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LIGHTNING DETECTION FROM SPACE - SCIENCE AND APPLICATIONS
TEAM REVIEW

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16. ABSTRACT <p>The Science and Applications Team (SAT) was organized to identify the various needs for lightning data that exist among potential users of satellite lightning data. In addition to SAT, two other teams (Optical and RF) were organized for the purpose of defining systems utilizing, respectively, the optical and radio-frequency radiations from lightning to serve as the satellite-based lightning mapper. The three teams worked interactively with NASA to develop a system concept during the 1-year period of the contract. The results of the review team effort are presented. An assessment of the results may be summarized as follows: A small sensor system can be easily designed to operate on a geostationary satellite that can provide the bulk of the real-time user requirements. Radio-frequency systems in space may be feasible but would be much larger and more costly; RF technology for this problem lags the optical technology by years. A hybrid approach (optical in space and RF on the ground) would provide the most complete information but is probably unreasonably complex and costly at this time.</p>					
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I would like to acknowledge the support and participation of all of the Science and Applications Team in the development of the requirements and concepts in this report. This work is work-in-progress, and refinements to these requirements and concepts will undoubtedly occur in the future. I also acknowledge the assistance of Dr. J. L. Bohannon at Rice University, who has worked with me on parts of this effort.

I wish to recognize the many helpful comments of Dr. J. C. Dodge, NASA Headquarters, and his leadership in the organization of this program.

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Summary

The Science and Applications Team (SAT) was organized to identify the various needs for lightning data that exist among potential users of satellite lightning data. As originally specified by NASA, the intent was to "let the user requirements drive the system design." In addition to SAT, two other teams were organized (Optical and RF), the objectives of which were to define systems utilizing, respectively, the optical and radio-frequency radiations from lightning to serve as the satellite-based lightning mapper. These three teams worked interactively with NASA to develop a system concept during the 1-year period of the contract.

During the course of this work several answers became evident, and problems developed that mandated a redirection of effort and an abandonment of several of the original goals and objectives. An assessment of the results of the review team effort is summarized as follows:

A small sensor system can be easily designed to operate on a geostationary satellite that can provide the bulk of the real-time user requirements. Radio-frequency systems in space may be feasible but would be much larger and more costly; RF technology for this problem lags the optical technology by years. A hybrid approach (optical in space and RF on the ground) would provide the most complete information but is probably unreasonably complex and costly at this time.

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Introduction

Several satellite sensors have been used for the past several years to detect lightning from space (Turman, 1979a, Orville and Spencer, 1979). Whereas these experiments have demonstrated the value of the satellite platform for lightning observations, they do not have the capabilities needed by most of the users of lightning information. In general, the sampling of lightning activity both in space and time by these sensors is highly restricted, and in many cases the dynamic range limits the flashes sampled to a small fraction of all lightning flashes (Turman, 1979b).

The National Aeronautics and Space Administration (NASA) has recognized the usefulness of the satellite-acquired lightning data and the restrictions of previous sensor systems. NASA has established a research and development program (1) to resolve problems in lightning detection, (2) to increase our understanding of the wide variety of radiations from lightning, (3) to improve our capabilities in obtaining quantitative lightning data by interpreting remotely sensed lightning radiations, (4) to define the relationships of lightning activity to other thunderstorm parameters and other areas of atmospheric science, and (5) to develop a satellite-based lightning mapping system that can best serve the needs of the users of lightning information.

In working toward the last item in the above list, NASA has set up three working teams--Science and Applications, Optical Sensor, and Radio-Frequency Sensor. These teams are trying to resolve the problem of providing the information requested by users of lightning data with the limitations imposed by lightning observables, sensor systems, background interference, costs, and politics. This report addresses the considerations of the Science and Applications Team; our responsibility is to define the needs of the users of lightning information.

The Spectrum of Users and User Needs

We will not reproduce here a list of the users and potential users of lightning information. There are many similarities among users who have similar functions to perform; hence it is more practical to address the information needs based on the user function. Examples of users and specific applications will be mentioned throughout the discussions to provide clarity.

