Space-based Concepts to Support the Tactical Weather Users

K. Yvonne Sheets
Roger Bennett
SPARTA, Inc.
23041 de la Carlota, Suite 400
Laguna Hills, CA 92653
(714) 768-8161

Abstract

Recent military theater operations such as Desert Storm have underscored the need for additional support for theater users. The needs of specific user communities are varied, and it is appropriate to examine those needs and develop system concepts which can enable the tactical community to more effectively perform their mission. This paper examines the needs and requirements of the tactical weather community and how additional space-based assets could be used to increase the tactical mission effectiveness. The approach investigated is to augment the current military meteorological satellite program, DMSP, which operates in low earth orbit with a geosynchronous platform capable of data collection and dissemination within the theater. This approach has several advantages, including the ability to provide focused, long-term coverage over the theater, with real-time downlink directly to the tactical user. One of the goals of the study was to determine what combinations of sensors and communications services might be provided from a smaller satellite on the order of 1000 lbs.

This study was performed to evaluate alternatives to providing the tactical military user with space-based environmental monitoring information as an augmentation to the Defense Meteorological Satellite System (DMSS). The effort was driven by the most recent requirements, the MAC SON 211-89 Tactical Weather Observing System (TWOS) and MAC SON 216-89 Tactical Forecast System (TFS). Emphasis on the study was the focus on geosynchronous augmentations to the current set of DMSS satellites, which included climatical scenarios and requirements analysis, as well as sensor technologies assessments.

Introduction

As seen in Desert Storm, the nature of the battlefield is rapidly changing; both in terms of agility and technology. To support future battle operations, intelligent preparation of the battlefield (IPB) is required and weather data provides crucial information to this planning process. Also the sophisticated weapon and acquisition systems being deployed are sensitive to various meteorological phenomena. Weather data provides critical data to effectively operate and plan the use of these systems. This weather payload can be specifically tailored to provide additional continuous real-time data to complement that provided by LEO satellites and could also include payloads, such as a lightning detection system, which could provide data not currently available. This resource would be under military control and not subject to some of the geo-political problems that arise with the usage of civilian meteorological resources. The links could also be encrypted to prevent their exploitation by adversaries in the theater. There are also a number of additional weather-related communications relay and dissemination services which could take advantage of a geosynchronous platform deployed over the theater. Several potential weather payloads and a number of communications services are examined in this paper. The communications services evaluated include 1) the TT&C of the satellite and its payloads, 2) collection of data from remote ground-based sensors, 3) dissemination and relay of weather data and voice channels (for weather-related activities), 4) relay of UAV (unmanned air vehicle) weather payload data, 5) relay of real-time DMSP data, and 6) crosslinking all or part of the data from one weather relay satellite to another to provide worldwide coverage and connectivity to CONUS. The evaluation of these concepts included link performance requirements, satellite sizing, and operational concepts for the individual services. These services were then combined in various ways to evaluate the size and weight impacts on the spacecraft. One of the goals of the study was to determine what combinations of sensors and communications services might be provided from a smaller satellite on the order of 1000 lbs.

Background

This study was conducted by SPARTA, Inc. and our subcontractor, Pacific-Sierra Research, under the direction of Air Force Space Systems Division (AFSSD)/DCS Plans and Advanced Programs. The study was conducted in concert with the Tactical Weather Alternatives Study Group, which provided review and guidance throughout the study.

The Tactical Weather Observing System (TWOS) is a validated Air Force Statement of Need that is complementary to the TFS SON. While the TFS SON deals with the receipt, processing, and dissemination of meteorological data, the TWOS SON deals with the need for developing additional observation capability.

There are two driving needs for tactical support identified in the TWOS Statement of Need. One need outlines the deficiencies in current observation capabilities that relate to requirements for more data, observed more frequently, with broader, more rapid distribution. The second need relates to the changing nature of the battlefield and weapons which require additional observations tn be effectively employed in combat situations, particularly to support the expanding developments of sophisticated, precision-guided munitions systems and target acquisition systems whose operations can be significantly impacted. by various weather phenomena.

The AWS concept of operations outlines the operations for the Air Weather Service to support the evolving tactical theater. One aspect of this support is the AIRLAND battle. This doctrine is currently under revision as a result of Operation Desert Storm, but the main influences will be to increase emphasis upon the rapidity of movement and agility of the battlefield and supplying resources that can adequately and rapidly support these types of operations. To support the AIRLAND battle operations, intelligent preparation of the battlefield (IPB) is needed. Weather data provides crucial information to this planning process.

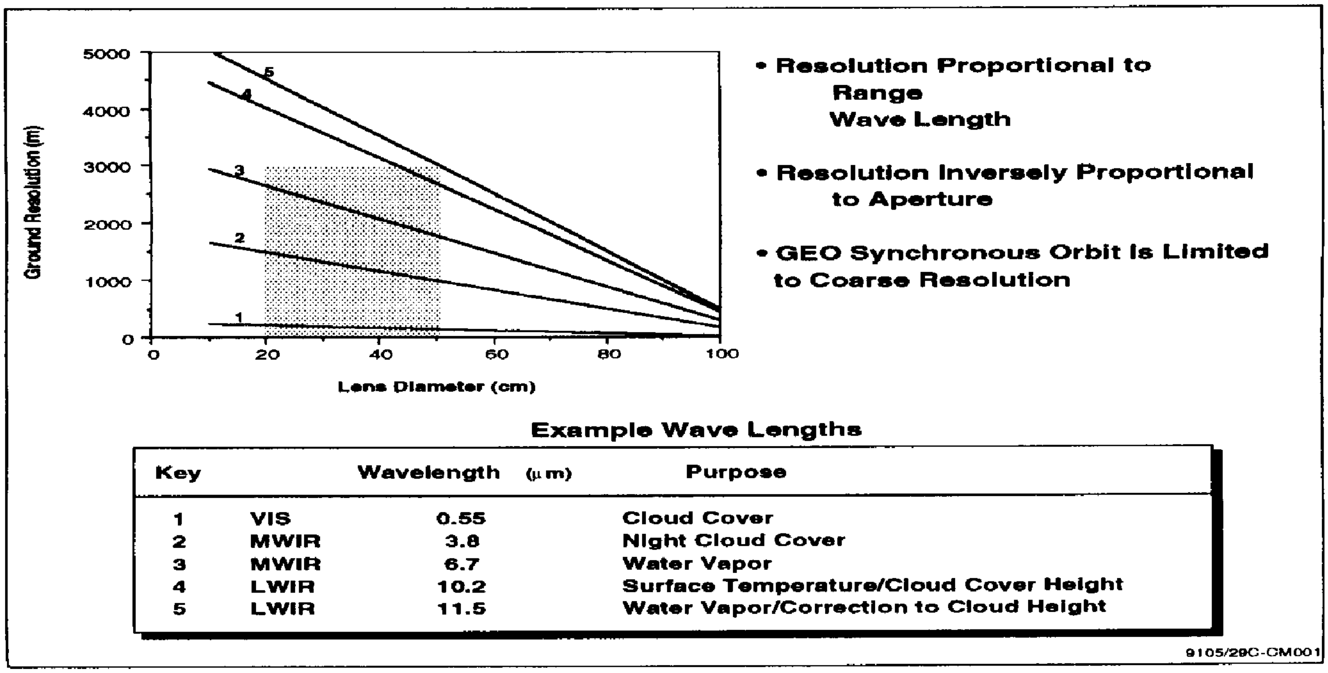
The increased agility in the battlefield is supported by employment of air power such as helicopters. These systems are vulnerable to weather effects and require adequate information both for planning and information in-flight. An example of the nature of this information is the sudden dust storm encountered during the Iran hostage rescue and the dramatic effect upon the success of the mission.

