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System Study of the Carbon Dioxide Observational Platform System (CO-OPS): Project Overview

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System Study of the Carbon Dioxide Observational Platform System (CO-OPS): Project Overview

by

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1. INTRODUCTION

The CO-OPS is a proposed near-space, geo-stationary, unmanned monitoring platform system (Figure 1). It could potentially operate continuously for periods of up to 3 months in a quasi-fixed position over regional targets of interest. CO-OPS can monitor an regional surface area about the size of Texas (observational diameter of between 600 to 800 statute miles) at approximately one-twentieth the cost of most currently utilized comparable remote sensing techniques [1].

While CO-OPS was initially concieved as a solution for the regional observational data requirements of the Department of Energy's (DOE) Carbon Dioxide Research Program, it became apparent early in the investigation that the applicability of CO-OPS was more extensive than just this program. This multi-user near-space platform potentially affords the scientific and engineering

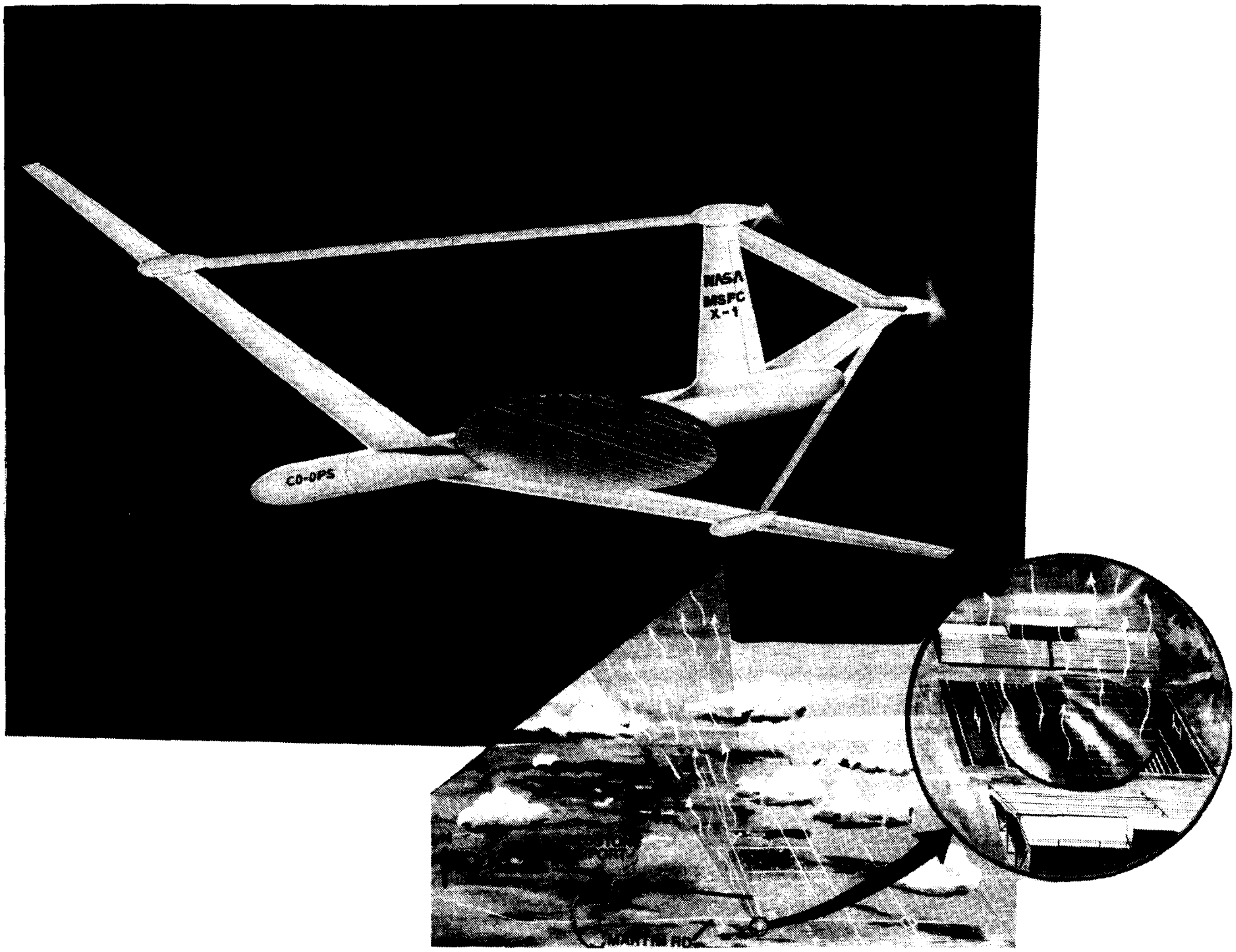

Figure 1. CO-OPS: Joined wing configuration.

community a low-cost means of meeting existing and potential observational data requirements and communications relay requirements (Table 1.).

This overview addresses options resulting from the NASA/MSFC CO-OPS feasibility system study. Alternate monitoring approaches will be considered in terms of costs and feasibility. Multi-user applications of CO-OPS are also briefly considered.

2. BACKGROUND

In 1982, the Department of Energy's (DOE) Carbon Dioxide Research Division, Office of Basic Energy Sciences engaged NASA/George C. Marshall Space Flight Center (MSFC) in a joint program to determine whether space observations could afford a cost effective means of obtaining the data needed to support their National Carbon Dioxide Research Program on the "greenhouse effect." In the 1983-84 time-frame, the system study, "Utilization of Space for Carbon Dioxide Research," was conducted by a NASA/MSFC contractor team led by Arthur D. Little, Inc (ADL) and supported by Boeing Aerospace Company and Ball Aerospace Systems Division [2].

Results from this space system study included: (1) A compilation of 23 Science Data Requirements (SDRs) pertinent to the DOE Carbon Dioxide Research Program by an ad hoc

Table 1. OVERVIEW of APPLICATIONS

EXISTING REQUIREMENTS:

- o Carbon Dioxide Observational Data Requirements
- o Communications Relay
- o Eye-in-the-Sky
  - Defense Department
  - Forestry Service
  - Coast Guard

POTENTIAL APPLICATIONS:

- o Earth System Science
- o Space System Science
- o Test and Verification: Satellite Sensors and Data Management Techniques

scientific advisory committee. A constraint imposed on these SDRs was that they be appropriate to the development of the general circulation models (GCMs) utilitized for long-term (30-50 years) predictions of climatological temperature changes resulting from the carbon dioxide greenhouse effects. (2) Space platforms subsystems (Boeing) and space sensors subsystems (Ball Aerospace) were identified that could best achieve these SDRs, in terms of current technologies (0-5 years), near-term technologies (5-10 years), and future technologies (10-20 years).