There are three principal variables that can be used to define users with similar data needs. The first two variables--Timeliness and Field of View--are displayed in Figure 1. Along the axis for timeliness we see the group of user functions requiring real-time data; an example of a function requiring this real-time data is hazard warning; an example of a specific user would be a port facility transferring fuel from ship or barge to a storage facility. Further down the Timeliness axis we found other user functions (such as Geophysical Correlations) requiring cumulative or delayed data, which may take the form of a monthly report or an annual computer tape or microfilm, etc. Finally, we have the users of analyzed data who are interested in statistical information on lightning occurrence and characteristics.

Across the axis labeled Field-of-View we see user functions that have needs in the field-of-view variable ranging from global to synoptic. Obviously some forecasting functions and geophysical correlations require a

global perspective of lightning activity. Many operational functions (power distribution and maintenance) are only concerned with a continental field of view. For the research-oriented functions such as coordination with ground-based research and tracking operations, such as for use with hurricanes and severe storm systems, a field of view on the synoptic scale is sufficient; but this synoptic-scale system would need to be pointable in order to fulfill the users' needs.

The third variable, Magnitude of Quantitative Requirement, is the most difficult to assess. In Figure 2 this quantitative requirement is plotted as the vertical dimension above the plane defined by the variables in Figure 1. The trends in the data requirements of the users are as follows:

- (1) Users interested in a smaller field of view also want more detailed information on lightning within that field.
- (2) Real-time data requirements can be a subset of the total data acquired for eventual retrieval for some functions.
- (3) Some functions have no real time requirement; some functions have no global requirements.

As a result of these trends, we have the data requirement distribution depicted qualitatively in Figure 2; the function, Damage Assessment, has been left out for later discussion. As an example of a user of global, real-time data we can look at the hazard avoidance function, such as airplane operations; this application would only require flash count and location. Continuing with another example, those users with planning and operations functions, such as specifying the location of landing fields, would need to have additional facts, including the climatology of cloud-to-ground lightning. The engineers who design the airplane and avionics (function--lightning protection design); require statistical information on lightning current parameters. In Figure 2 we list some of the stated requirements of users at the two extremes in the quantitative requirement.

The damage assessment function was left out of the discussion above because it imposes a special need that greatly increases the magnitude of the requirements; this need is for high resolution of the cloud-to-ground strike point. The volume of space involved in a thunderstorm's electrical activity and the volume of space of the electrical hazard posed by an active thunderstorm are large ($> 125 \text{ km}^3$); the area of hazard on the ground ($> 50 \text{ km}^2$) for even a small thunderstorm is also large. Hence, the special resolution requirement for locating lightning activity is not stringent. For the damage assessment function this is not the case because the information needed is the point on the ground that is struck by the cloud-to-ground lightning flash. The Forest Service is a user with an important damage assessment function; they have requested a 250m resolution of all cloud-to-ground lightning within the Western U. S.; other users with a potential damage assessment function would be insurance and power transmission.

To achieve the high-resolution data needed by the damage assessment function, we will need capabilities beyond that needed to resolve areas of lightning activity. In Figure 3 we have illustrated the impact of the damage-assessment function to the quantitative requirements with the addition of the shaded volume added to the top of the requirements of Figure 2. The impact is smaller in the synoptic regime because the previous requirements for

quantitative data implicitly required many of the capabilities incorporated in the damage assessment function requirement.

A point to notice is that if a system is designed to provide real-time damage-assessment support, it can probably supply most of the needs of all of the other users, except those requiring a global field of view.

The Science and Applications Team has attempted to quantify where possible the requirements of our users. For convenience, we have grouped the users into three groups (A, B, and C), which correspond to the three fields-of-view -- global, continental, and pointable synoptic. Table I gives a synopsis of the requirements. In addition to these requirements, there is also a need to add to the research system, C, a lightning spectrometer that views a single 8 km x 8 km area within the field-of-view of system C.

Sensor System Concepts

The two NASA Sensor Teams, Optical and RF, are concerned with the capabilities of the specific sensors; our discussion in this section will be directed toward the the sensor system concepts and their relationships to the user requirements.

A meeting was held in February, 1979, at the Tennessee Space Institute in Tullahoma to address this subject of lightning observations from space, and the proceedings [Workshop on the Need for Lightning Observations from Space (Christensen et al., 1979)] provide a foundation from which our present considerations proceed. A very wide range of potential users of lightning data attended and participated in these discussions. One of the sensor system requirements that became evident early in the discussions was that the system needed a geostationary orbit. This was driven by user functions such as hazard warning, hazard avoidance and geophysical correlations that require uninterrupted monitoring of lightning activity.