Sophisticated weapons systems and target acquisition systems employ sensing technology which can degrade under certain weather phenomena. It is import to have the information available to the weapon system planners to evaluate the effectiveness of their systems and, in some cases, improve operation by using weather information to refine their modeling process. Weather also has known effect upon communications system and can significantly degrade performance.

Orbital Considerations

Operation at a particular orbital altitude carries with it certain advantages and disadvantages that need to be weighed in light of the goals of a particular mission. Operation at geosynchronous altitude provides several advantages for tactical support because the resource can be positioned over a theater and provide continuous, real-time coverage of a particular area for the period of the crisis. While location at geosynchronous orbit provides utility to the tactical users, there are certain system limitations that limit what can be achieved for that orbit; these include limitations in sensor performance and impacts upon the choice of a launch vehicle.

As mentioned, there are limitations to the resolution available at GEO orbit. This limitation deals with the range from GEO and the relative aperture size needed on the platform. The aperture size is limited by the ability to produce large apertures and place them in orbit. As can be seen in **Figure 1**, the shaded area shows a range of apertures that are produced with today's technologies. As can be seen, this does limit the resolution available. However, this does not imply that useful data cannot be obtained; it is just not possible to match the resolution that can be afforded by low-altitude platforms such as DMSP.Sensor resolution performance at geosynchronous orbit depends on the wavelength desired, the telescope aperture, and the range-to-geo orbit. The shaded area shows a range of technologically feasible apertures. As can be seen, the resolution that can be achieved is limited to the thousands of meters. However, it should be noted that this range of resolution is satisfactory for many tactical missions.



- **Resolution Proportional to**
  - **Range**
  - **Wave Length**
- **Resolution Inversely Proportional to Aperture**
- **GEO Synchronous Orbit Is Limited to Coarse Resolution**

Example Wave Lengths

Key		Wavelength (μm)	Purpose
1	VIS	0.55	Cloud Cover
2	MWIR	3.8	Night Cloud Cover
3	MWIR	6.7	Water Vapor
4	LWIR	10.2	Surface Temperature/Cloud Cover Height
5	LWIR	11.5	Water Vapor/Correction to Cloud Height

Figure 1. Diffraction-Limited Ground Resolution

Analysis of the geosynchronous orbit was performed in order to determine the availability and performance of a METSAT located in that orbit. A primary issue is the determination of available orbital locations that are not allocated to existing or planned systems. If a satellite transmits/receives in the same frequency band, in the same polarization, as another satellite at the same orbital location, then the two satellites will interfere with each other. Therefore, the ITU regulates and coordinates the application for all geosynchronous satellites. Interference between satellites is also a function of the antenna coverage areas of the satellites in question.

Satellites in the geosynchronons orbit that provide meteorological data and data dissemination are shown in **Figure 2**. These satellites utilize the UHF, L-band, and S-band frequency bands. It can be seen that there are few satellites in the geosynchronous orbit, which, therefore, implies that there would be little problem locating a new system at this band.