During this system study, ADL concluded that: (1) The current, near-term, and future NASA satellite instrumentation plans relative to the climatological area were basically adequate to meet the vast majority of the SDRs if this instrumentation was co-located on the same space platform. The co-location of instrumentation is for designed attenuation in the complexities of the data management system. ADL anticipated that some supplemental instrumentation would be required for the specialized needs of the Carbon Dioxide Research Program. (2) There is a need for improved strategies for the CO-OPS data management system. Further, it was recognized that a carbon dioxide data management system is a key issue to the success of this activity. (3) Near-space observations and sun-synchronous space observations could afford cost-effective and unique means of meeting the SDRs.

Recommendations for the utilitization of space from the ADL system study included:

Current Development (0-5 years):

a. Develop a near-space carbon dioxide observational platform (CO-OP) system.

b. Develop improved infrared and microwave sounders.

c. Develop a carbon dioxide data management system.

Near-term Development (5-10 years):

a. Develop a sun-synchronous carbon dioxide research satellite (COORS).

In 1984, the DOE Carbon Dioxide Research Division activities continued with a follow-on system study for the development of a near-space carbon dioxide observational platform system (CO-OPS). In 1985, NASA/MSFC selected a second contractor team for the CO-OPS system study consisting of the Lockheed-Georgia Company supported by Raytheon, Ball Aerospace Systems Division, and Sundstrand [3]. At the same time, NASA/MSFC conducted in-house investigations of potentially new technological CO-OPS infrared sensing applications and CO-OPS data management systems [4]. NASA/MSFC also monitored the results of the Army's Strategic Defense Command's system study for the use of the joined wing airframe for near-space observational applications [5].

3. METHODOLOGY

The CO-OPS study is a space system study and not a technology development activity. This is the sine qua non that differentiates the approach used in the CO-OPS study from the approach utilized in many of the other high altitude powered platform system (HAPPS) studies.

The objective of this space system study is to satisfy a specific set of data requirements supplied by the user. Rather than trying to develop a specific technology, all technologies are considered in a system study which can meet the user data requirements for each subsystem in the system. The total system is analyzed in terms of state-of-the-art of available technology, development times, costs, etc. Then a matrix of options optimized in terms of the user's requirements is provided for a management decision.

The results reported here are based on semi-empirical computer simulation models developed by David W. Hall at Lockheed, Julian Wolkovitch at ACA Industries, et al [3,5-11]. These models are based on classical aerospace sizing and cost optimization algorithms which have been tuned with empirical data derived from wind tunnel tests and model flight tests. While these computer models provide an excellent method of developing an optimum design model, they will ultimately require wind tunnel and model verification.

4. CO-OPS DATA REQUIREMENTS

Observational data requirements (ODRs) were defined as those parameters deemed desirable to support DOE Carbon Dioxide Research Program activities. These ODRs are the drivers in the CO-OPS configuration definition.

These ODRs are a subset of the Scientific Data Requirements (SDRs) that were defined in the system study of "The Utilization of Space for Carbon Dioxide Research" [2]. The original SRDs were compiled and reviewed by an ad hoc scientific advisory committee composed of representative members of the carbon dioxide scientific community This committee selected these SDRs based on discussions with a representative cross-section of the carbon dioxide scientific community, a selective survey of literature

dealing with measurements, and modeling of carbon dioxide induced climate change. The SDRs were defined in terms of global observations. Based on these SDRs, the DOE Carbon Dioxide Research Division refined these requirements in terms of regional observations and issues of concern to the

DOE Carbon Dioxide Research Program to generate the ODRs (Appendix A).

These ODRs may be summarized as falling within six different categories: (1) atmospheric thermodynamic and kinematic profiles, (2) profiles of the atmospheric species, (3) vertical cloud structure, (4) sea and ocean observations, (5) snow and ice observations, and (6) surface observations. The generic candidate CO-OPS sites are of the following types: (A) mid-latitude land site for prototype observations, (B) mountain site for terrain effect observations, (C) mid-latitude land-sea site for land-sea interface effect observations, (D) inter-tropical zone site for land-sea effects observations and cloud development observations, (E) high-latitude land-sea site for land-sea effects observations and ice observations, (F) West Antarctic site for first detection of changes due to increased concentrations of carbon dioxide, and (G) a mobile site for targets of opportunity observations such as volcano plumes.

5. PAYLOAD AND OPERATIONS GUIDELINES

Based on the observational data requirements (ODRs) of the DOE Carbon Dioxide Research Program, the basic candidate payload and operation requirements can be defined for system design of CO-OPS(Table 2.).

The CO-OP System is being designed to be a near-space platform that the scientific community can use to acquire data to satisfy the ODRs of the DOE Carbon Dioxide Research Program. As such, a matrix of potential instrumentation and missions were identified for design purposes that could satisfy the ODRs.

Ball Aerospace identified a basic integrated instrumentation package of existing space sensor systems COORS in the ADL study system [2]. During the CO-OPS system study, Ball revisited that study and ascertained that the 10 sensor systems in this package (Appendix B) were the appropriate sensor packages to achieve the basic ODRs [3]. This package weighs 270 kg (595 lbs). Therefore, the payload weight guidelines for CO-OPS were defined as being from 227 to 680 kg (500 to 1500 lbs) to provide growth for future mission requirements.

The nominal CO-OPS operational altitude range of 20 to 22 km (65,600 to 72,200 ft) was optimized based on trades between the ODRs, atmospheric constraints, and operational costs. The basic GCM models being utilized in the DOE Carbon Dioxide Research Program have a resolution of 500 km (313 miles) -- hence, the ODRs requirement for mesoscale surface and atmospheric observations. This implies an absolute minimum altitude of about 4.9 km (16,000 ft). To minimize the operational costs, it is desirable to operate CO-OPS at the lowest altitude possible which has the minimum wind speed. In the United States, a region of minimum winds exits in the stratosphere typically somewhere between an altitude of 20 and 22 km [12,13]. At 20 km, the horizon observation circle is about 960 km (600 miles) in diameter.