The various systems that were discussed at the Tullahoma Meeting and are being considered further by the NASA Teams are summarized below:

1. Optical Sensor: using planer arrays of solid state photo-sensitive elements.
2. RF Sensor: using an interferometer at 250 MHz operating from geostationary orbit.
3. Hybrid Continental: using satellite plus ground-based wideband direction finding network operating as a system.
4. Hybrid Global: using satellite plus ground-based ELF or VLF direction finding network operating as a system.

The problems, capabilities, and details of these systems are described in other papers at this conference. The optical technology appears to be sufficiently well developed to evaluate the feasibility of an optical sensor system, whereas the other systems require additional research. To obtain most of the information needed by our users, we would require the more complex hybrid systems. For example, the simple optical system can measure directly only flash count and location, and perhaps it will be possible to make the flash-to-ground discrimination in some cases.

Data Dissemination, User Displays, Data Archives

One of the shortcomings of many early satellite programs was inadequate integration of the ultimate user of satellite data into the system specification. We plan to avoid this pitfall in the program by evolving the design of the user's data displays and recording formats in parallel with the sensors themselves. This approach maintains the "system" concept throughout the program development, and it forces the user to be more precise in requesting the time and format of each datum.

Figures 4-7 give satellite perspective views of (4) the North American Continent and (5,6,7) the Earth viewed from three different longitudes. The effect of curvature and longitude selection on data biasing is evident to users from displays of this type. Figure 8 is a map projection of the Earth which also shows the horizon lines of the three satellite perspective views in Figures 5-7. In some areas the perspectives have a generous overlap; data from the polar regions will not be adequately sampled. Fortunately, for the lightning monitoring program the polar regions are not active lightning-producing regions.

A wide range of real-time data displays are being considered by the Science and Applications Team. The simplest system is an audio single point alarm which sounds when lightning activity is observed within a preset zone. The most complex is a minicomputer-based, color graphics systems that can access all of the real-time data. Figure 9 gives a tabular summary of some of the displays being considered. Reference to sensors A and B in this figure corresponds to the User Group A and B of Table 1.

Another data format being considered is similar in concept to the NOAA's publications: Climatological Data National Summary and Climatological Data National Summary, Annual and their regional equivalents. These would be computer-produced summaries of national or regional lightning data for the month with an annual summary providing an update of the statistical data of record. A detailed event-by-event listing would be maintained on computer tapes at a national facility such as The National Climatic Center for future access by users.

Conclusions

The research and development program being implemented by NASA to produce lightning observation from satellite is a broadly based, well-thought-out plan to employ satellite technology to produce the data needs of user's of lightning information. The ultimate users of the data from the satellite system are participating in the program from the beginning. We think that this program and this approach will be successful.

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TABLE 1

User Group A (Global view) - atmospheric electrical research, climatological research, hazard warnings to exposed or sensitive operations, hazard avoidance by aircraft and ships, weather forecasting aid, lightning protection design and planning.

User Group B (U.S. view) - same interests as in Group A but with higher resolution,

User Group C (pointable research instrument) - lightning research, cloud physics research, severe storm research, tropical storm research, oceanic storm research, coordination with ground-based research programs, and support, testing, and calibration of sensors for A and B.

The table below lists some of the requirements of the user groups and the information that is requested by approximate priority.

Requirement	A	B	C
1. Sensor field of view	full disk	Cont. U.S.	1000 km
2. Desired resolution	-10 km	4 km	1-2 km
Acceptable resolution	-50 km	10 km	4 km
3. Real-time data update interval	15 min.max	1 min.max	programable
4. Lightning flash count and location	yes	yes	"
4a. Flash fail to detect	-10%	<10%	"
4b. Flash false alarm	-20%	<30%	"
5. Cloud-to-ground discrimination	yes	yes	"
6. Strokes per ground flash	yes	yes	"
7. Charge and/or Current for Stokes	yes	yes	"
8. Current Rise Time	no	yes	"
9. Continuing Currents	no	yes	"