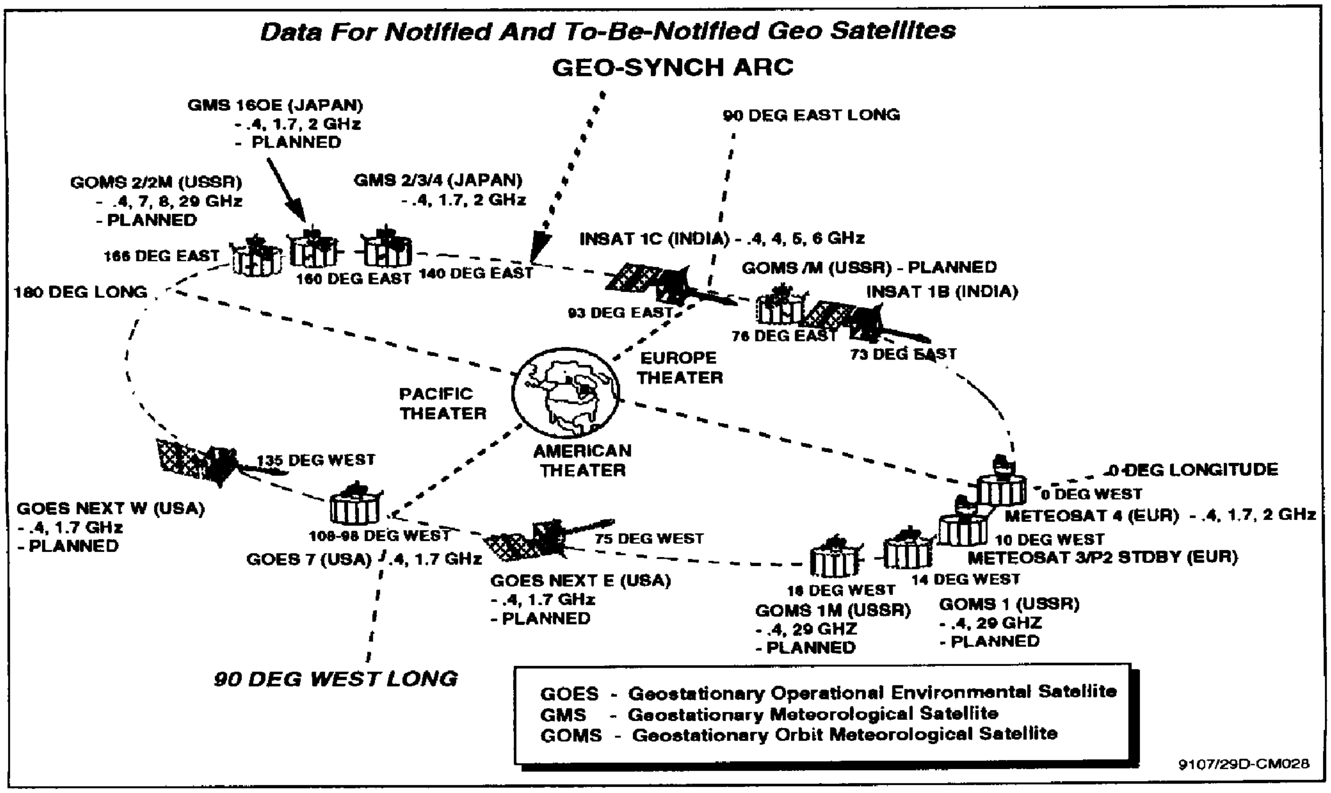


Figure 2. Meteorological Satellites In Geostationary Orbit

The coverage of a geosynchronous satellite has been analyzed in order to determine the impact on the operational capabilities of the system. A satellite in the geosynchronous orbit can provide both worldwide and theater coverage.

Worldwide coverage is obtained through the use of crosslinks or earth-coverage antenna, while theater coverage utilizes area antenna beams of 4- to 5-degrees beamwidth. The antenna size on the satellite is inversely proportional to the coverage on the ground. Multiple-beam antennas, however, can provide both high gain and wide coverage but do not provide this coverage to all area simultaneously. Multiple-beam antennas are also heavier and more complex than wide-area, single-beam antennas, which may impact satellite weight.

The coverage of a single, geosynchronous satellite located at 40 degrees east longitude is shown in **Figure 3**, with theater-coverage antenna beams superimposed over the earth-coverage beam. Three minimum-elevation angle 3-dB contours are shown. The spot beams correspond to an antenna beamwidth of 4.5 degrees. From the satellite location at 40 degrees east, both the European and Middle Eastern theaters may be covered.