The ODR for in-cloud sampling implicitly implies an altitude range of from the surface to about 40 km (131,000 ft). However, the sailplane type construction of CO-OPS for near-space operations means that the operations in a turbulent environment should be minimized; that is, a minimum operations altitude of about 6 km (19,700 ft). Effectively, the higher the altitude of operations, the larger the wingspan and the greater the cost. Design constraints limit the maximum altitude to somewhere between 33.5 km (110,000 ft) and 37 km (121,000) -- therefore, the CO-OPS altitude guidelines of 6 km to 35 km operational range, with a nominal operations range of about 20 km.

The temporal sampling period for CO-OPS is defined by atmospheric statistics [12-14]. Typically, the temporal period associated with the movement of a synoptic system is from 4 to 9 days, depending on the season of the year. For a statistically meaningful ensemble, it is desirable to have a minimum of about 10 cycles of data. However, the period of seasonal ergodicity is around 3 months typically in the United States. Thus, a 3-month mission duration was selected as the temporal guideline.

Table 2. PAYLOAD AND OPERATIONS GUIDELINES

PAYLOAD WEIGHT

MINIMUM	NOMINAL	MAXIMUM
227 kg (500 lb)	270 kg (595 lb)	680 kg (1,500 lb)

ALTITUDE RANGE

MINIMUM	NOMINAL	MAXIMUM
6 km (19,700 ft)	20 km (65,600 ft)	37 km (121,000 ft)

OBSERVATIONAL COVERAGE

MINIMUM	NOMINAL (Diameter of Observation)	MAXIMUM
560 km (350 mi)	1,090 km (680 mi)	1,280 km (800 mi)

DURATION

Up to 90 days

In summary, for this CO-OPS investigation, the prescribed study guidelines for the payload weight were from 227 to 680 kg with 270 kg nominal; the prescribed altitude guidelines were from 6 km to 35 km, with 20 km nominal; and with a prescribed nominal mission duration of 3 months. The prototype CO-OPS configuration is designed toward the nominal guidelines.

6. POWER SOURCE OPTIONS

Before considering platform configurations, it is necessary to address the power source options for the platform. This power source could be supplied from either an internal or an external source.

Internal power source options include the internal combustion engine (reciprocating, turbojet, turbofan, and cryogenic), radioisotope, fuel cell, and electric battery. External power source options include solar and microwave [15].

For long-endurance near-space applications, the power options can be narrowed to just radioisotope, solar, and microwave generators [6,14,15]. The radioisotope thermoelectric generator option was eliminated for safety and environmental considerations. While solar power offers a potentially viable solution for daytime operations, the current weight of an energy source for nighttime operations eliminates solar power as a viable near-term solution. Hence, a ground-based microwave power subsystem was selected as the power source of CO-OPS.

In this scenario, the ground-based microwave power subsystem is defined as having a microwave antenna on the ground that transmits microwave energy to CO-OPS. The rectenna (rectifying antenna) on the underside of CO-OPS receives the microwave energy from the ground antenna and converts it to electrical power to operate the motors, the avionics, and the payload.

As management options for future applications, two additional power subsystem scenarios may have potential. The first scenario is a hybrid microwave-solar power subsystem. In this scenario, during the day solar power would be utilized to supplement the primary microwave power subsystem to reduce operating cost and add flexibility to mission operations. The second scenario, for future applications, is to provide the microwave power to CO-OPS from a geosynchronous power satellite. This satellite could be a small solar powered satellite (SPS).

7. PLATFORM CONFIGURATIONS

In this system study, both lighter-than-air and heavier-than-air platforms were initially considered. Then two primary airframe configurations were identified for study emphasis--the cantilever wing-plus-tail and joined wing airframes. These two generic configurations were optimized in terms of a microwave beam.

According to recent studies [3,22,24], a lighter-than-air airship similar in design to the Hi-Spot airships that could operate at an altitude around 20 km for long periods (3 or 4 months) with a 455 kg (1,000 lbs) payload would be in excess of two football fields in length. Such an airship would have a volume of around 42,000 cubic meters (1.5 million cubic feet), a non-buoyant takeoff gross mass of around 12,000 kg (13 tons), and would require at least 155 kW (208 hp) of thrust power. High altitude airships experience extreme degradation in materials due to solar radiation effects; and there is a large diurnal effect due to expansion and contraction of internal gases requiring careful center-of-buoyancy management. As one increases either design airspeed or operational altitude, there is an exponential increase in both the size of the airship and the power requirement. Thus, based on the current literature, it appears that airships have a feasible operational altitude limit in terms of CO-OP system requirements of considerably less than 30 km. (There is a potential requirement for CO-OPS operations up to an altitude of 40 km.) Hence, a more detailed consideration of airships was not made.

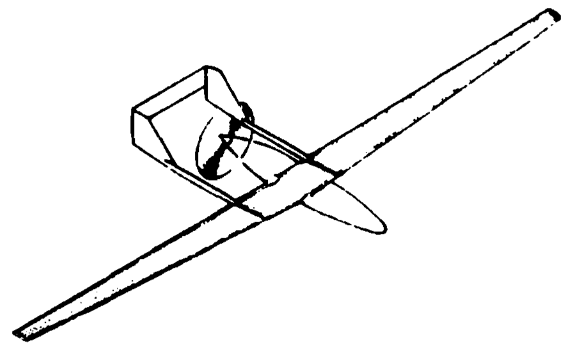

Figure 2. Cantilever wing-plus tail airframe.

In this investigation, several different heavier-than-air configurations were considered for operation at the nominal altitude of 20 km. Initially, a sailplane -- a cantilever-mono-wing airframe -- was considered because it had a high aspect ratio [(wingspan)/(wing chord)] for minimum drag and maximum lift (Figure 2.). Since this type of cantilever airframe had shown great promise in solar powered near-space applications [3,6], this type of airframe with the rectenna mounted on the underside of the wing could be a potential solution for a microwave powered platform. The wingspan of such an airframe is 55 m (179 ft).