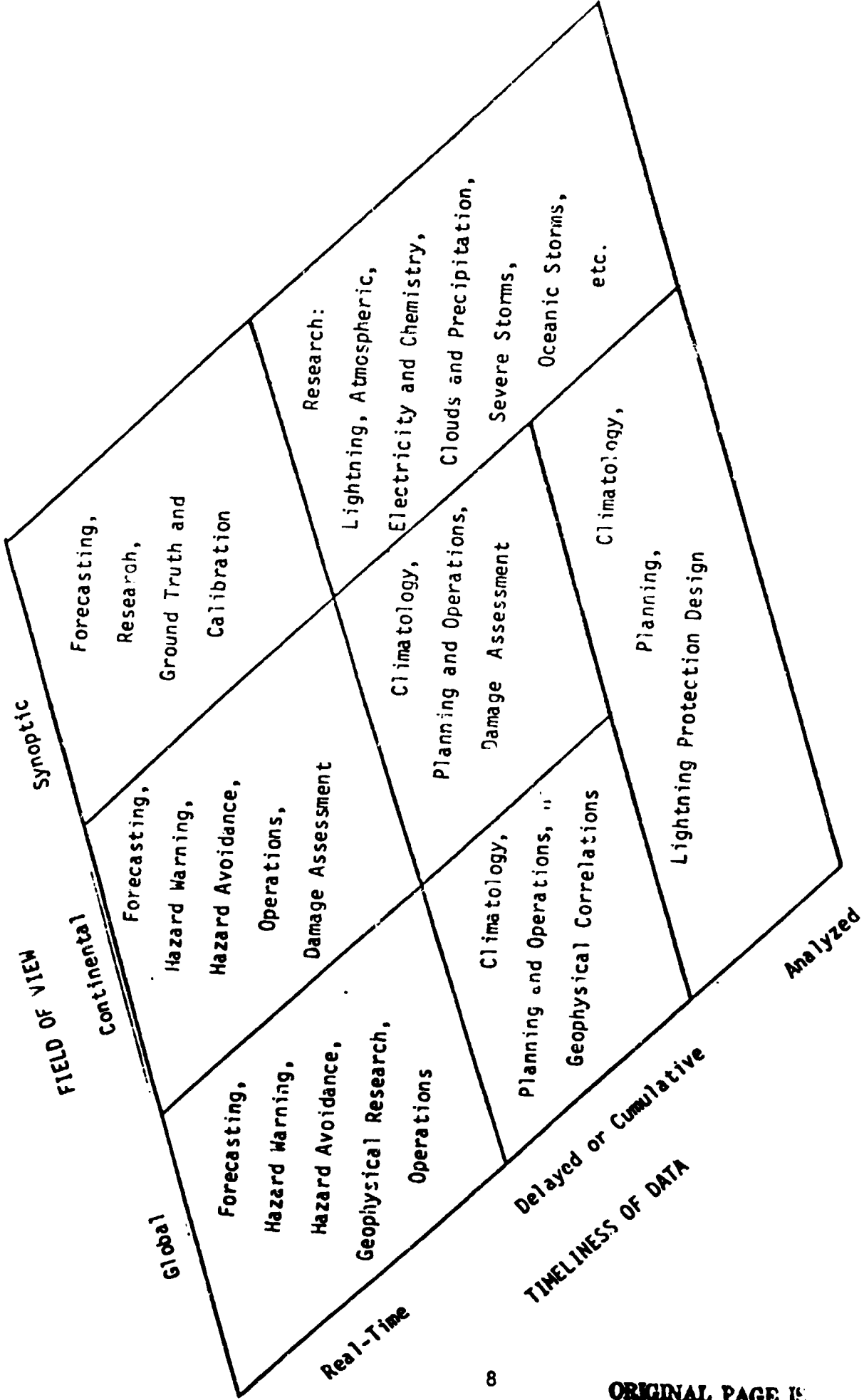


Figure 1. Two-dimensional display of user functions versus the variables Timeliness and Field-of-View. Specific users of lightning information require data for various functions. Each function will have a range of needs in the two variables Timeliness, which refers to how soon the function needs the information, and Field-of-View, which refers to total coverage required for that function.