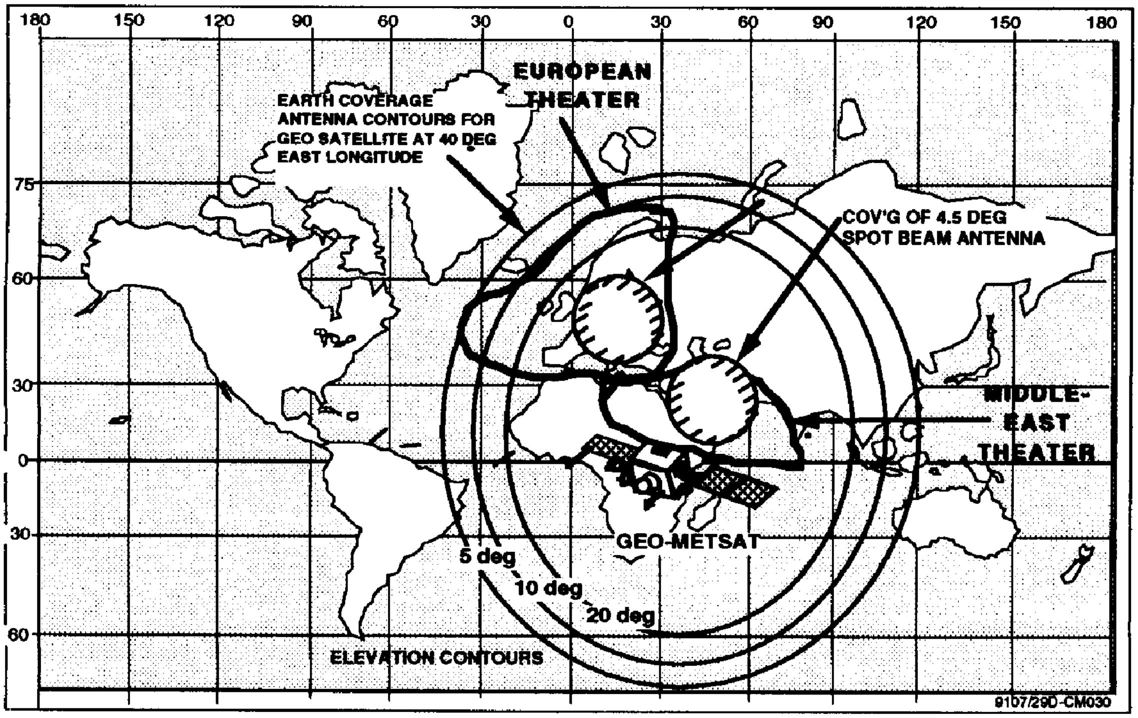


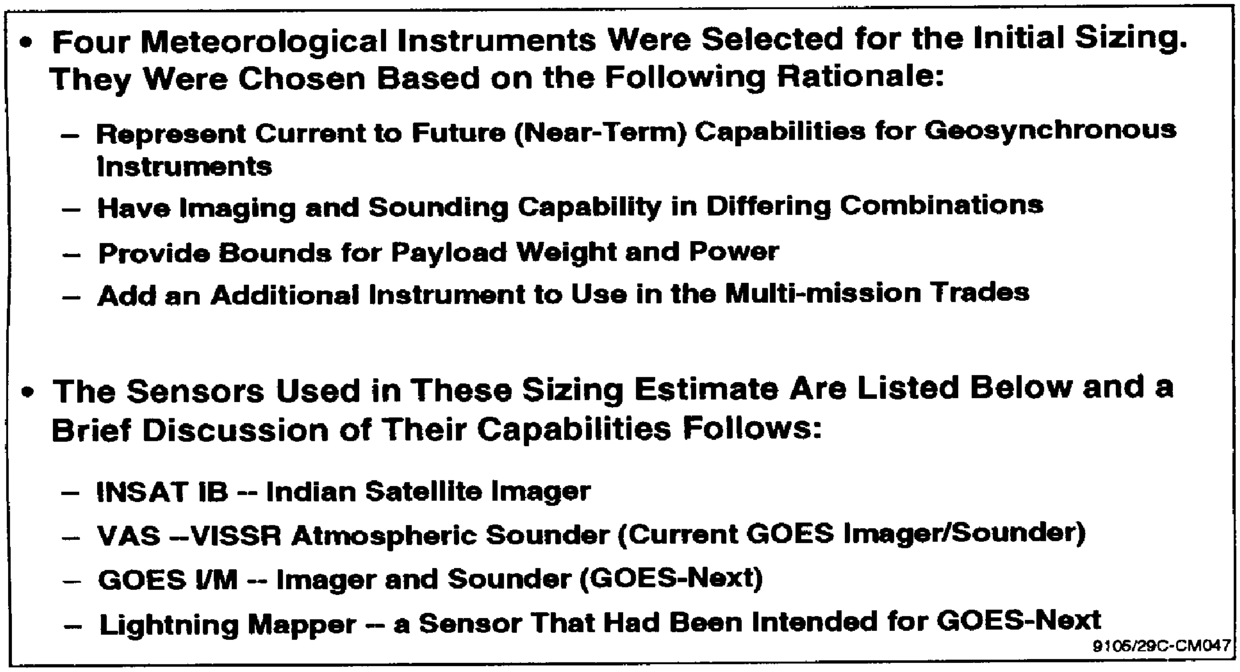
Figure 3. GEO-METSAT Located At 40 Deg East Longitude

The geosynchronous orbit has been selected because of its great coverage, and because it simplifies the tracking requirements of a ground-based antenna since the satellite appears stationary. From a satellite in low earth polar orbit, a satellite in the geosynchronous orbit (which is over the equator) will be in view from 50% to 100% of its orbit, depending on the relative angle between the two satellites. If the geosynchronous satellite is positioned at a longitude 90 degrees from the longitude of the polar orbiting LEO satellite descending node, then the LEO satellite will be in view 100% of its orbit. If the GEO satellite is at the same longitude as the LEO satellite descending node, then the LEO satellite will be in view of the geosynchronous satellite for approximately half of its orbit (for a typical LEO satellite, the period is 90 minutes). The geosynchronous satellite could see a Polar Low Earth Orbiting satellite either l00% of the time or approximately 50% of the time depending on the longitude of the Geo satellite.

Meteorlogical Payloads

Based on the choice if imaging and sounding technologies, four instruments were used for the sizing exercise. The rationale for this choice is shown in **Table 1** below. Again, the goal was to provide a representative spectrum of payloads in capability, size, weight, and power.

Table 1. Meteorological Instruments For Preliminary Sizing Estimates



- Four Meteorological Instruments Were Selected for the Initial Sizing. They Were Chosen Based on the Following Rationale:
  - Represent Current to Future (Near-Term) Capabilities for Geosynchronous Instruments
  - Have Imaging and Sounding Capability in Differing Combinations
  - Provide Bounds for Payload Weight and Power
  - Add an Additional Instrument to Use in the Multi-mission Trades

- The Sensors Used in These Sizing Estimate Are Listed Below and a Brief Discussion of Their Capabilities Follows:
  - INSAT IB -- Indian Satellite Imager
  - VAS --VISSR Atmospheric Sounder (Current GOES Imager/Sounder)
  - GOES I/M -- Imager and Sounder (GOES-Next)
  - Lightning Mapper -- a Sensor That Had Been Intended for GOES-Next

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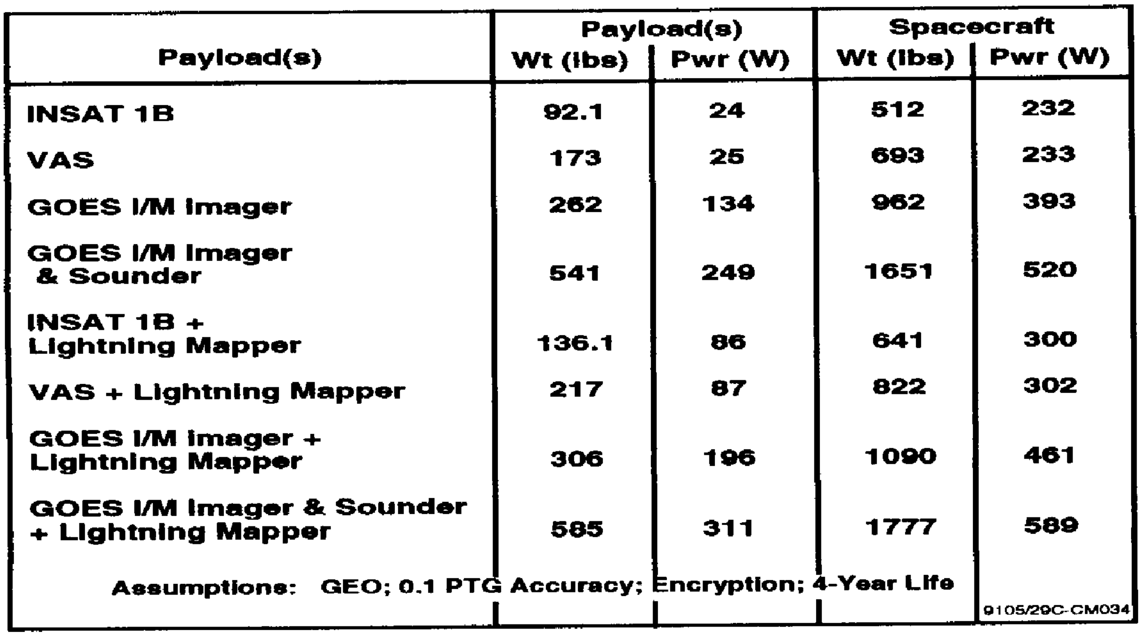
Table 2 shows the payloads that were identified as potential sensors for the meteorological mission of geosynchronous orbit. The weight and power of each payload were estimated and provided to a SPARTA CAD tool that calculates satellite weight based on input data including payload characteristics, orbit, life, etc. The spacecraft weights may be considered to be in the TACSAT "class".

