition of sophisticated data on heating of the storms might be obtained with a land-based system. We envision modified emergency vehicles equipped with gyrotron-based microwave generators. These trucks would converge on the probable path of a mesocyclone and beam power into the cold rainy downdrafts. These heating beams would be directed by targeting the areas defined by Doppler radar and computer analysis. Feedback on the heating effect could be obtained by tracking the heated regions with appropriate radiometers.

It is conceivable that this experimental system could be developed into an operating tornado mitigation system. Each truck would have two to three microwave generators at 10 MW each. Ten trucks near the same storm could give 1000 MW of heating beam. Requirement for this level of capability must be verified by computer simulation.

Weather modification by a ground-based system has certain advantages. Local control and monitoring are immediate and include visual assessment. Microwave beams are directed upward which does not require the degree of safety interlocks of the space-based system. The cost of the system should be considerably lower than the space system. On the other hand, storm chasers have a low probability of encountering tornadoes. It will require a complex operation to determine the storm structure and to position the transmitters. At a minimum, the ground-based system will have a role in validating the effect of selective heating on thunderstorm convection.

The flight TSPS is expected to result in a greater capability to monitor storms and to react if necessary. Investment in the TSPS would be considerably greater than a ground-based system for interacting with storms. Definition of an integrated approach involving computer simulation, technology development and demonstration will provide a basis for action.

7. ISS Space Demonstration Concept

The ultimate goal of the weather research is to enable development of dual use Space-Based Solar Power with its application to weather modification. A key element in the concept is wireless power transmission [Ref. 2]. The International Space Station(ISS) is a potential platform for demonstrating power beaming. An initial test could be a transmitting antenna on the Earth's surface with the receiving rectenna on the ISS. A large phased array about 2280 meters in diameter could transmit 10kw of radiated power at 35 Ghz. The flat rectenna on ISS could be 4m in diameter and expected to collect 5kw power. The microwave frequency was selected to take advantage of a dip in the atmospheric absorption and to minimize the flight hardware. The next level of demonstration of wireless power transfer is to transmit from ISS to the Earth's surface. The ISS installation would include an energy storage module weighing 10,000 Kg. It could be powered from outlets built into the space station for experimentation. The antenna is a 40x60m crossed beam. The system is transmitting up to 100Kw in 1 minute bursts. The 152 m rectenna can receive the bursts converting about 50Kw. This is intensity within the 5 mw/cm^2 safety standard. The 35 Ghz planned for this demonstration is higher frequency than the communications and control bands on the ISS. Antenna and rectenna sizing is based on the following formula:

$$D_{antenna}\, D_{rectenna} = 2.8\,\lambda H$$

Where:

$D_{antenna}$ = Diameter of phased array antenna

$D_{rectenna}$ = Diameter of receiving rectenna

λ = Wavelength of microwaves

H = Distance between antenna and rectenna

The demonstration of wireless power transmission is one of the initial elements of an evolutionary development of SBSP. It also represents a key factor in the feasibility of generation of plasma patterns for weather research. As such, other research activities in the weather modification process may be integrated in to the development plan.

8. Space-based Solar Power

SBSP provides a source of beamed energy and an overview effect sort of capability to access storm systems. The system parameters must be defined through computer simulations and analysis of research results. It is important to link the weather research activities to a logical evolution of space power. This provides significant benefits from the required demonstration tests to validate the space power concept.

The report[Ref.1] on SBSP identified urgent national security strategic goals:

A. Assist in achieving national energy independence from current liquid fuel providers

1. Reduce level of national interest in unstable regions
2. Reduce national dependence on unfriendly foreign governments
3. Reduce the risk of energy competition wars in the 21st Century

B. Assist allies in achieving their national energy independence

1. Develop and strengthen broad international partnerships
2. Participate in international energy consortia and alliances

C. Economic: Become an energy exporter

1. Increase national ability to influence or avoid geopolitical events
2. Increase GNP, wealth of the nation, and increase tax revenue
3. Use energy earnings to pay off national debt

D. Environmental: Dramatically reduce carbon emissions into the atmosphere

1. Prevent food wars which might happen if global warming continues
2. Enhance soft power and green credibility around the world
3. Lead the international clean energy movement by example

These strategic goals strengthen the need for Space-Based Solar Power. The report supports an evolutionary route to the final system. There are a number of demonstration projects that should be integrated into a coherent program plan. It is not clear as to where the primary authority should be in the government, but it is clear that it is too great an effort to expect private business to take the lead in the initial stages.

9. Conclusions

Advanced computer simulations of severe weather systems, such as the ARPS code, require accurate boundary condition information. Data, such as wind profiles as a function of altitude, are an essential input. Hurricane simulations likewise have identified the steering winds as crucial to the development and track of hurricanes. This paper describes a method of creating artificial ionized plasma patches in the atmosphere. These can be rapidly heated and used to provide time dependent diagnostics of temperature patterns, wind velocity, thermal conductivity and electrical conductivity in real time in severe storm systems. Ground based microwave phased arrays, focused on specific locations in the atmosphere, will be used to create the plasma patch and to heat the atmosphere. Initial experiments would correlate heating in a specific region of a weather system with computer simulations of the weather system. Application of such a capability to weather research and eventually to weather modification is anticipated.

The flight TSPS is expected to result in a greater capability to monitor storms and to react if necessary. Investment in the TSPS would be considerably greater than a ground-based system for interacting with storms. Definition of an integrated approach involving computer simulation, technology development and demonstration will provide a basis for action.

These initial research activities will provide a link to the eventual development of Space-Based Solar Power[Ref. 7]. The potential of SBSP is the provision of clean renewable energy to the world. There are many development routes to this capability. The Department of Defense is currently studying the application of Space-Based Solar Power to battlefield power requirements. Other applications include controlled modification of severe storm systems. One such objective is to prevent concentration of storm energy in tornadoes and to diffuse it over a larger area. The anticipated result is minimum impact on overall weather without the death and destruction from tornadoes.

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Biography

Dr. Bernard J. Eastlund *has a B. S. in physics from MIT and a PH. D. in physics from Columbia University. He has started two venture backed corporations based on applications of microwave power. He was the principal inventor of a microwave lamp used for uv curing of coatings. Over 35,000 of his lamps are in industrial use world wide. Also, he applied microwave power to heating of heavy oil and removal of paraffin from oil wells. Through his involvement with fusion program of the Department of Energy he is familiar with all aspects of high power, high frequency microwaves. He has published 48 papers and has 15 patents. Dr. Eastlund died December 12, 2007.*

Lyle Jenkins *is currently a consultant on development of the tornado-taming project. He retired from NASA* *after 38 years of systems engineering activity. Major projects included Apollo and Space Shuttle. Space construction studies on the Solar Power Satellite concept led to concentration on space telerobotics technology. A vision of the potential for space systems to interact with the global environment motivated an interest in geoengineering. Prior to NASA, he was a design engineer on the Atlas ICBM and the Centaur, first liquid hydrogen upper stage. He served as gunnery officer on a destroyer. Education was at University of Kansas and University of California, Berkeley, with a BS and MS in Civil Engineering. . He has published 32 papers and has 1 patent. Recreational activities include tennis, fishing and skiing.*