A second type of airframe that was considered was the innovative Wolkovitch joined wing

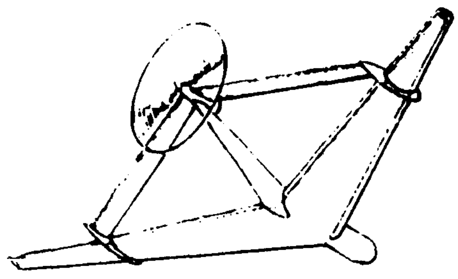

Figure 3. Joined wing airframe.

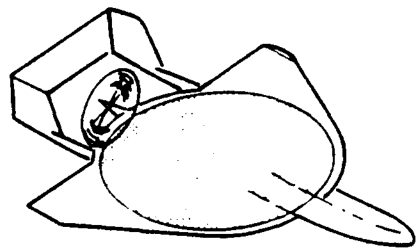

Figure 4. Cantilever airframe with disk rectenna.

with the rectenna on the underside of the wing (Figure 3.) [5,11]. The joined wing airframe, theoretically, weigh only about 65 percent of the weight of cantilever wing-plus-tail systems having the same lift and drag, with similar wing span and total surface areas. This lighter airframe means you have the option of either increasing the payload weight or reducing the operating power. Further, the high aspect ratio joined wing airframe has more usable wing area for a rectenna within a smaller diameter microwave beam; hence, the microwave beam's power density could be less. Wolkovitch has designed a joined wing configuration that folds up for easy ground handling. In addition, the joined wing offers the growth potential of modular options such as longer wings and increased payload bays as the demands warrant.

The use of a disk rectenna to increase the efficiency of the microwave energy transfer to CO-OPS was considered. The third option is a low aspect ratio cantilever wing-plus-tail airframe with a disk rectenna in the airfoil (Figure 3.). The wingspan of this option is 40 m (135 ft). In spite of the increased drag inherent to this configuration, the overall efficiency of this disk cantilever wing-plus-tail airframe is very good. This led to a forth configuration, the joined wing airframe with a disk rectenna (Figure 5.). Unlike the low aspect ratio cantilever wing-plus-tail airframe design, the rectenna disk is not a part of the wing; rather, in the joined wing configuration, the disk is located between the wings. This means that the rectenna disk can be rotated to eliminate power losses due to the polarization of the microwave beam. In addition, the disk can be gimballed so as to maintain the disk normal to the microwave beam. Hence, this airframe can receive the optimum power from the beam even when it is not operating directly over the zenith of the ground antenna.

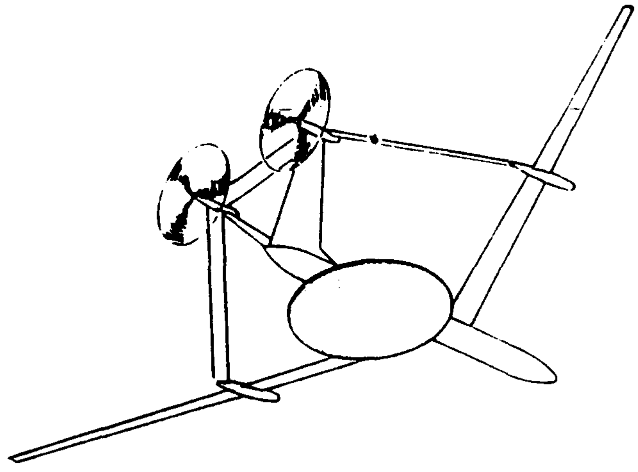

Figure 5. Joined wing with disk rectenna.

As a management option for future applications, Lockheed sized a cantilever wing-plus-tail configuration for an altitude of 37 km (121,000 ft). The wingspan required for such a configuration was 110 m (360 ft); that is, it would have a wing area of almost twice (1.8) the area of the USAF/Lockheed C-5A aircraft. In an independent study for the Army's Strategic Defense Command, Wolkovitch calculated that a joined wing airframe would require a wing span of 57.9 m (190 ft) to operate at an altitude of 33.5 km (110,000 ft).

8. GROUND POWER SUBSYSTEM

The CO-OPS ground power subsystem is designed to provide a microwave power spot with about 10 to 40 m (33 to 131 ft) diameter and with a power density of about 500 to 1,000 W/m^2 at an altitude of about 20 km. This power subsystem was configured to insure that ground personnel will not be exposed to microwave radiation levels over 10 mW/m^2. To achieve these objectives, three basic power transmitters -- klystron, magnetron, and solid state -- operating at either 2.45 GHz or 5.8 GHz were considered during this study. In addition, three basic antenna arrays -- dish, slotted array, and slotted array on pedestals -- covering an area about the size of the area enclosed by a quarter mile track around a football field were considered [2,18,19].

Two basic microwave frequency transmission bands were potential available candidates for the microwave beam of the CO-OPS. The availability of off-the-shelf microwave oven magnetrons which operate at 2.45 GHz made this an attractive candidate. Also, this frequency has the minimal amount of atmospheric attenuation. The 5.8 GHz band is attractive because the ground antenna would be only about a quarter the size of that required at 2.45 GHz. However, at 5.8 GHz there is some atmospheric attenuation in rain -- about 20 percent with a precipitation rate of 50 mm/hr. At 5.8 GHz commercial magnetrons are not available, and more costly klystrons would need to be employed. Hence, the focus of this investigation was directed toward the 2.45 GHz microwave band.

Typically, klystrons, which are liquid cooled, are used with a dish antenna to transmit large amounts of power (20 to 300 kw). To meet the CO-OPS ground power subsystem requirements, a circular ground antenna 96 m (315 ft) in diameter with 100 randomly spaced 11 m (36 ft) dishes with klystrons is one option. The input power required would be about 0.85 MW and the beam power flux density at one meter above the antenna would be about 78 W/m^2. The 11 m dish with klystron is an off-the-shelf system that is readily available without significant further development.

Microwave oven magnetrons, which are air cooled, are used with slotted waveguides and produce about 500 W each. To meet the CO-OPS ground power subsystem requirements, a 55 m (180 ft) by 55 m ground antenna with 3,025 magnetrons, each mounted on a one square meter transmitter panel, is a second option. The input power required would be about 1.66 MW and the beam power flux density at one meter above the antenna would be about 237 W/m^2. The three primary advantages of slotted arrays with magnetrons over the 11 m disks with klystrons are: they cost less than one-half of what the klystron system costs, they are more mobile, and they are air-cooled. The slotted array with magnetrons is an off-the-shelf system that is readily available without further development.