Communications System

Figure 4 shows an overview of the potential data links that provide for a variety of new weather data dissemination and relay capabilities. The weather satellite (METSAT) is in the Geosynchronous orbit, with crosslinks linking the satellites, a shown. The METS AT that is in view of the theater receives tactical weather data from the ground sensors and UAV's that are in line-of-sight. DMSP data may be downlinked to the theater directly or via the METSAT and/or crosslinked to another METSAT and downlinked to CONUS in real time. The DMSP satellite must be modified to permit these communications links with the METSAT. The RF frequencies utilized for these links are shown in the table. Controllers located in

CONUS can command the METSAT payload, as well as the DMSP and UAV payloads,via the METSAT in real time. Communications between CONUS control and theater terminals are also possible.

Table 2. Satellite Sizing Summary Meteorological Sensors



Payload(s)	Payload(s) Wt (lbs)	Payload(s) Pwr (W)	Spacecraft Wt (lbs)	Spacecraft Pwr (W)
INSAT 1B	92.1	24	512	232
VAS	173	25	693	233
GOES I/M Imager	262	134	962	393
GOES I/M Imager & Sounder	541	249	1651	520
INSAT 1B + Lightning Mapper	136.1	86	641	300
VAS + Lightning Mapper	217	87	822	302
GOES I/M Imager + Lightning Mapper	306	196	1090	461
GOES I/M Imager & Sounder + Lightning Mapper	585	311	1777	589

Assumptions: GEO; 0.1 PTG Accuracy; Encryption; 4-Year Life

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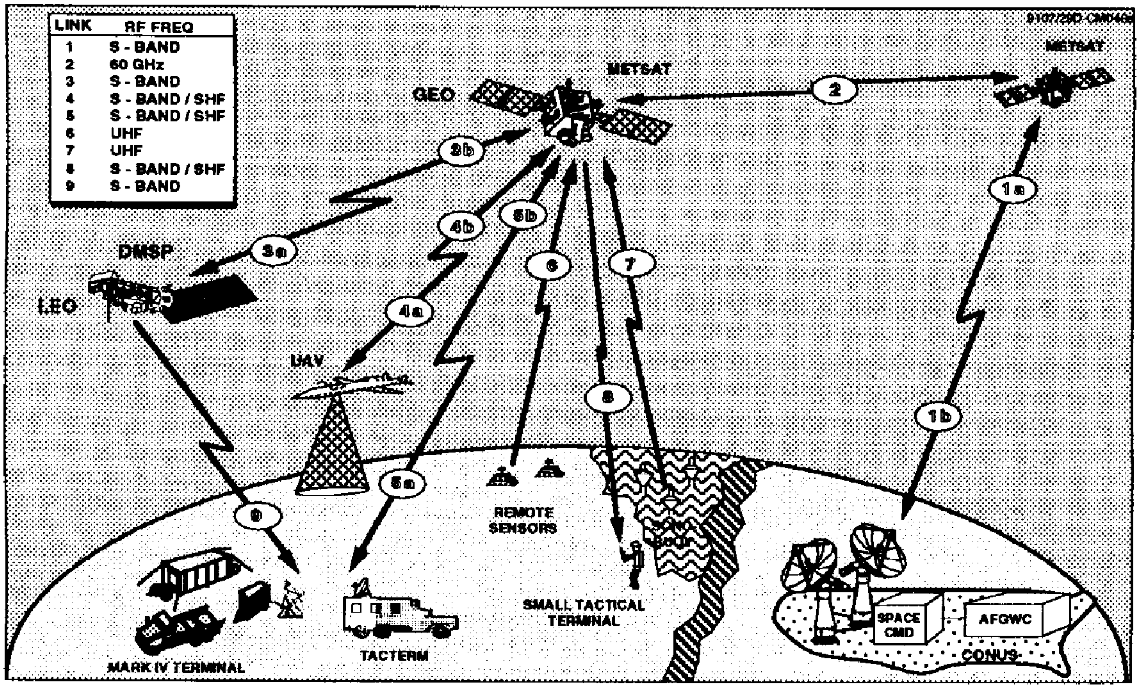


Figure 4. Tactical Geo-Metsat System Communications & Data Links

As an example of the communications analysis performed for this effort Figure 5 shows the link sizing analysis for the DMSP satellite flying in a LEO orbit to the Geosynchronous METSAT. The achievable data rate is determined as a function of the METSAT receive antenna diameter and the required DMSP transmitter output power. For a 250 Kbps data rate, a 20 Watt DMSP transmitter will close the link to a 3 foot METSAT antenna.