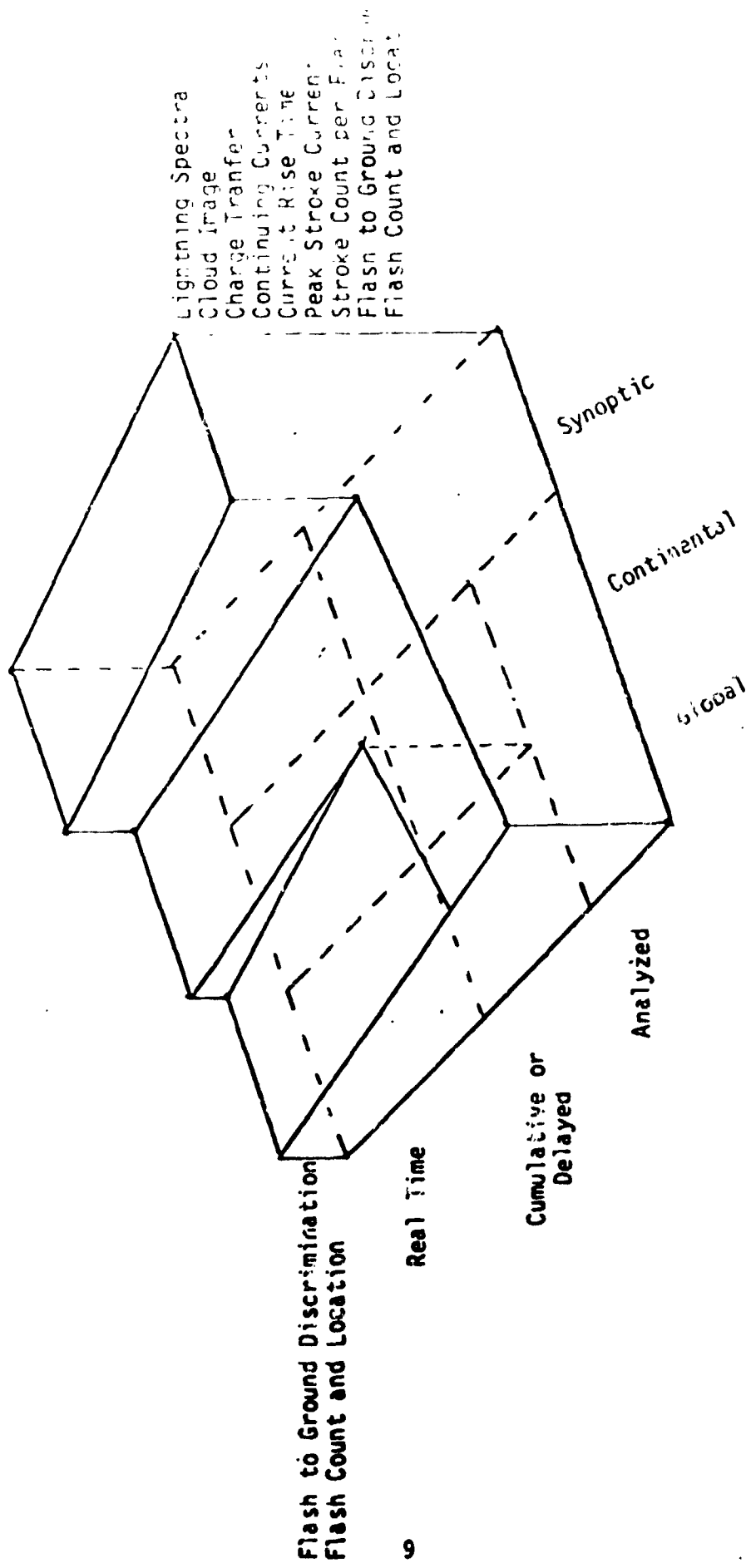


Figure 2. Quantitative requirements, (exclusive of damage assessment). A third variable, Quantitative Requirements, of the user's needs is displayed qualitatively as the vertical coordinate above the plane defined by the two variables Timeliness and Field-of-View. There is a systematic change in the quantitative requirements for the functions of Timeliness and Field-of-View.