The CO-OPS will need to maintain an air speed of at least 50 m/s (119 MPH); however, at an altitude 20 to 22 km, the 99 percentile wind speed is about 42 m/s (94 MPH) [12]. This implies that the CO-OPS will need to fly in some type of circular pattern. Thus, either a large microwave power spot or a microwave power spot that tracks the CO-OPS along its flight path will be required. An advantage of the 11 m disk with klystron is that it can track the CO-OPS over its flight path for a few degrees (couple of kilometers) above the antenna's zenith.

This leads to a third option, slotted array magnetrons mounted on pedestals and deployed in a 72 m (236 ft) circular pattern similar to the deployment utilized with the 11 m dish with klystrons. The input power required would be about 1.03 MW, but the beam power flux density at one meter above the antenna would be only about 78 W/m^2. The slotted array with magnetrons on pedestals is a off-the-shelf system that is readily available without further development.

A fourth option is slotted arrays with 3.5 m^2 solid state air cooled microwave transmitter panels that produce 5 to 20 watts of power each. To

Table 3. CO-OPS PERFORMANCE AND COST COMPARISONS WITH BALLOONS

Radiosondes:		CO-OPS
Column Thermodynamics & Kinematics	-	Regional Coverage Multi-user Sensors
Costs: $280/sounding	-	Costs: $300/hr
Airships (Hi-Spot):		
Diurnal Changes	-	
Complex Handling	-	Relative Ease of Handling
Costs: $90,000,000 $5,000,000	- Development - Annual operation-	Costs: $21,000,000 $500,000

meet the CO-OPS ground power subsystem requirements, a 85 m (279 ft) by 85 m ground antenna with 1142 panels will be required. The input power required would be about 0.89 MW and the beam power flux density at one meter above the antenna would be about 25 W/m^2. The primary advantages of this solid state slotted array are: they have the longest life, lowest maintenance, and are low voltage. While the solid state slotted array technology is an off-the-shelf technology that is readily available, the production of the solid state components for this application does require further development.

9. DATA MANAGEMENT

The data management system is the heart of CO-OPS since useful information is the product of timely analysis of archived data and the timely interchange of results among scientists. Many typical payloads could reasonably involve raw data rates of 2 to 6 Mb/sec; that is, up to 500 Gb per day [2]. These data must be archived and transmitted in a timely manner to the many users involved in the DOE Carbon Dioxide Research Program throughout the world; otherwise, the data become a wasted resource.

NASA has been criticized for designing high resolution Earth observation satellites and later addressing the data management issues. The result can be an inefficient data management system that does not optimize the user needs [2,20,21]. NASA has taken generic steps to eliminate this data management issue. Since 1980, NASA/Goddard Space Flight Center (GSFC) has had the Pilot Climate Data Base Management System (PCDBMS) under development. This data base management system has concentrated, thus far, on developing a comprehensive catalog of existing climate data bases generated from NASA missions. NASA/MSFC has been developing an interactive data base management system, the Space Plasma Analysis Network (SPAN). SPAN provides the ground and satellite links between the data archives and the scientists. These activities have not solved the data management issue, but they have clearly scoped the magnitude of data management issue.

Currently, the CO-OPS data management issue has not been penetrated significantly. This is an area where there is a clear need for future study at the earliest possible time.

Table 4. CO-OPS PERFORMANCE AND COST COMPARISONS WITH AIRPLANES

ER-2 (U-2)		CO-OPS
Manned	-	Unmanned
Wanders	-	Quasi-Stationary
2-4 hours Observations	-	3 month Observations
Cost: $8,000/hr	-	Costs: $300/hr

10. PERFORMANCE AND COST COMPARISONS

Ultimately, the economy of a data collection systems must be assessed. To achieve this objective, a candidate from each type of existing data collection systems will now be compared with CO-OPS in terms of performance and cost.

Lockheed has estimated that the nominal prototype CO-OPS can be produced with the cost of the first system around $21,000,000. This system will have a 10 year design life. The costs to operate the CO-OPS at NASA/MSFC full-time would be about $500,000 per year. This means the annual cost to operate CO-OPS full-time, including the 10 years amortization of the system, would be about $2,600,000 per year or roughly $300 per hour.

There are basically two types of balloons that are normally used for to obtain environmental data (Table 3.): atmospheric soundings with radiosondes and atmospheric observations with airships. Radiosondes are used normally to measure a vertical profile of the wind direction, wind speed, temperature, and relative humidity. Normally a radiosonde goes from the ground to 20 km (66,000 ft) in roughly an hour (1,000 ft/sec rise rate). NOAA currently is charging $280 per sounding. This compares roughly with the cost of $300 per hour for operating CO-OPS. However, CO-OPS has the potential to observe a region about the size of the state of Texas for these parameters plus other observables.

Hi-Spot is an example of an airship that could operate in the region around 20 to 22 km. It has the potential of achieving the same observational data requirements as CO-OPS. As discussed earlier, its operations are effected by diurnal changes and its large size makes it difficult to handle. A balloon like Hi-Spot costs about $90,000,000 to build and about $5,000,000 per year to operate [22]. This is about 5 times more than CO-OPS.

The NASA/Lockheed ER-2 (U-2) (Table 4.) is probably the closest near-space platform to CO-OPS currently being operated. By definition, an airplane wanders,; whereas, CO-OPS is quasi-stationary. The period of observation of the ER-2 is limited to about 2 to 4 hours. Lockheed estimates that the annual cost to operate a ER-2 under the conditions required to satisfy the ODRs would be $90,000,000 per year. That is, the ER-2 costs more than 30 time more per year to operate than CO-OPS.

The third method of making observations is by use of satellites (Table 5.). The major differences between satellites and CO-OPS are coverage and resolution. That is, satellites provide both regional and global coverage, while CO-OPS can provide only regional coverage. This means that the satellite must normal be operated within international agreements; where as, CO-OPS can be operated within agreements governing just the region of observation. Hence CO-OPS can have extremely high resolution observations. Other difference between satellites and CO-OPS are the development time for a payload and the fact thatsatellite coverage would cost about 20 times more than CO-OPS [1].