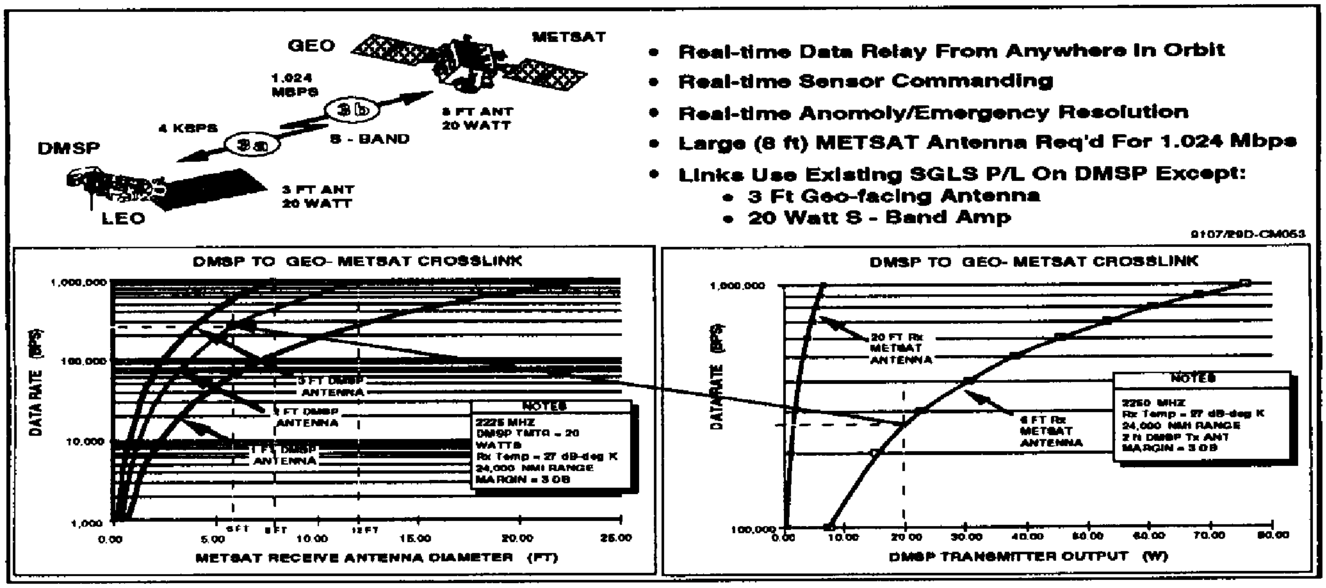
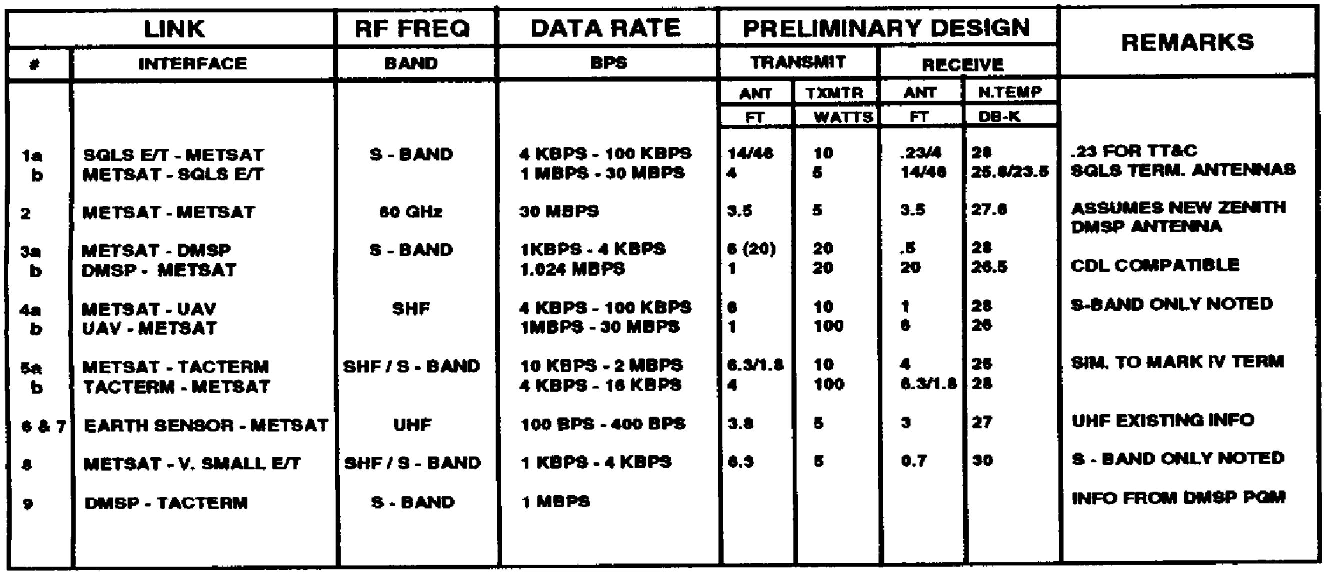


Figure 5. Geo-Metsat Communications Analysis, Link 3: Metsat - DMSP Crosslink

Table 3 lists the characteristics of the various data links, including the RF frequencies used, the data rates for each link, and the transmit and receive system characteristics. In some instances, a range of data rate capabilities have been identified. The major parameters for the transmit function are the antenna size and transmitter output power. The primary receive system parameters are the antenna size and receive system noise temperature. If the transmit and receive systems utilize the same antenna, then a trade between antenna size and transmit/receive performance must be made.

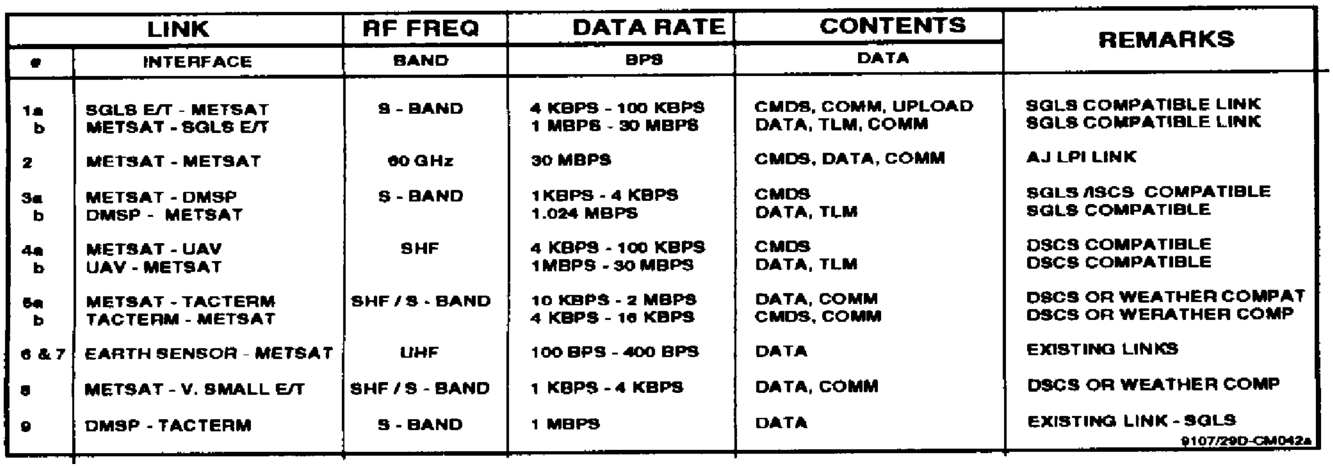
The contents of each of the links identified for the METSAT system are listed in **Table 4**. The CONUS station sends commands, as well as uploads data bases, to the METSAT and receives data telemetry from the METSAT. Also, the CONUS station can communicate to the theater via the METSAT. The METSAT crosslinks contain commands, data, and communications. A modified DMSP satellite, as well as a UAV, receives commands and sends both data and telemetry to the METSAT for relay to the ground users. A METSAT receives data and communications from theater tactical terminals and relays commands and communications to theater tactical terminals The METSAT also receives data from remote earth sensors and sonobuoys for relay to ground users. The DMSP-to-TACTERM link is the unchanged, existing S-band link.