(Continental Field of View, 250m resolution of cloud to ground strike point)

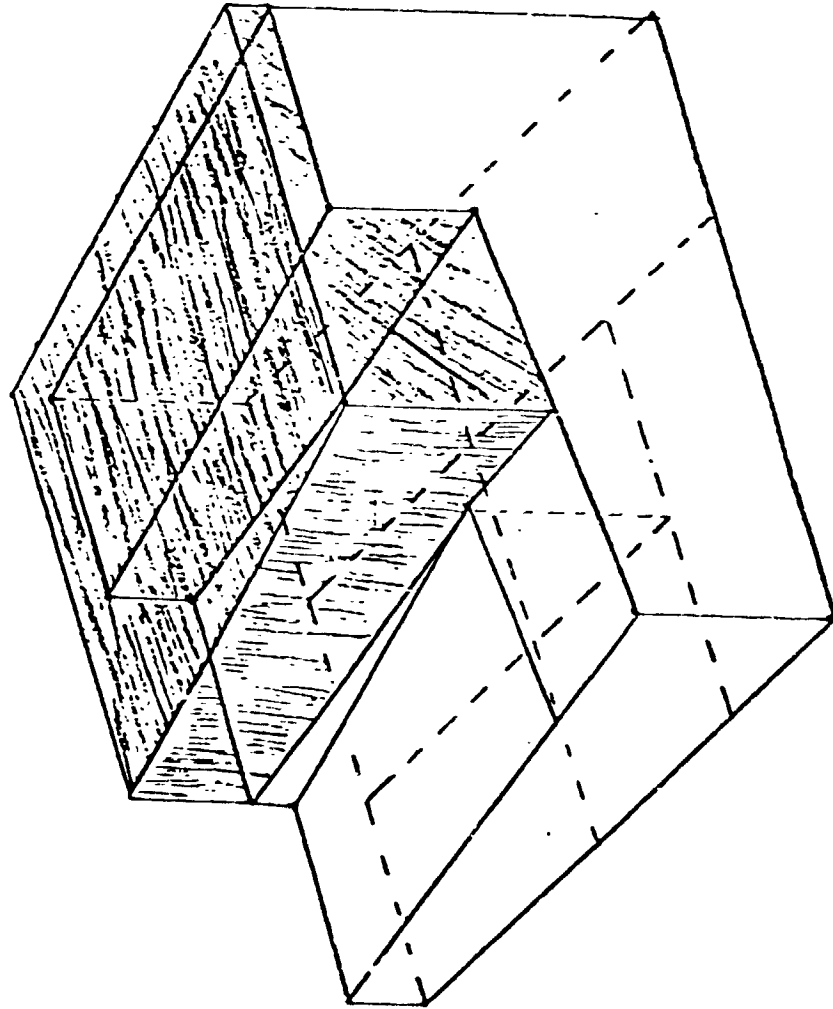


Figure 3. The addition of the damage assessment requirement. The damage assessment requirement adds to the other requirements the need of knowing the location of the strike point of each continental cloud-to-ground lightning flash with a precision ~ 250 m.