Table 5. CO-OPS PERFORMANCE AND COST COMPARISONS WITH SATELLITES

	Satellite	CO-OPS
Coverage:	Global	Regional
Operating Policies:	International Agreements	Local/National
Resolution		
VISSR:	1,000 m (GEO)	0.5 m
LANDSAT:	10 m (LEO)	0.5 m
Payload:	Expendable	Retrievable
Approximate Development Time:	10 years	1 - 2 years
Cost:	$200,000,000 - $750,000,000	$25,000,000

Thus, it can reasonably be concluded that CO-OPS is a cost-effective remote sensing platform for making long term regional observations.

11. ALTERNATIVE CO-OPS APPLICATIONS

While CO-OPS is being configured primarily to support the DOE Carbon Dioxide Research Program, CO-OPS has the potential to support a number of other activities which have requirements for near-space geo-stationary platform. The following are a few generic examples of these activities.

CO-OPS could be utilized as a regional communications relay platform. Operating at an altitude of about 20 to 22 km (66 to 72 kft), CO-OPS could retransmit radio, television, microwave or laser signals between points on the ground up to 1,300 km (812 miles) away. The Canadian Government has studied applications of microwave powered high altitude relays for this mission in the Stationary High Altitude Relay Platform (SHARP) program [23-26]. CO-OPS basically meets the SHARP design criteria.

CO-OPS could be instrumented for long-endurance eye-in-sky ballistic missile defense activities. Operating at an altitude of about 33 km (110,000 ft), CO-OPS would have the capability of seeing incoming ballistic missiles 680 km (425 miles) away. The Army Strategic Defense Command has studied applications of microwave powered, high altitude, long-endurance platform for such missions [5]. CO-OPS basically meets their design criteria.

CO-OPS could be instrumented for coastal monitoring of shipping traffic within U.S. Territorial Waters and within the 371 km (200 nm) fishing limit. Operating on the shoreline at an altitude of 20 km (65,600 ft) the radio horizon would be 556 km (300 nm) away. This mission has been studied by the U.S. Coast Guard [27]. CO-OPS meets their design criteria.

CO-OPS could be employed for forestry observations. The U.S. Forestry Service has an ongoing need to monitor the health of forested lands and for fire detection and control [28]. CO-OPS could meet their design criteria.

12. SYSTEM STUDY STATUS

This investigation has identified four options for airframes and three options for ground power subsystems that could be utilized for a CO-OPS that will afford a near-space, geo-stationary, monitoring platform system. All of the configurations could potentially operate continuously for periods of up to 3 months in quasi-fixed position over most global regional targets of interest and could make horizon observations over a land-sea area of circular diameter up to about 600 to 800 statute miles. It has been shown that this system could afford the scientific and engineering community a low-cost means of operating their multi-user payloads for monitoring the regional parameters they deem relevant to their investigations at a cost of less than one-twentieth the cost of most currently utilized comparable remote sensing techniques. CO-OPS also can be employed for regional augmentation of global satellite coverage or as a communications relay.

While radio-control model tests and wind tunnel tests have been run on the Wolkovitch joined wing, additional model testing and wind tunnel testing is warranted because of its uniqueness. If these tests support the computer analysis, then the joined wing airframe would be the prime candidate for CO-OPS. Currently, based on SHARP model tests with the slotted array with magnetrons [23-26], the prime candidate for the ground power subsystem is the slotted array with magnetrons on a pedestal. However, if the solid state microwave system's production problems could be overcome, then it would be a prime candidate for the ground power subsystem because of high reliability and low operating cost.

Ground data management represents an area of concern. There does not appear to be a problem getting data from CO-OPS to the ground. However, a system of archiving the data like PCDBMS is needed, and systems for distributing the data to the scientific community like SPAN is required. Other areas where additional study is required include ground handling, launch, flight paths, and recovery operations. It would be desirable to examine the option of a hybrid solar cell microwave system and the option of powering the CO-OPS with a small SPS in the future.

Currently, there do not appear to be any technical problems that would prevent a first flight of CO-OPS three years after program start according to Lockheed if the resources are available. The current estimate costs for the first CO-OP system is between $20,000,000 and $30,000,000.

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Appendix A. CO-OPS OBSERVATIONAL DATA REQUIREMENTS

1. Background

The preliminary guidelines for the DOE CO-OPS observational data measurement requirements will be summarized in terms of: (1) the candidate categories of CO-OPS observational data requirements, and (2) a list of candidate geographical CO-OPS operation sites. The basis for these requirements is taken from the NASA/MSFC system study of the utilization of space for carbon dioxide research conducted in support of the DOE Carbon Dioxide Research Program [2]. This study addresses the global observational data objectives and requirements of the DOE Carbon Dioxide Research Program. The global observational data requirements were defined in terms of the *modeling data base* for global circulation models utilized in the DOE Carbon Dioxide Research Program. Based on DOE requirements, the *modeling data base* refined by DOE to reflect the CO-OPS *observational data requirements.* DOE also provided a list of candidate geographical CO-OPS operation sites with the observational data requirements for each site. Table 6, summarizes the space-observable data requirements that the above referenced contract study identified.

2. Candidate Categories of CO-OPS Observational Data Requirements

As stated previously, the objective of the NASA/MSFC CO-OPS system study is the conceptual design of a high altitude observational platform system that can meet the guidelines for the data measurement requirements for the DOE Carbon Dioxide Research Program. To achieve this objective, it is necessary to determine as many of the DOE requirements as possible for: (1) the categories of CO-OPS observational data requirements in terms of the scientific data requirements, and (2) a list of geographical CO-OPS operation sites with the appropriate categories of CO-OPS observational data requirements. These categories are given in Tables 7 through 12.