TABLE 3. Geo-Metsat Communications Link Design Parameters



LINK		RF FREQ	DATA RATE	PRELIMINARY DESIGN				REMARKS
#	INTERFACE	BAND	BPS	TRANSMIT		RECEIVE		
				ANT	TXMTR	ANT	N.TEMP	
				FT	WATTS	FT	DB-K	
1a	SGLS E/T - METSAT	S - BAND	4 KBPS - 100 KBPS	14/46	10	.23/4	28	.23 FOR TT&C
b	METSAT - SGLS E/T		1 MBPS - 30 MBPS	4	5	14/46	25.6/23.5	SGLS TERM. ANTENNAS
2	METSAT - METSAT	60 GHz	30 MBPS	3.5	5	3.5	27.6	ASSUMES NEW ZENITH DMSP ANTENNA
3a	METSAT - DMSP	S - BAND	1KBPS - 4 KBPS	6 (20)	20	.5	28	
b	DMSP - METSAT		1.024 MBPS	1	20	20	26.5	CDL COMPATIBLE
4a	METSAT - UAV	SHF	4 KBPS - 100 KBPS	6	10	1	28	S-BAND ONLY NOTED
b	UAV - METSAT		1MBPS - 30 MBPS	1	100	6	26	
5a	METSAT - TACTERM	SHF / S - BAND	10 KBPS - 2 MBPS	6.3/1.8	10	4	26	SIM. TO MARK IV TERM
b	TACTERM - METSAT		4 KBPS - 16 KBPS	4	100	6.3/1.8	28	
6 & 7	EARTH SENSOR - METSAT	UHF	100 BPS - 400 BPS	3.8	5	3	27	UHF EXISTING INFO
8	METSAT - V. SMALL E/T	SHF / S - BAND	1 KBPS - 4 KBPS	6.3	5	0.7	30	S - BAND ONLY NOTED
9	DMSP - TACTERM	S - BAND	1 MBPS					INFO FROM DMSP PGM

Table 4. Geo-Metsat Communications Link Contents



LINK		RF FREQ	DATA RATE	CONTENTS	REMARKS
#	INTERFACE	BAND	BPS	DATA	
1a	SGLS E/T - METSAT	S - BAND	4 KBPS - 100 KBPS	CMDS, COMM, UPLOAD	SGLS COMPATIBLE LINK
b	METSAT - SGLS E/T		1 MBPS - 30 MBPS	DATA, TLM, COMM	SGLS COMPATIBLE LINK
2	METSAT - METSAT	60 GHz	30 MBPS	CMDS, DATA, COMM	AJ LPI LINK
3a	METSAT - DMSP	S - BAND	1KBPS - 4 KBPS	CMDS	SGLS /ASCS COMPATIBLE
b	DMSP - METSAT		1.024 MBPS	DATA, TLM	SGLS COMPATIBLE
4a	METSAT - UAV	SHF	4 KBPS - 100 KBPS	CMDS	DSCS COMPATIBLE
b	UAV - METSAT		1MBPS - 30 MBPS	DATA, TLM	DSCS COMPATIBLE
5a	METSAT - TACTERM	SHF / S - BAND	10 KBPS - 2 MBPS	DATA, COMM	DSCS OR WEATHER COMPAT
b	TACTERM - METSAT		4 KBPS - 16 KBPS	CMDS, COMM	DSCS OR WERATHER COMP
6 & 7	EARTH SENSOR - METSAT	UHF	100 BPS - 400 BPS	DATA	EXISTING LINKS
8	METSAT - V. SMALL E/T	SHF / S - BAND	1 KBPS - 4 KBPS	DATA, COMM	DSCS OR WEATHER COMP
9	DMSP - TACTERM	S - BAND	1 MBPS	DATA	EXISTING LINK - SGLS

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Satellite Design

SPARTA has developed a computer tool to quickly estimate the weight and power of a conceptual satellite in order to evaluate the feasibility of system concepts. An overview of the algorithm is shown in Figure 6. The program, called SATSYN, runs on a Sun computer and requires the input parameters listed. Each subsystem weight is calculated on the basis of algorithms related to hardware and subsystem requirements.

Operational Concepts

As part of an overall assessment of system concepts, it is necessary to investigate how the proposed concepts might operate. This is particularly important since military space systems must integrate into a specific architecture and control structure and the targeted user also has constraints and existing systems which must be taken into consideration. This task involved a top-level look at integrating the concepts into the existing space command and control architecture and also looked at each specific user service to understand how they might operate. Several potential concepts for operation were presented for each, with some top-level advantages/disadvantages and system impacts.

The data collection system involves collecting data from remote sensors deployed in the theater and getting that information to the users in the theater. The most straightforward concept has the data being collected and downlinked to the theater user for pressing. There is no payload control from the theater and no crosslinking to CONUS.