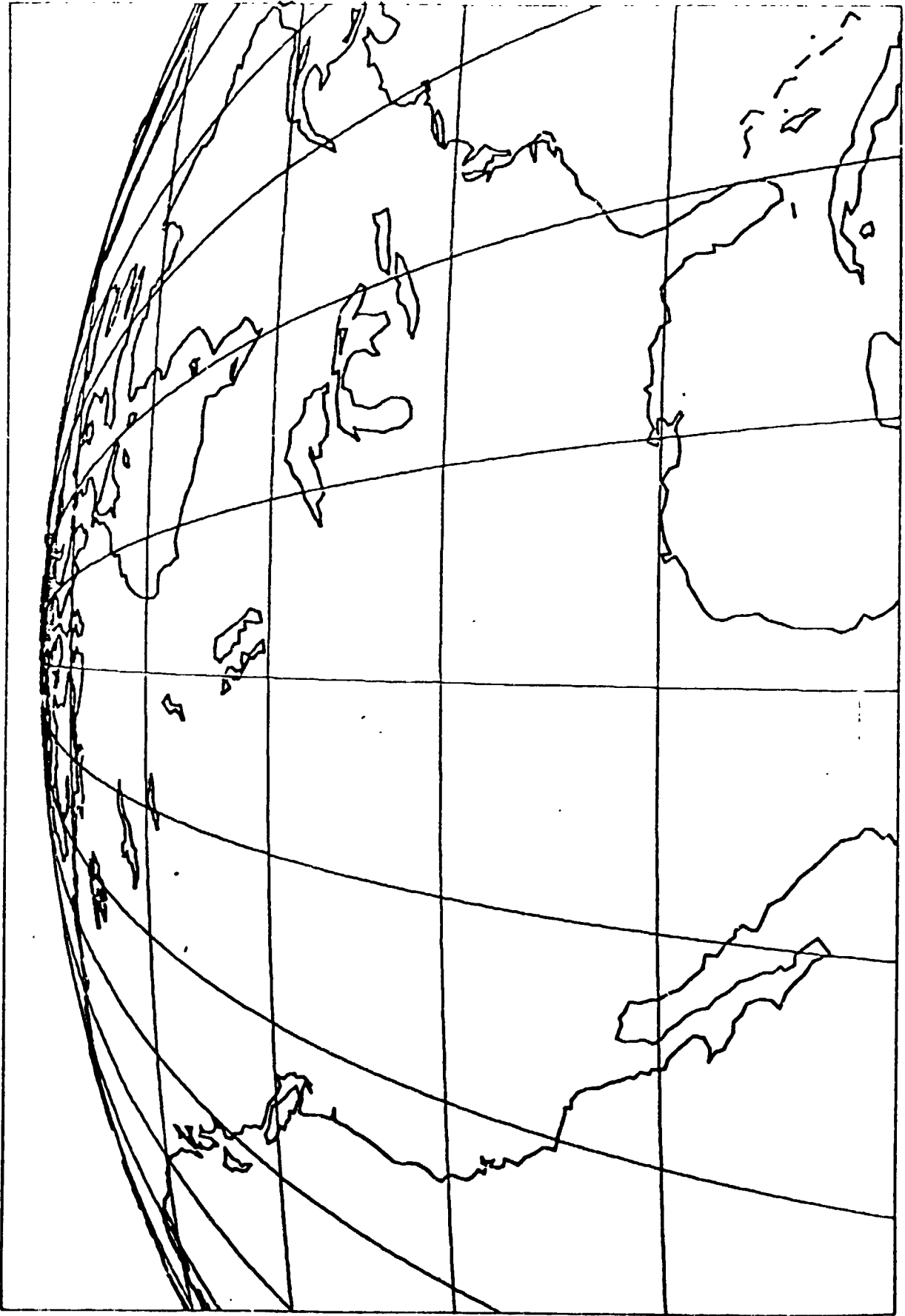


Figure 4. A continental perspective from geostationary orbit. This is a view of most of North America from a geostationary orbit located at 99° W longitude; the continental system would have a view similar to this or some subset of this view.



Figure 5. A global perspective view at 99° W from geostationary orbit. A global sensor placed at 99° W longitude would see this view of the world.



Figure 6. A global perspective view at 29° E from geostationary orbit. A global sensor placed at 29° E longitude would see this view of the world.



Figure 7. A global perspective view at 141° E from a geostationary orbit. A global sensor placed at 141° E longitude would see this view of the world.