Table 6. SCIENTIFIC DATA REQUIREMENTS[2]

SDR NO.	SPACE DATA REQUIREMENTS	GRID SIZE (km)	TEMPORAL SAMPLING (DAYS)	ACCURACY
1.	AEROSOL CONCENTRATION.	1000	30	10%
2.	ATMOSPHERIC CONCENTRATIONS, CARBON DIOXIDE.	500	3	1 ppm
3.	ATMOSPHERIC CONCENTRATIONS, TRACE GASES.	1000	30	0.5 ppm
4.	BIOSPHERE, VEGETATION INDEX.	200	30	-
5.	CLOUDS, CIRRUS.	200	1	-
6.	CLOUDS, FRACTIONAL COVERAGE.	200	0.5 HOUR	5%
7.	CLOUDS, VERTICAL STRUCTURE.	200	0.5 HOUR	0.5
8.	LAND ICE.	—	365	1 mei
9.	PRECIPITATION.	200	1	10%
10.	RADIANCE AT THE TOP OF THE ATMOSPHERE	1000	1	0.1–5%
11.	SEA CURRENTS.	200	30	2–5 cm
12.	SEA ICE.	200	5	1%
13.	SEA LEVEL.	200	30	10 cm
14.	SEA SURFACE TEMPERATURE.	200	5	0.2° C
15.	SEA SURFACE WINDS.	100	30	2 m/sec
16.	SNOW COVER.	200	5	5%
17.	SURFACE ALBEDO.	200	30	2%
18.	SURFACE ATMOSPHERIC PRESSURE.	500	30	1.5 mb
19.	SURFACE MOISTURE, SOIL.	500	30	10%
20.	SURFACE TEMPERATURE, SOIL.	500	30	1° C
21.	VERTICAL TEMPERATURE PROFILE.	500	5	1–2° C
22.	VERTICAL WATER VAPOR PROFILE.	200	2	10%
23.	WIND FIELD.	500	0.5	0.3 m/sec

Table 7. CATEGORY A - Atmospheric profiles

SOR NO.	OBSERVATIONAL DATA REQUIREMENTS	MODELING DATA BASE			OBSERVATIONAL DATA BASE		
		GRID SIZE (km)	TEMPORAL SAMPLING (DAYS)	ACCURACY	GRID SIZE (km)	TEMPORAL SAMPLING (DAYS)	ACCURACY
21.	VERTICAL TEMPERATURE PROFILE.	500	5	1–2° C	~ 150	4 HRS	~ 0.2° C
22.	VERTICAL WATER VAPOR PROFILE.	500	5	10%	~ 150	4 HRS	5 – 10%
23.	WIND FIELD	500	0.5	0.3 m/sec	~ 150	4 HRS	0.1 m/sec

Table 8. CATEGORY B - Atmospheric species

OBSERVATIONAL DATA REQUIREMENTS (ODR) ODR NO.	MODELING DATA BASE			OBSERVATIONAL DATA BASE		
	GRID SIZE (km)	TEMPORAL SAMPLING (DAYS)	ACCURACY	GRID SIZE (km)	TEMPORAL SAMPLING (DAYS)	ACCURACY
1. AEROSOL CONCENTRATION.	500	30	10%	~ 150	4 HRS	5%
2. ATMOSPHERIC CONCENTRATIONS. CARBON DIOXIDE.	500	3	1 ppm *	10—100	LOCAL NOON & MIDNIGHT	0.3 ppm
3. ATMOSPHERIC CONCENTRATIONS. TRACE GASES.	500	30	0.5 ppb	10—100	LOCAL NOON & MIDNIGHT	0.3 ppb
ODR ON PLATFORM MEASUREMENTS: A. TEMPERATURE, PRESSURE, & WIND VELOCITY GAS & AEROSOL SAMPLING				LOCAL	HOURLY	STATE-OF -THE-ART
B. PARTICLE CONCENTRATIONS.				LOCAL	HOURLY	STATE-OF -THE-ART

Table 9. CATEGORY C - Clouds

SDR NO.	OBSERVATIONAL DATA REQUIREMENTS	MODELING DATA BASE			OBSERVATIONAL DATA BASE		
		GRID SIZE (km)	TEMPORAL SAMPLING (DAYS)	ACCURACY	GRID SIZE (km)	TEMPORAL SAMPLING (DAYS)	ACCURACY
5.	CLOUDS. CIRRUS. COMMENTS: CLOUD TOP & BUTTOM TEMPERATURES AND ALTITUDES ARE DESIRED.	200	1 HR	—	1.0	20 MIN	0.5° C
6.	CLOUDS. FRACTIONAL COVERAGE.	200	0.5 HOUR	5%	200	20 MIN	5%
7.	CLOUDS. VERTICAL STRUCTURE. COMMENTS: MEASUREMENTS SHOULD INCLUDE: A. ICE CONTENT: B. WATER CONTENT. C. PRECIPITATION D. RATE PRECIPITATION (mm/hour) E. ALTITUDE OF TOP & BOTTOM OF CLOUDS F. TEMPERATURE STRUCTURE OF CLOUDS.	200	1.0 HOUR	5%	0.5	10 MIN	TBD
10.	RADIANCE AT TOP OF THE ATMOSPHERE.	500	1	0.1–5%	TBD	TBD	TBD

Table 10. CATEGORY D - Sea/ocean

SOR NO.	OBSERVATIONAL DATA REQUIREMENTS	MODELING DATA BASE			OBSERVATIONAL DATA BASE		
		GRID SIZE (km)	TEMPORAL SAMPLING (DAYS)	ACCURACY	GRID SIZE (km)	TEMPORAL SAMPLING (DAYS)	ACCURACY
11.	SEA CURRENTS.	200	30	2–5 cm	10	0.5	TBD
12.	SEA ICE.	200	5	1%	10	0.5	TBD
13.	SEA LEVEL.	200	30	1 cm	10	0.5	TBD
14.	SEA SURFACE TEMPERATURE.	200	5	0.2° C	10	0.5	TBD
15.	SEA SURFACE WINDS.	100	30	2 m/sec	10	0.5	TBD

Table 11. CATEGORY E - Snow/ice

SDE NO.	OBSERVATIONAL DATA REQUIREMENTS	MODELING DATA BASE			OBSERVATIONAL DATA BASE		
		GRID SIZE (km)	TEMPORAL SAMPLING (DAYS)	ACCURACY	GRID SIZE (km)	TEMPORAL SAMPLING (DAYS)	ACCURACY
9.	PRECIPITATION. COMMENTS: WHICH CLOUDS. AT WHAT RATE AND TOTAL AMOUNT.	200	1	10%	10	0.25	5%
17.	SURFACE ALBEDO.	200	30	2%	100	1	1%
18.	SURFACE ATMOSPHERIC PRESSURE.	500	30	1.5 mb	500	1	1 mb
19.	SURFACE MOISTURE, SOIL.	500	30	10%	100	7	5%
20.	SURFACE TEMPERATURE, SOIL.	500	30	1° C	100	7	0.5° C