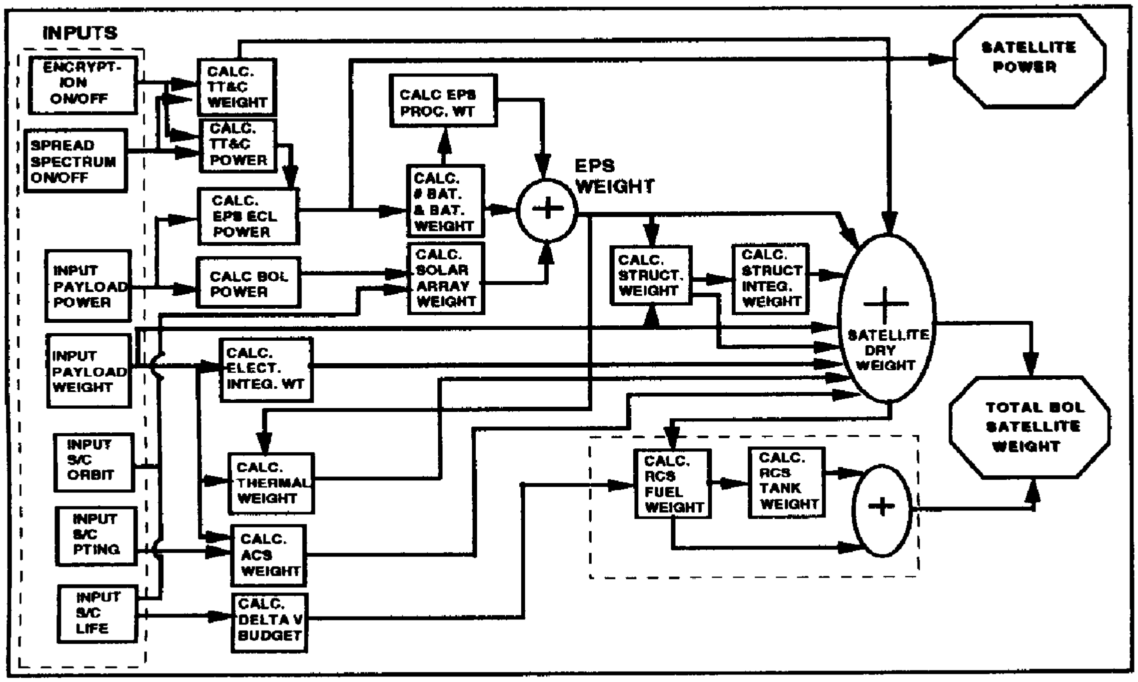

Figure 6. Satellite Synthesis Program Algorithm

Figure 7 shows how a tactically-oriented METSAT could integrate into the space command and control architecture. The concept shown has no crosslinking capability, so all command and control is maintained by the AFSCN through its network. The user might have the ability to command his payload in-theater, if required.

This concept is the same as the previous command and control structure, except the METSAT has crosslink capability. This crosslink capability could allow real-time commanding from CONUS and allow real-time health and status data relay back to CONUS.

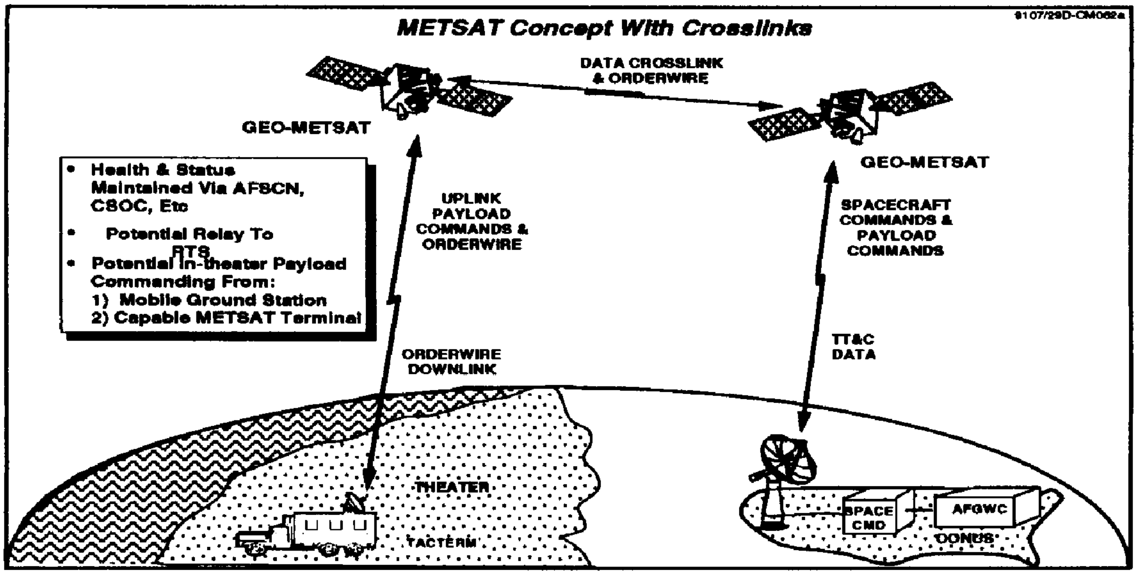

Figure 7. Preliminary Command And Control Architecture

Summary

Providing a tactical METSAT at geosynchronous orbit provides several advantages to the theater user. One of the most important characteristics of GEO is the ability to provide long-duration, focused coverage over an area of interest and to support that coverage by providing real-time data downlink to the user in the theater. Current geosynchronous meteorological platforms provide data to the military, but they are under civilian control and the downlinks are unencrypted, making the data available to both sides in a conflict. A dedicated, tactical METSAT system would be under military control and could employ encrypted links to control usage.

Although the concepts have centered on providing support during conflicts, these resources would also be available in peacetime and could be used for training and exercise support. Also, depending upon the sensors being flown, the assets could be used for meteorological research during peacetime.

Although a GEO platform has many advantages for tactical support there are some disadvantages, which include limited resolution and the inability of some sensors to operate that require spacecraft motion. Also, the lift required to place a platform to GEO orbit drives one to at least a medium-sized launch vehicle.

The analysis described above indicates the feasibility and capabilities of providing real-time weather data dissemination and relay to tactical forces via a geosynchronous METSAT. Specifically, relay of data from ground sensors, UAV's, and DMSP data has been shown to be feasible by utilizing relatively small antennas and transmitters.

Links between the GEO-METSAT and ground users, both in the field and in CONUS, have likewise required small communication components--i.e., antenna and transmitters. This analysis implies low to moderate risk for communication technologies required. Compatibility with communications or existing weather links will determine the desirability of the RF frequency band to be utilized. The satellite beamwidth assumed for this analysis has been sized to theater coverage. This analysis has shown that the satellite weight requires mid-size launch vehicle (MLV).

Although this was not a large study, we were able to reach some conclusions regarding the utility and feasibility of a geosynchronous METSAT platform. The basic conclusions are that significant contributions to tactical user's mission satisfaction can be made available from the augmentation of DMSP with a complementary capability which can both contribute to observations and observational frequency and enhance the ability to disseminate that data within the theater.

Additionally, the desired capabilities are feasible with low to moderate risk technology, and a significant capability can be provided with a 2000-pound class satellite system.