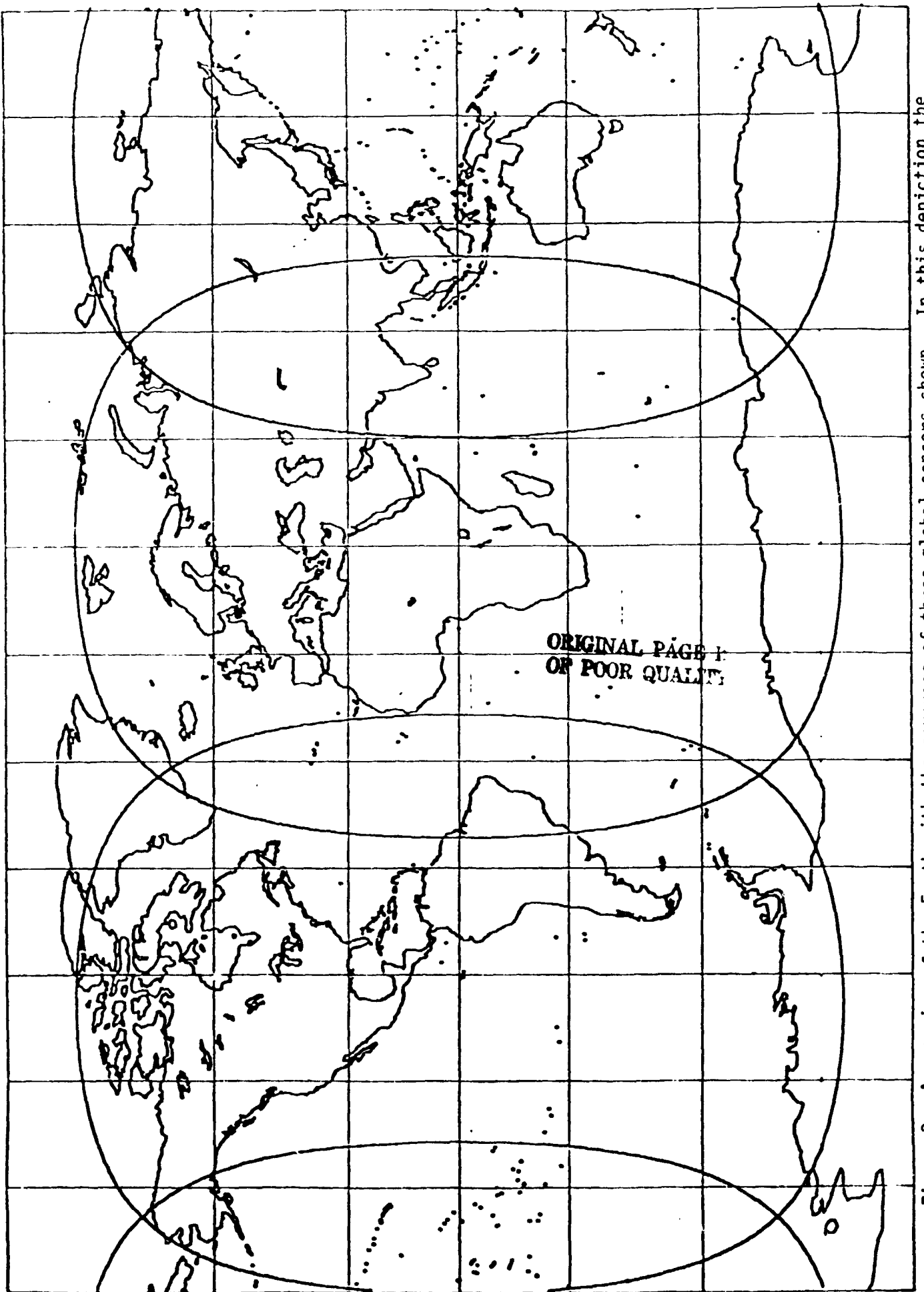


Figure 8. A map view of the Earth with the coverage of three global sensors shown. In this depiction the apparent horizons of the global sensors illustrated in Figures 5 through 7 are drawn on a map of the world. The distorting effects of both mapping and perspective viewing are seen by comparing Figures 5, 6, and 7 with Figure 8.

REAL-TIME DISPLAYS

<u>TYPE</u>	<u>AUDIO ALARM</u>	<u>VISUAL DISPLAY</u>	<u>SENSORS SAMPLED</u>	<u>HARD COPY OR LOCATION LISTING</u>	<u>DATA STORAGE</u>	<u>EVENT FREQUENCY DISPLAY</u>	<u>COMMENTS</u>
Single Point	Yes	Lights	B	No	No	No	Indicates activity in local and adjacent pixels
Area	Yes	Light on map of area	B	No	No	Optional numeric	Indicates activity over area of map
Single Area Graphic	No	Graphic CRT	B	Yes	Yes	Color code	Draws a pre-defined map with color codes for each reporting period
Multiple Area Graphic	No	Graphic CRT	A,B	Yes	Yes	Color code	Can display any of several pre-defined maps
Full Graphic	No	Graphic CRT	All	Yes	Yes	Color code	Displays any area on any scale for any sensor

Figure 9. Real-time data displays; some of the systems being considered for the display of real-time lightning for various users are illustrated.