Table 12. CATEGORY F - Surface conditions

SDR NO. / OBSERVATIONAL DATA REQUIREMENTS	MODELING DATA BASE			OBSERVATIONAL DATA BASE		
	GRID SIZE (km)	TEMPORAL SAMPLING (DAYS)	ACCURACY	GRID SIZE (km)	TEMPORAL SAMPLING (DAYS)	ACCURACY
8. LAND ICE.	—	365	1 m elev	100	7	TBD
16. SNOW COVER.	200	5	5%	100	1	TBD

3. Candidate Geographical CO-OPS Operation Sites

The preliminary guidelines for the DOE CO-OPS observational data measurement sites will be summarized. It must be emphasized that CO-OPS should be designed to be a quasi mobile system that can be moved to new sites as the DOE Carbon Dioxide Research Program requires.

Table 13. CO-OPS OPERATIONAL SITE No. 1: NASA/MSFC

The initial CO-OPS operational site will be at NASA/MSFC.

OBSERVATIONAL REQUIREMENTS		
Observational Categories	Altitude (km)	Observation Time
A, B, C, & F	20	TO BE DETERMINED
Comments: NONE		

Table 14. CO-OPS OPERATIONAL SITE No. 2: VAFB/EAFB

The next site of operation probably will be Vandenberg/Edwards Air Force Base.

OBSERVATIONAL REQUIREMENTS		
Observational Categories	Altitude (km)	Observation Time
A, B, C, D, & F	20	TO BE DETERMINED
Comments: NONE		

Table 15. CO-OPS OPERATIONAL SITE No. 3: East Coast

East coast site in the New Jersey area.

OBSERVATIONAL REQUIREMENTS		
Observational Categories	Altitude (km)	Observation Time
A, B, C, D, & F	20	TO BE DETERMINED
Comments: NONE		

Table 16. CO-OPS OPERATIONAL SITE No. 4: Other Sites

Other potential site for long-term CO-OPS include, but not limited to, the West Antarctic, the Inter-tropical Zone (e.g.
Panama) and an east coast site at about 60^{o} North latitude.

OBSERVATIONAL REQUIREMENTS		
Observational Categories	Altitude (km)	Observation Time
A, B, C, D, E, & F	20	TO BE DETERMINED
Comments: NONE		

Table 17. CO-OPS OPERATIONAL SITE No. 5: Target of Opportunities

Other operation sites will include targets of opportunities such a areas associated with volcanic activity.

OBSERVATIONAL REQUIREMENTS		
Observational Categories	Altitude (km)	Observation Time
A, B, C, & F	6 to 40	Hourly
Comments: a. Emphasis should be placed on ODR A in Category B.		

Appendix B. SUMMARY OF PAYLOAD SUBSYSTEM

The mass, power requirements and performance characteristics of an atmospheric observation payload were determined early in the CO-OP System pre-Phase A study. Key interface parameters of the potential payload complement for the prototype verification test site are summarized in Table XIII below. A total of ten instruments will be required to meet ODR sensing requirements over the site. This package will probably weigh 270 kG (595 lbf) and might require a total of 185 watts of power during their duty cycles.

Table 18. POTENTIAL PAYLOAD COMPLEMENT FOR THE PROTOTYPE VERIFICATION TEST SITE.

(Off-the-Shelve Sensor for ODRs)

REMOTE SENSING from CO-OPS:

HIRS-2:	High Resolution Infrared Radiation Sounder	- Temperature and Water Vapor Profile
AVHRR-2:	Advanced Very High Resolution Radiometer	- Cloud Distribution, Veg Index, Water Temp, etc
SAGE-2:	Stratospheric Aerosol and Gas Experiment	- Aerosol and Gas Measurements
SMMR:	Scanning Multichannel Radiometer	- Soil Moisture, Ice & Snow Cover, Wind Fields, etc
SBUV:	Solar Backscatter Ultraviolet	- Ozone Profile
TOMS:	Total Ozone Mapping Spectrometer	- Solar UV Irradiance
ERBE:	Earth Radiation Budget Experiment	- Solar and Terrestrial Radiation Budget
ASAS:	Advanced Solid-state Array Spectroradiometer	- Imaging Spectroradiometer
THIR:	Temperature, Humidity Infrared Radiometer	- Imaging Temperature and Humidity
ALT:	Altimeter	- Sea Level, Land Ice

	INSTRUMENT	MASS	POWER
	HIRS-2	32.3KG	22.8W
	AVHRR-2	28.7KG	26.2W
	SAGE-2	29.5KG	14.0W
	SMMR	52.5KG	60.0W
	SBUV	35.0KG	
	TOMS	31.0KG	12.0W
	ASAS		
	ERBE		
	SCANNER	29.0KG	
	NON-SCANNER	32.0KG	50.0W
TOTAL		270.0KG	185.0W

IN-SITU on CO-OPS:

Temperature Sensor
Pressure Sensor
Wind Velocity Sensor
Gas Sampler
Aerosol Sampler
Particle Sampler

The initial payload complement may be some subset of these instruments along with some ground based senso could evolve by adding and deleting instruments as observational requirements and budgets dictate. The advanced soli example of an existing sensor. Such instrumentation, if it can be acquired, could provide a low cost initial payload.

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16. ABSTRACT

The resulting options from a system study for a near-space, geo-stationary, observational monitoring platform system for use in the Department of Energy's (DOE) National Carbon Dioxide Reserach Program on the "greenhouse effect" are discussed.

CO-OPS is being designed to operate continuously for periods of up to 3 months in quasi-fixed position over most global regional targets of interest and could make horizon observations over a land-sea area of circular diameter up to about 600 to 800 statute miles. This affords the scientific and engineering community a low-cost means of operating their payloads for monitoring the regional parameters they deem relevant to their investigations of the carbon dioxide "greenhouse effect" at one-tenth the cost of most currently utilized comparable remote sensing techniques.

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